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**9TH INTERNATIONAL RAINWATER CATCHMENT
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**"Rainwater Catchment: an answer to the water
scarcity of the next millennium "**

Impacto do Fenômeno El Niño na Captação de Chuva no Semi-árido do Nordeste do Brasil

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Resumo

Neste estudo foram utilizados os totais anuais de precipitação pluvial de 88 postos pluviométricos do Nordeste do Brasil. Os desvios de precipitação pluvial de cada posto foram obtidos com relação à média climatológica de 82 anos de dados. As distribuições espacial dos desvios de precipitação pluvial do Nordeste do Brasil foram analisadas nos anos de ocorrência apenas dos eventos fortes do fenômeno El Niño compreendidos no período de 1911 a 1992.

INTRODUÇÃO

A grande variabilidade espacial e temporal da precipitação pluvial no Nordeste do Brasil é provocada pela atuação dos vários sistemas de circulação atmosférica que atuam na região. O desvio médio em relação à normal climatológica é superior a 25%. A estação chuvosa do Nordeste é geralmente curta e se concentra, na maior parte, nos meses de fevereiro a maio. Na faixa do litoral a média da precipitação anual atinge 2.000 mm, enquanto que na região do polígono das secas a média varia em torno de 800 mm, existindo, entretanto, localidades no interior do semi-árido como Cabaceiras e Olho D'água, no Estado da Paraíba, com média anual em torno de 300 mm e 1000 mm, respectivamente (Rodrigues da Silva et al., 1998).

As secas que assolam periodicamente o Nordeste do Brasil constituem um fenômeno de natureza devastadora que provoca grandes impactos sociais, econômicos e ambientais. A população dessa região não convive satisfatoriamente com a instabilidade climática, tornando o flagelo da seca, desde o século XIX, um grande problema de política governamental, sem nenhuma ação concreta para minimizar seus efeitos, sobretudo no que se refere à captação de água para o consumo humano e animal. As principais consequências das secas são relacionadas, principalmente, com a baixa produtividade na agricultura, pecuária e abastecimento d' água aos centros urbanos e comunidades rurais.

As anomalias positivas das Temperaturas da Superfície do Mar (TSM) no oceano Atlântico ocorridas no ano agrícola de 1982/1983 provocaram consequências desastrosas para agricultura e pecuária do Nordeste do Brasil. A ocorrência do fenômeno forte de 1998 foi mais severo do que o de 1983 e um dos maiores do século, onde as anomalias da TSM do oceano Pacífico superaram 6 °C.

Nos últimos anos a agricultura nordestina vem sofrendo uma profunda crise, fundamentalmente devido à periodicidade das secas que desestimulam o plantio em sistema de sequeiro. Essa situação agrava-se mais ainda com relação ao uso consultivo das águas. A persistência das secas ocorridas nas últimas décadas, contribuíram indubitavelmente para redução dos níveis de água dos grandes reservatórios. Os pequenos e até mesmo os médios açudes foram praticamente extintos, decorrente do déficit acumulado de captação de água provocado pelas grandes secas, ocorridas no passado, como por exemplo as que ocorreram apenas nesse século: 1915, 1919, 1932, 1942, 1951, 1952, 1953, 1958, 1966, 1970, 1976, 1982, 1983 e a de 1998.

As altas taxas de evaporação, que em dias de “pico” pode superar 10 mm, afetam substancialmente a regularização do nível d’água dos reservatórios de água do Nordeste. A construção desordenada de pequenos e médios açudes a montante das grandes barragens retém a água precipitada na bacia que eventualmente chegaria no reservatório principal. Com isso, a contínua redução dos níveis de água dos reservatórios que abastece a população urbana e rural tornou-se abrupta com a grande seca 1998, provocando um colapso no abastecimento de água para o consumo humano em praticamente todo Nordeste do Brasil. As grandes secas ocorridas no Nordeste são atribuídas a ocorrência dos eventos fortes do fenômeno El Niño, sendo considerados os mais fortes aqueles que ocorreram nos anos de 1983 e 1998.

Nesse contexto, o presente trabalho objetiva analisar a influência dos eventos fortes do fenômeno El Niño na captação de chuva pelos reservatórios de água do Nordeste do Brasil e localizar as áreas mais afetadas pelo fenômeno dentro do polígono das secas.

MATERIAL E MÉTODOS

Os eventos quentes das anomalias da TSM nas regiões do Pacífico Niño 1, Niño 2 e Niño 3 são denominados de El Niño. Alguns pesquisadores observaram que o evento quente é relacionado com seca no Nordeste e chuva no sul do Brasil (Aragão, 1986; Roucou et al., 1996). A região do Pacífico Niño 3 é a que mais se relaciona com chuva e compreende uma área entre os paralelos 5° S - 5° N e meridianos de 90° - 15° W.

Neste estudo foram utilizados os totais anuais de precipitação pluvial de 88 postos pluviométricos do Nordeste do Brasil. Os desvios de precipitação pluvial de cada posto foram obtidos com relação à média climatológica de 82 anos de dados. As distribuições espaciais dos desvios de precipitação pluvial nos anos de ocorrência do fenômeno El Niño forte foram analisadas no período de 1911 a 1992. Com base nas anomalias de TSM ao longo da costa do Equador-Peru, o fenômeno El Niño pode ser classificado como: forte ($>2,9^{\circ}\text{C}$), moderado ($2,0 - 2,9^{\circ}\text{C}$) e fraco ($<2,0^{\circ}\text{C}$) (Quinn et al., 1978) citado por Kane (1997). Os anos que ocorreram os eventos fortes do fenômeno El Niño, no período estudado, foram os seguintes: 1918, 1925, 1941, 1957, 1982 e 1983 (Aragão, 1986). Como os eventos classificados com fracos e moderados do fenômeno exerce pouca influência no regime de chuva do Nordeste do Brasil (Rodrigues da Silva et al., 1998), somente serão analisadas os eventos classificados como fortes.

RESULTADOS E DISCUSSÃO

As distribuições espaciais dos desvios de precipitação pluvial do Nordeste do Brasil nos anos de ocorrência dos eventos fortes do fenômeno El Niño são apresentadas nas Figs. 1-6. As áreas hachuradas correspondem aos desvios de precipitação igual ou superior à média e as não hachuradas aos desvios inferiores à média climatológica de 82 anos de dados de chuva. Observa-se que o El Niño provoca precipitação abaixo da média na região, numa área maior na parte norte e numa área menor na parte sul do semi-árido, apresentando, inclusive, no ano de 1983 chuva acima da média no litoral sul do Estado da Bahia (Fig. 6). Independente da extensão da área, em todos os anos de ocorrência do fenômeno, a parte semi-árida da região é invariavelmente atingida. Mesmo no ano de 1925 (Fig. 2), onde o relacionamento do fenômeno com chuva na região foi menor do que nos outros anos, o El Niño provocou precipitação abaixo da média no semi-árido do Nordeste.

Os fenômenos El Niño de 1918 (Fig. 1), 1941 (Fig. 3), 1957 (Fig. 4), 1992 (Fig. 5) e de 1983 (Fig. 6) foram os mais relacionados com seca; enquanto que, o El Niño de 1925 (Fig. 2) foi o que menos apresentou desvios negativos de chuva. O ano mais atingido pela seca foi 1983 e menos atingido 1925. A medida que ocorre um novo evento forte do fenômeno El Niño, aumenta significativamente a área afetada na parte semi-árida da região Nordeste do Brasil. Isto é comprovado pelo exame das

Figs. 3 - 6. Muito embora o evento forte do fenômeno El Niño que teve início em 1997 não tenha sido analisado nesse estudo, também reflete sua influência na grande seca de 1998.

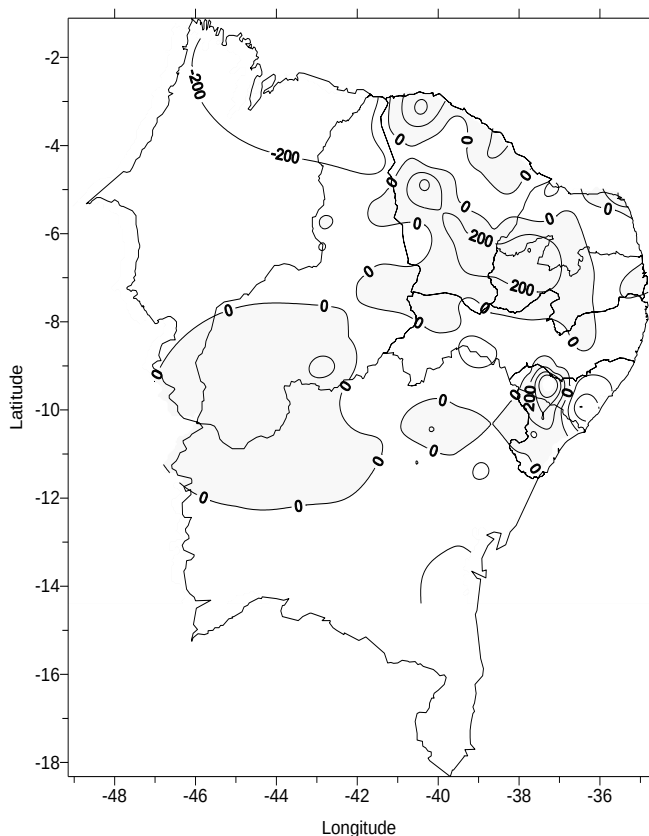


Figura 1. Desvios de precipitação pluvial no Nordeste do Brasil no ano de 1918.

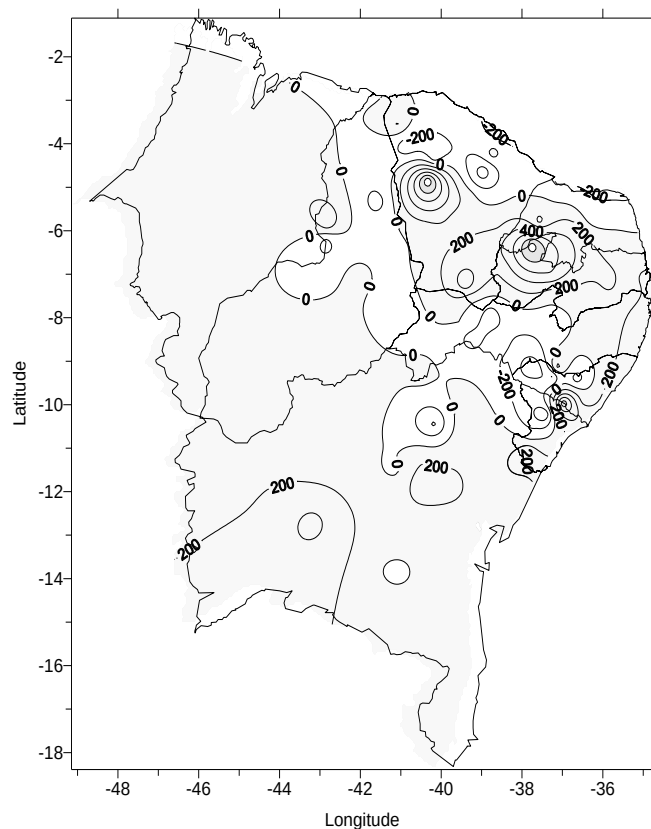


Figura 2. Desvios de precipitação pluvial no Nordeste do Brasil no ano de 1925.

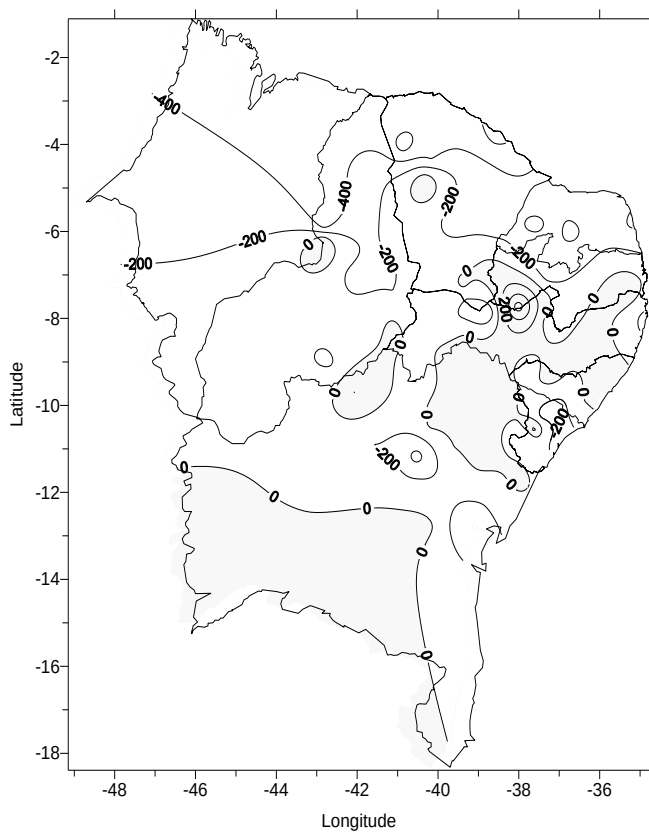


Figura 3. Desvios de precipitação pluvial no

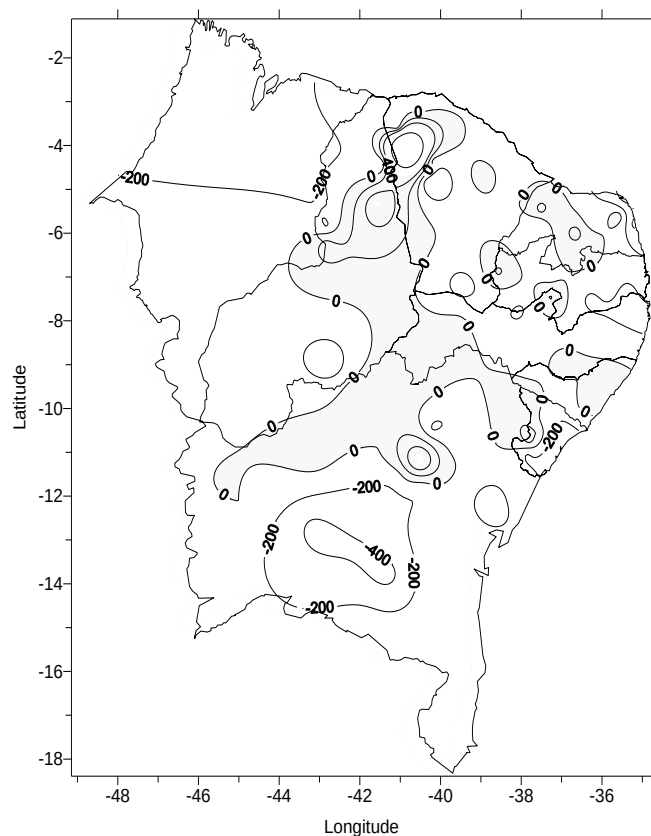


Figura 4. Desvios de precipitação pluvial no

Nordeste do Brasil no ano de 1941.

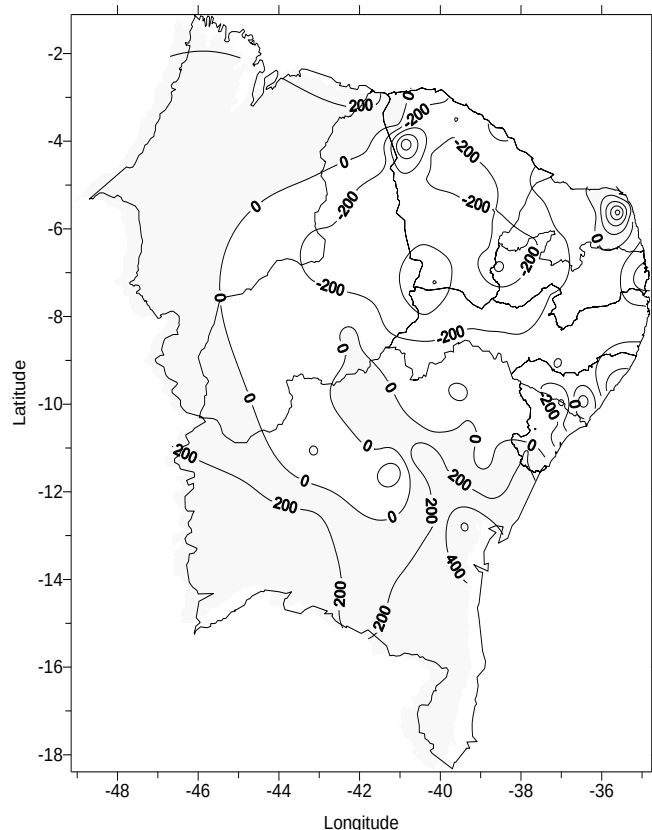


Figura 5. Desvios de precipitação pluvial no Nordeste do Brasil no ano de 1982.

Nordeste do Brasil no ano de 1957.

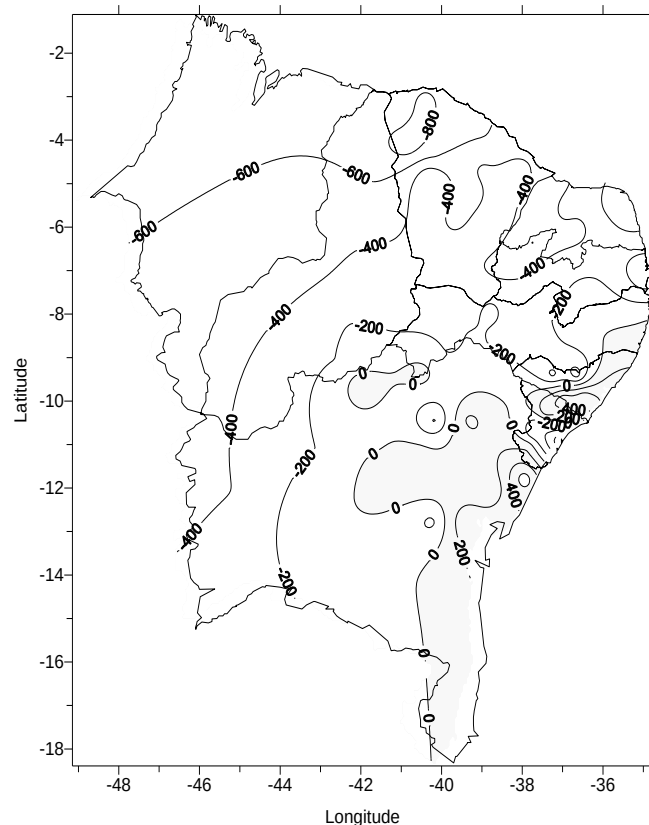


Figura 6. Desvios de precipitação pluvial no Nordeste do Brasil no ano de 1983.

O exame das Figs. 1 - 6 evidencia ainda que os eventos fortes do fenômeno El Niño ocorridos nesse século provocaram um redução acumulado na captação de chuva pelos pequenos, médios e grandes reservatórios d'água do Nordeste do Brasil. E que a grande crise no abastecimento d'água nos centros urbanos e rurais ocorrida no ano de 1998 foi provocado por essa acumulação do déficit de captação de água nos anos de ocorrência desse fenômeno.

CONCLUSÕES

Os resultados apresentados permitem concluir o seguinte:

nos anos que ocorrem o evento forte do fenômeno El Niño o semi-árida da região Nordeste do Brasil apresenta, invariavelmente, precipitação pluvial abaixo da média; sendo a parte norte mais atingida do que a parte sul;

a medida que ocorre um novo evento forte do fenômeno El Niño, aumenta significativamente a área afetada pela seca na parte semi-árida da região Nordeste do Brasil;

a redução acumulada na captação de chuva pelos açudes do Nordeste do Brasil, durante os anos de ocorrência do fenômeno El Niño, foi o principal responsável pela crise no abastecimento de água na região durante o ano de 1998.

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Potential benefits of tropical seasonal rainfall forecasting for rainwater catchment systems

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Abstract

Much work has been done recently on interannual and seasonal rainfall forecasting for the tropics. Such forecasts are usually reliable at a regional or macro scale, but are less successful at the meso- or local scales, which are of interest for rainwater catchment systems. Methods are needed for the transfer of seasonal rainfall forecasts to the management of rainwater catchment systems and for evaluating their performance. This paper addresses the topic and presents an approach for transferring forecasts from regional to basin or local scales and an evaluation of their skill (as defined in the paper) for the Brazilian Nordeste. The results show that forecast skill decays as the scale becomes smaller and that forecasts are still of limited use at the local scale. On the other hand, they can be immediately useful for regional early warning applications, as well as for the management of larger rainwater catchment systems, such as those of large reservoirs.

Introduction

Rainwater catchment systems are more vulnerable and less reliable when located where rainfall is highly variable in space and time. This is the case of several tropical regions in the world. Procedures for designing such systems must consider this variability and, even so, their management is complicated by the uncertainty of future rainfall. In recent years, better understanding of atmospheric and oceanic behaviour has resulted in improved early estimates of seasonal rainfall for the Tropics. These forecasts are potentially useful for managing rainwater catchment systems. Currently, however, tropical seasonal rainfall forecasts are at the regional scale, and their usefulness – whether for water management, rain-fed agriculture, domestic supply or irrigation – will depend on how far they can be decomposed to give forecasts at smaller scales. This paper addresses this question and presents an assessment for the Brazilian Nordeste.

Seasonal rainfall forecasting

A number of research groups are working on seasonal rainfall prediction for the Tropics, using methods falling into two broad classes: (a) statistical-empirical, and (b) dynamic (Hastenrath, 1995). The first group contains methods based on regression, discriminant analysis, and neural networks, among others. The second group includes models of atmospheric behaviour. Many of these methods present their results including a measure of uncertainty. One common format presents the forecasts in categories (usually three or five)

assigning an expected probability of occurrence to each category. Although this kind of forecast delivers more information to the user, it is more difficult to link with conventional approaches for management and decision making.

Resampling procedures have been proposed for coping with the problem of transferring probabilistic rainfall forecasting into probabilistic estimates of other variables of interest, such as river runoff and soil moisture (Croley, 1996; Briggs and Wilks, 1996). This approach basically consists of building a structured set of coupled events of seasonal rainfall and, say, runoff (or rainfall at a different scale) anomalies from the historical record that gives relative frequencies of seasonal rainfall satisfying the probabilities of the climate forecast. The probability distribution of the structured set of seasonal runoff (or rainfall at a different scale) can be determined by considering the relative frequencies of the events. Relevant features of resampling are its mathematical and computational simplicity and that it estimates other variables also in probabilistic fashion. This paper uses the method presented by Croley (1996), outlined below. Consider the case of a forecast expressed in five categories, which specifies the following probabilities for seasonal rainfall:

$$\begin{aligned} \hat{P}[Q \leq \theta_{0.2}] &= a; & \hat{P}[\theta_{0.2} < Q \leq \theta_{0.4}] &= b; & \hat{P}[\theta_{0.4} < Q \leq \theta_{0.6}] &= c; \\ \hat{P}[\theta_{0.6} < Q \leq \theta_{0.8}] &= d; & \hat{P}[Q > \theta_{0.8}] &= e \end{aligned} \quad (1)$$

where Q = seasonal rainfall; θ_γ = rainfall reference γ -probability quantiles for the season; and a, b, c, d, e = forecast settings.

A very large structured set can be built, which relative frequencies satisfy (1), by duplicating the years in the historical time series, such that:

$$\frac{N_A}{N} = a; \quad \frac{N_B}{N} = b; \quad \frac{N_C}{N} = c; \quad \frac{N_D}{N} = d; \quad \frac{N_E}{N} = e$$

where, N is the size of the structured set, N_A is the number of years in the structured set with $Q \leq \theta_{0.2}$, N_B is the number of years with $\theta_{0.2} < Q \leq \theta_{0.4}$, etc. The historical time series of rainfall of n years has n_A years with $Q \leq \theta_{0.2}$, n_B years with $\theta_{0.2} < Q \leq \theta_{0.4}$, etc. The structured set is constructed by duplicating each of the n_A years N_A/n_A times, each of the n_B years N_B/n_B times, and so on. Each year i ($i = 1, \dots, n$) is duplicated r_i times. By judiciously choosing these duplication numbers ($r_1, r_2, \dots, r_n$), it is possible to force the relative frequency of any arbitrary defined group of scenarios in the structured set to any desired value. For sufficient large N , we can approximate a priori settings at any precision by using integer-valued duplication numbers, r_i .

Now consider the historical seasonal time series of a related variable X – runoff, rainfall at a smaller scale, soil moisture, etc. ($x_1^n, \dots, x_n^n$), corresponding to the seasonal rainfall time series. This series is resampled following the r_i determined for the rainfall series, generating a seasonal structured set of variable X of size N , which can be considered as the forecast sample of X . Statistics can be written as functions of either the structured set ($x_1^N, \dots, x_N^N$) or the original set ($x_1^n, \dots, x_n^n$). For example, the probability distribution of the structured set of seasonal variable X can be determined by considering the relative frequencies of events x (Croley, 1996):

$$\hat{P}[X \leq x] = \frac{1}{n} \sum_{i \in \Omega} w_i, \Omega \equiv \{i | x_i^n \leq x\}$$

where, being q_i = seasonal precipitation of year i ,

$$\begin{aligned} w_i &= \frac{n}{N} r_i = a \frac{n}{n_A}, \forall i | q_i \leq \theta_{0.2}; & w_i &= \frac{n}{N} r_i = b \frac{n}{n_B}, \forall i | \theta_{0.2} < q_i \leq \theta_{0.4}; \\ w_i &= \frac{n}{N} r_i = c \frac{n}{n_C}, \forall i | \theta_{0.4} < q_i \leq \theta_{0.6}; & w_i &= \frac{n}{N} r_i = d \frac{n}{n_D}, \forall i | \theta_{0.6} < q_i \leq \theta_{0.8}; \\ w_i &= \frac{n}{N} r_i = e \frac{n}{n_E}, \forall i | q_i > \theta_{0.8} \end{aligned}$$

To assess the value of using seasonal rainfall forecasting for rainwater catchment systems, it is necessary to establish some evaluation criteria. The *ranked probability score* (RPS) is an appropriate measure of accuracy for probabilistic forecasts of categories, such as those described above. It penalizes forecasts increasingly as more probability is assigned to event categories further removed from the actual outcome (Wilks, 1995). The score for a perfect forecast is $RPS = 0$; the worst possible score is $RPS = J - 1$, where J is the number of categories in which the forecast space is divided. In case of five categories, $J = 5$ and the worst score is $RPS = 4$. The *skill score* refers to the relative accuracy of a set of forecasts, with respect to some set of *reference* forecasts (taken in this paper to be long-term average values of the predictand). It is interpreted as a percentage improvement over the reference forecasts. The skill score for RPS is $S_{ref} = 100 (1 - RPS/RPS_{ref})$. If the forecasts being evaluated are inferior to the reference forecasts ($RPS > RPS_{ref}$), $S_{ref} < 0\%$; if the forecast is perfect, $RPS = 0$, and the skill score attains its maximum value of 100%; otherwise, if $RPS = RPS_{ref}$, then $S_{ref} = 0\%$, indicating no improvement over the reference forecasts (Wilks, 1995).

The Brazilian Nordeste

The north-eastern region of Brazil, the ‘Nordeste’, has an approximate area of 900000 km² in a semiarid and drought-prone climate. The rainy season of the ‘north of Nordeste’, a region of about 500000 km² within Nordeste (Fig. 1), although highly variable in space and time, presents a relatively high predictability. It generally falls between January and July, but concentrated in the four months February to May.

One of the policies traditionally pursued to cope with drought is to build large storage reservoirs. These reservoirs are ‘interannual’, i.e., designed to store water for use over several years. They supply cities, industries, irrigation districts and are also used for fisheries and power generation. At the local scale, micro-catchment systems, such as small dams, cisterns and wells occur widely. These operate on an annual basis, i.e., they are designed to store wet-season water for use during only the following dry period. They serve for supplementary irrigation of small fields, animal feeding and household supply. All of these systems are very vulnerable to climate variability, particularly the small ones.

The potential benefits of seasonal rainfall forecasting for managing rainwater catchment systems in the Nordeste can be evaluated by the forecast skill on the regional scale, important for actions at the institutional level (governmental or otherwise), on the basin scale, where

runoff is generated for input into the large reservoirs, and on the local scale, the scale of the individual micro-catchment systems.

Hydrological records, particularly for discharge, are limited in the region. For this study, rainfall records were available for 1912-88 from a network of stations sited in the 'north of Nordeste'. Seasonal (February to May) rainfall anomalies averaged over this area constitute the 'regional rainfall' series used in this paper. Piancó, a typical drainage-basin in the region, was selected for study, where nine raingauges provided data for the 'basin rainfall', two of them belonging to the regional-rainfall network. Discharge was measured at the basin outlet (area 4550 km²) from 1964-88 and extended to the period 1912-63 by a monthly hydrological rainfall-runoff model. The 'local rainfall' is a seasonal series for one raingauge, located within Piancó Basin.

A series of forecasts for the period 1912-88 was simulated using the forecasting method based on linear discriminant analysis used by the Hadley Centre for Climate Prediction and Research of the UK Meteorological Office (Ward & Folland, 1991). This method was calibrated using average values of eigenvectors of sea-surface temperature anomalies in the Pacific and Atlantic Oceans for months preceding the wet season, November to January, to produce forecasts of seasonal 'regional rainfall' anomalies, February to May. The forecasts are issued as probabilities associated with seasonal rainfall anomalies falling in five pre-defined categories. The resampling procedure was applied to produce estimates of runoff at Piancó Basin and estimates of rainfall at the basin and the local scales. The methods employed in this study were calibrated for 1912-1963 and successfully validated for 1964-1988.

Results and discussion

Fig. 2 illustrates the forecast for the regional rainfall in categorical form. The category of highest forecasted probability is assumed to be the 'forecast'; the 'observed' category that containing the seasonal rainfall actually recorded. According to this criterion, in 48% of the years the forecasted and observed rainfall fell into the same category and in 22% they fell in neighbouring categories, totalling 70%. In only 8% of the cases was an extreme category predicted as the opposite one. This kind of representation loses important information regarding the probability distribution around the 'forecast' category. A fuller, although less clear description, is given by the ranked probability scores (RPS), defined above and shown in Table 1.

The accumulated dilution of the value of forecasts resulting from conversion of regional rainfall forecasts to runoff sequences and to rainfall at the basin and the local scales is evident from Table 1. Comparison of their skill for regional rainfall with that of basin and local rainfall shows that the value of forecasts diminishes as the information is disaggregated to a smaller scale; and it also diminishes as information is transferred to another variable, as in the case of runoff volumes derived from rainfall.

The forecasts at the regional scale coupled with forecasts at the sub-regional or basin scale can be very useful for decision making at governmental and institutional level. Their skill is sufficient to provide information for early estimation and warning of failures of catchment systems over wide areas, identifying regions which are threatened by water scarcity and prompting alleviation actions. Currently, these forecasts are already employed to estimate crop production and the needs for emergency water supply in the region. However, as pointed

out by Hulme et al. (1992), on the impacts of seasonal forecasting for Africa, improvements in institutional efficiency and interaction will need to be made before more benefits of the forecasts can be realised.

The forecasts at the basin scale are also potentially important for reservoir management. For example, runoff between February and May is 94% of the total annual runoff from the Piancó Basin. Therefore, if it were possible accurately to forecast runoff during these periods, difficulties of reservoir operation would largely disappear. Is the forecast skill of basin runoff, as shown in Table 1, sufficient to achieve this goal? Galvão et al. (1999) evaluated these runoff forecasts for the operation of a reservoir located downstream of Piancó Basin. The average shortage for 1979-88 was reduced in about 30% when forecasts were used. However, for the most critical period, 1983-84, there was not significant improvement in the operation. One of the possible reasons for the small gain in 1983-84 lies, perhaps, in the fact that the reservoir is interannual, so that single-season forecasts are of lesser value. If this is the case, methods giving forecasts over a longer period, but with less skill, may be useful, perhaps to indicate trends two or three years ahead. A combination of these two types of information can potentially increase the benefits for interannual reservoirs like those of the Nordeste.

Forecasts at the local scale, aiming at the management of individual micro-catchment systems, are yet to be assessed in the way used for reservoir operation. However, the convective rainfall in the region, highly variable within small areas, prevents much hope for forecasts sufficiently skilful for this purpose. Forecasts at this scale are likely to be of more help for early warning at the sub-regional level, when coupled with the more skilful regional and basin forecasts. For example, disaggregation of regional rainfall to a number of sites within a sub-region could provide maps of estimates of the spatial variability over the area. In another application, time series of water shortage can be generated by simulation of behaviour of micro-catchment systems of various types subjected to the historical records of rainfall at several sites in a sub-region. These series would be resampled in the same way as done for the runoff time series, producing estimates of water shortage at individual sites, which could be subsequently mapped to the sub-region.

Conclusions

Seasonal rainfall forecasts expressed in probabilistic form can be successfully disaggregated from a regional scale to a basin or local scales by means of resampling methods. Forecasts of related variables, such as river runoff, can also be produced using the same approach. The analyses performed for the Brazilian Nordeste show that forecast skill decays as the scale becomes smaller and that forecasts are still of limited use for the management of individual micro-catchment systems. They can be immediately useful, however, for regional early warning applications, as well as for larger rainwater catchment systems management, such as large reservoirs.

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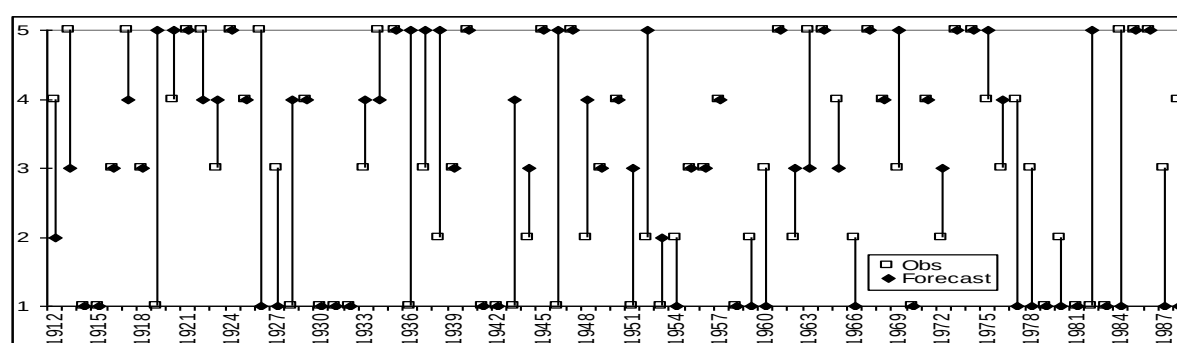


Figure 2. Forecasts for regional rainfall: the category to which the forecast attributed the higher probability was assumed to be the best estimate. Categories are defined as in eqn. (1). For example, category 5 is that of highest seasonal rainfall ($Q > \theta_{0.8}$).

Table 1. Performance measures for evaluating the forecasts: ranked probability score (RPS) and its reference (RPS_{ref}), averaged over 1912-88, and skill score (for definitions of RPS and skill score, see text).

Predictand	RPS	RPS_{ref}	Skill (%)
Regional rainfall	0.63	0.88	29
Basin rainfall	0.71	0.85	16
Local rainfall	0.72	0.81	11
Basin runoff	0.76	0.84	10

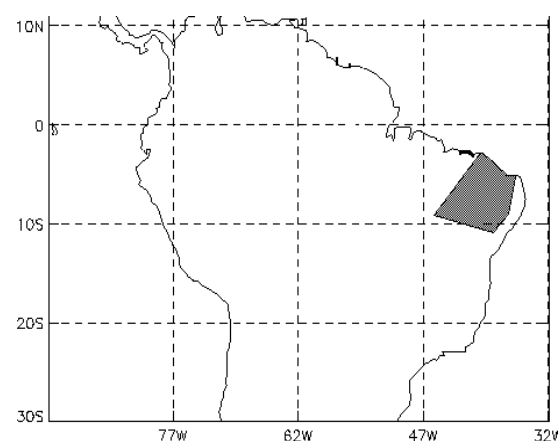


Figure 1. The 'north of Nordeste'.

Drought Criteria

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Abstract

Rainwater catchment is an anticipatory response to drought. Catchment design requires a prudent definition of target drought. Target drought might be a normal dry season, two rainless weeks, etc. Definition is by both duration and depth of precipitation. Target drought is often a balance drawn from past hydrologic history, consequences of rainwater catchment system failure, social implications and public acceptance. Most of the numerous drought indices are inappropriate as catchment performance targets. This paper briefly reviews drought definitions and suggests an analysis for identifying proper rainwater catchment design criteria.

Analysis must anticipate the variety of meteorological futures that a catchment might experience. Stochastic analysis improves understanding of probable catchment behavior and the risks associated with alternative catchment designs. Drought Duration Depth Frequency analysis allows the time step for which a system is sized to be matched to the duration of drought. An example illustrates such assessment.

Types of Drought

Drought differs from aridity, a permanent feature of low rainfall. Drought is a deviation from the long-term balance between precipitation and evapotranspiration. Deviation can be an issue of magnitude, timing (e.g., delay in the start of the rainy season) or effectiveness of precipitation (e.g., number of rainfall events). Climatic factors such as high wind can aggravate drought impact.

Meteorological Drought is defined on the basis of the degree and duration of dryness compared to some “normal” state. Some definitions identify periods by the number of days with precipitation less than some threshold. Other definitions relate deviations on monthly, seasonal, or annual time scales.

Hydrological Drought is associated with the effects of precipitation shortfall on water supply. Frequency and severity are often defined on a river basin scale. Precipitation deficiency may result in a rapid depletion of soil moisture, but the impact of this deficiency on reservoir levels may not be noted for many months. Although climate is a primary contributor to hydrological drought, factors such as land use and the construction of dams also affect basin hydrology. Because hydrologic systems often interconnect regions, hydrological drought may extend beyond the borders of meteorological drought.

Agricultural Drought links meteorological or hydrological drought to agricultural impact. Agricultural drought accounts for the variable susceptibility of crops from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to reduction of final yield. If topsoil moisture is sufficient for early growth requirements, however, deficiencies in subsoil

moisture at this early stage may not affect final yield if subsoil moisture is replenished during the growing season.

Socioeconomic Drought associates the supply and demand of economic goods with elements of meteorological, hydrological, and agricultural drought. Socioeconomic drought depends on characteristics of supply and demand. The supply of such economic goods as water, forage and hydroelectric power depends on weather. Water supply is thus ample in some years but unable to meet human and environmental needs in others. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

Indices of Drought

Palmer Drought Severity Index (PDSI) is a meteorological estimate of soil moisture departure from normal conditions in response to abnormally dry or wet weather. PDSI uses precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. A basic water balance is determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts are not considered.

PDSI criteria determines when a drought or a wet spell begins and ends. An abnormally wet month in the middle of a long-term drought has little impact on PDSI. A series of months with near normal precipitation following a serious drought does not necessarily signal that the drought is over.

PDSI calculates three intermediate parallel indices. If the probability that a drought is over is 100 percent, one index is used. If the probability that a wet spell is over is 100 percent, another index is used. If the probability is between 0 and 100 percent, the third index is employed. When conditions change from dry to normal or wet, the drought measured by PDSI ends without considering longer-term hydrologic impacts. PDSI is typically calculated on a monthly basis. Table 1 illustrates PDSI values.

Table 1. PDSI Classification

>	4.00	Extremely wet
3.00 to	3.99	Severely wet
2.00 to	2.99	Moderately wet
1.00 to	1.99	Mildly wet
0.50 to	0.99	Incipient wet spell
0.49 to	-0.49	Near normal
-0.50 to	-0.99	Incipient dry spell
-1.00 to	-1.99	Mild drought
-2.00 to	-2.99	Moderate drought
-3.00 to	-3.99	Severe drought
<	-4.00	Extreme drought

PDSI provides a standard for comparisons between locations and between months. A -4.0 in Brazil has the same meaning in terms of the moisture departure from a climatological normal as a -4.0 in California.

Drawbacks include sensitivity to AWC of a soil type, conceptual simplification of soil horizons, exclusion of snow and frozen ground, non-consideration of the natural lag between

precipitation and runoff, the estimate of potential evapotranspiration, and its inappropriateness over large topographic variations.

Modified Palmer Drought Severity Index (PMDI) differs from the PDSI during transition periods between dry and wet spells. PMDI weights the wet and dry index terms by probability. PMDI and PDSI are the same during an established drought or wet spell, but differ during transition periods.

Palmer Hydrological Drought Index (PHDI) is a near-real time hydrological index of soil moisture based on moisture inflow (precipitation), outflow, and storage, without regard to the long-term trend. PHDI numeric values correspond to the meanings of PDSI.

Palmer "Z" Index (ZNDX) measures moisture anomaly. The Z statistic indicates departure from normal monthly PDSI. ZNDX responds to a month of above-normal precipitation, even during periods of drought. Table 2 compares PHDI and ZNDX values.

Table 2. PHDI and ZNDX Classification

Cumulative Frequency Percent		PHDI		ZNDX					
>	96	>	4.00	>	3.50	Extremely wet			
90 to	95	3.00 to	3.99	2.50 to	3.49	Severely wet			
73 to	89	1.50 to	2.99	1.00 to	2.49	Mildly to moderately wet			
28 to	72	-1.49 to	1.49	-1.24 to	0.99	Near normal			
11 to	27	-1.50 to	-2.99	-1.25 to	-1.99	Mild to moderate drought			
5 to	10	-3.00 to	-3.99	-2.00 to	-2.74	Severe drought			
<	4	<	-4.00	<	-2.75	Extreme drought			

Surface Water Supply Index (SWSI) is computed with snowpack, precipitation, and reservoir storage inputs in the winter. During the summer, streamflow replaces snowpack as a component. Monthly data are summed for precipitation, reservoir, snowpack and streamflow stations. Long-term frequency analysis yields the normalized nonexceedence probability for each component. Component are weighted depending on contribution to surface water and summed. SWSI is centered at zero and has a range between -4.2 and +4.2.

SWSI is simple to calculate and gives a representative regional indication of surface water supplies. Adding or dropping stations requires new frequency determinations. Changes in water management, such as flow diversions or new reservoirs, require redeveloped weights. Thus, it is difficult to maintain a homogeneous record. Extreme events beyond the historical time series also cause problems.

Standardized Precipitation Index (SPI) is the number of standard deviations that the observed precipitation deviates from the long term mean, assuming normal distribution. SPI can be compared across regions with markedly different climates. Since precipitation is not normally distributed, an appropriate transformation is required.

Crop Moisture Index (CMI) is a meteorological monitor of week-to-week crop conditions. CMI was developed from procedures within the PDSI. Whereas PDSI monitors long-term meteorological wet and dry spells, CMI evaluates short-term moisture conditions. CMI is based on the mean temperature and total precipitation for each week as well as CMI of the previous week. CMI's rapid response to changing conditions may provide misleading

information about the long-term. CMI typically begins and ends each growing season near zero, preventing CMI use in droughts extending over several years.

Percent of Normal Precipitation (PNP) is one of the simplest measurements of rainfall for a location. PNP can be calculated for a variety of time scales but can be used for a single region or a single season. PNP comparison implies that the mean and median are the same. PNP is easily misunderstood and may give different indications depending on location and season.

Deciles divide precipitation occurrences over a long term into ten percent groupings. The first decile is the rainfall amount not exceeded by the lowest 10 percent of the precipitation occurrences. The fifth decile is the median. The decile method is simple to calculate, and requires less data and fewer assumptions than the PDSI.

National Rainfall Index (NRI) compares precipitation abnormalities on a continental scale. NRI is calculated for a country by taking a national annual precipitation average weighted according to long-term averages of all stations. Because NRI is weighted by annual rainfall, stations in wetter areas have a greater influence. NRI is independent of absolute amounts of localized rainfall. A frequency distribution of NRI allows historical comparisons not possible with PNP. If the record is not complete for an individual station, NRI can be calculated without that station.

Dependable Rains (DR) are rainfall occurring in four of every five years. The relationship of the DR to the mean may reflect characteristics of annual precipitation across a continent. Near the Sahara, DR is approximately 40-50 percent of the annual mean, while in the 700-800 mm precipitation zone DR is about 80 percent of the mean.

Keetch-Byram Drought Index (KBDI) is a soil/duff index based on a soil capacity of 20 mm of water. KBDI factors are maximum daily temperature, daily precipitation, antecedent precipitation, and annual precipitation. As noted in Table 3, KBDI is used for wildfire management.

Table 3. KBDI Classification

0	to	200	Soil moisture and large class fuel moistures are high and do not contribute to fire intensity. Typical of spring dormant season.
200	to	400	Typical of late spring, early growing season. Lower litter and duff layers are drying and beginning to contribute to fire intensity.
400	to	600	Typical of late summer, early fall. Lower litter and duff layers burn actively.
600	to	800	More severe drought with increased wildfire occurrence. Live fuels expected to burn actively at these levels.

Drought Duration Depth Frequency (DDDF) analysis is akin to the *Precipitation Duration Depth Frequency* (PDDF) analysis common in hydrology. DDDF shows the historic relationship of average precipitation, duration and probability at the bottom end of the distribution. DDDF is obtained by stepping through m consecutive days of precipitation record, counting the number of n -day series in which precipitation equals or exceeds a given proportion of the long-term average. A string of m days yields $m-n$ comparisons. The results plots as a cumulative distribution.

Fig. 1 illustrates DDDF drought definition for Albuquerque, NM, USA. The record is 47 years and n varies from 2 to 90 days

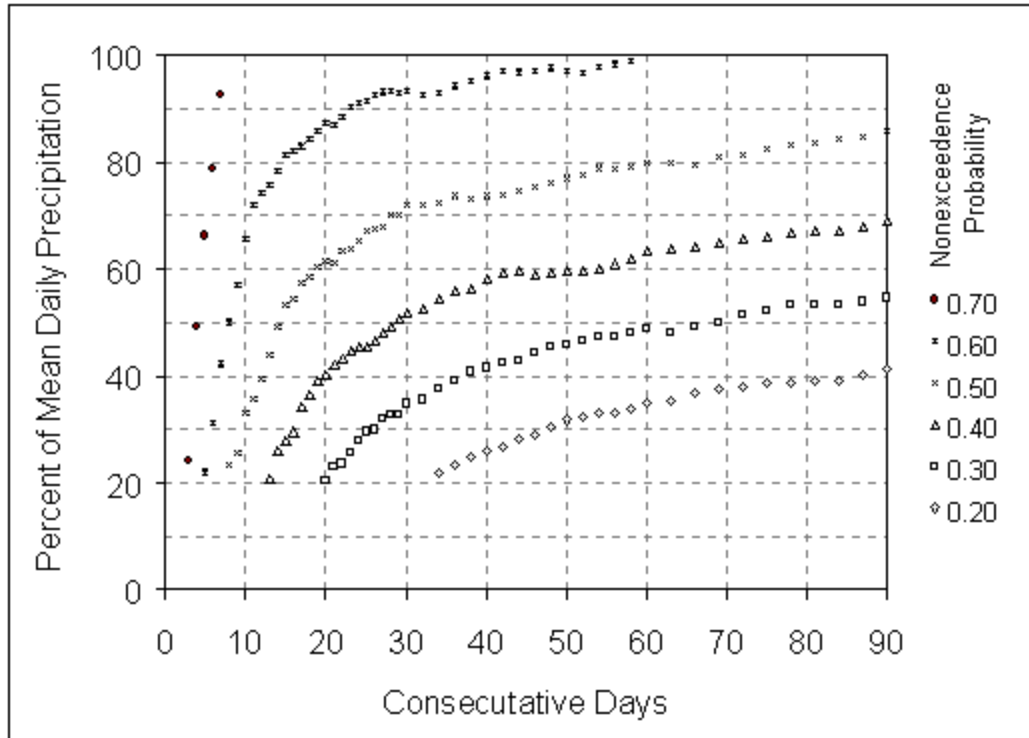


Figure 1. Drought Duration Depth Frequencies, Albuquerque, NM

Fig. 1

Average

Average

Average

Average

Rainfall

precipitation

RWC

failure

often

anticipate

both

receive

all two

1:4

0.05

0.05

0.05

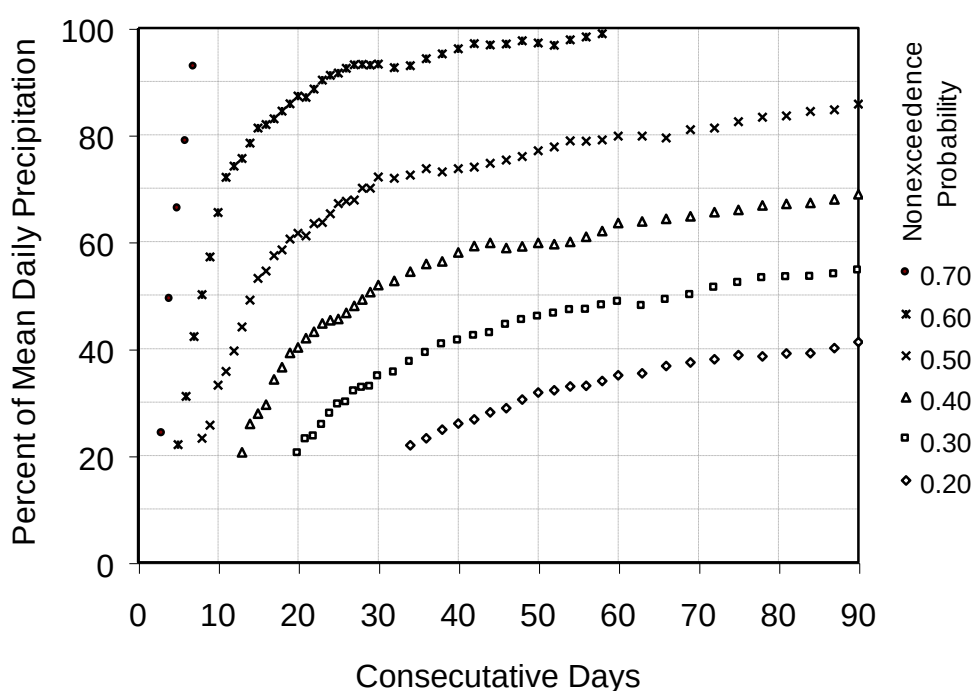
0.05

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mean daily
on occasion.
sized that
RWCS is
consumers

level over
In Fig. 1,
percent of
rarer than

1:4 of days, so days with 10 percent average precipitation is probably not perceived to be a drought. A socially reliable RWCS should be built large enough for this scenario. On the other hand, three months with only ten percent average rainfall has an extrapolated probability of something less than 0.10. The designer may not need to size the RWCS for this target, as users would not likely not expect full RWCS target supply in 9 out of 10 three-month periods. While the numeric

targets, both in terms of catchment yield and drought duration, will vary with applications, the concept of trying to target a prudent expectation is universal.

The 47 years of record provides this case study some accuracy in anticipating the duration of extreme dry periods. Were only 10 years available, one would be less certain about the low 10 percent. For most RWCS, such certainty is not a critical issue. No RWCS design guarantees 100 percent reliability. Users learn that their cisterns may go dry, say, a third of the time if they do not ration or secure an alternative water source for the short term. With a realistic expectation of drought, consumption adjusts. DDDF drought criteria help identify when such adjustment is statistically warranted.

Conclusions

Criteria for drought serve many purposes. As RWCS design generally deals with meteorological abnormalities and human consumption, there is little cause to confuse the goals with agricultural or complex water balance criteria. DDDF requires only a record of historic rainfall and can address system behavior for duration and risk appropriate to RWCS needs. DDDF analysis anticipates how often a RWCS will fail to sustain a given rate of consumption.

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Extensive information is electronically published on all referenced drought indices except the DDDF.

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Modelling of rainwater catchment and utilization on farmsteads in Sipili, Kenya

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Abstract

Undependable and erratic rainfall patterns, with frequent rainless periods within the rainy season in Sipili location, a semiarid area in Kenya, is the primary natural limiting factor to the rain-fed agricultural production potential of the area. Although the average annual rainfall of 600 - 800 mm would appear sufficient for one or two good crops per year, at times, the harvest is poor or there would be a total crop failure due to poor rainfall distribution. The level of supplemental irrigation mainly for horticultural crops is inadequate since farmers lack guidance on how efficiently harvested rainwater could be utilized for maximum returns.

A computer model was developed based on the mass balance equation to facilitate simulation of water utilization from different tank capacities meant to provide water for domestic use, watering two grade dairy cows and supplemental irrigation of a cabbage crop. The maximum cropped areas for different planting decades (10-day period) of the year up to crop maturity were determined for tank capacities of 50, 100, 150, 200, and 250 m³. The optimum cropped area for each tank capacity could be obtained when planting was done on the 14th decade. The maximum cropped area could be achieved when planting was done on the 2nd, 14th and 26th decades for 50, 100, and 150 m³ tanks and on the 1st, 13th and 25th decades for 200 and 250 m³ tanks. Such results would give farmers in Sipili and its environs an opportunity to strategize for the highest market prices of the cabbage crop or the highest crop yield.

Introduction

The world's demand for more food and fibre has led to a growing awareness of the value of arid and semi-arid lands (ASAL) of the tropics if sufficient and economical water supplies can be found or developed (Frasier, 1981). The consequences of water shortage to plants and animals are disastrous, especially in countries, which depend primarily on rainfed agricultural production for both crops and livestock. According to Jackson (1977) and Stewart and Hash (1982) the need to increase agricultural production in many tropical developing countries calls for improvements in production of subsistence smallholder farmers even in drier lands.

Rainwater has been purposely collected and stored in ponds, cisterns, surface tanks and in the soil to support human habitation for over 4000 years in many parts of the world. Stored rainwater can be a valuable supplement to other, possibly inadequate, domestic water sources and also for irrigation. Its use is particularly appropriate in ASAL of the world where heavy, intense storms are followed by prolonged periods of little or no rainfall (Pickford, 1991). The supply of domestic water is an important objective in rural development for its benefits to human health and welfare (Curtis, 1989). The technique of rainwater harvesting (RWH) for domestic supply, livestock and crop production is essentially small-scale. It utilizes the roofs of individual house and ground catchment as the collecting systems. Therefore, in ASAL of the tropics where rivers may be few and ephemeral, water is the main constrain to increasing production and hence,

rainwater harvesting (RWH) offers a high potential for alleviating water constraints to the habitation and development of arid and semi-arid lands. This work was thus, designed to establish how the production potential of farmsteads in Sipili location, Laikipia district in Kenya could be exploited through rainwater harvesting technology.

Methodology

Rainfall Distribution in Sipili

To facilitate proper agricultural planning and utilization of the stored water, knowledge of rainfall onset and cessation is essential (Alusa and Mushi, 1974). According to Griffiths (1972) a monthly rainfall amounting to 50 mm is considered adequate for crop production. In this work a decade (10-day period) was considered wet if it received rainfall amounting to or greater than 15 mm. The 1st decade of the year referred to the first 10 days of January and the 36th decade referred to the last 11 days of December.

Rainfall and evaporation data for 33 years (1964 to 1996) for Rumuruti area station 8936/064 in the vicinity of Sipili was used. Using the Weibull formula, the rainfall amount occurring at 67 percent probability was obtained and used to determine the runoff generated from the ground catchment and the effective rainfall. The rainfall onset in Sipili occurs during the 10th decade of the year with wet spells occurring on the 10th to 12th, 19th to 22nd and 30th decades (Kiggundu, 1998). On the other hand, the dry spells occur on the 1st to 9th, 13th to 18th, 23rd to 29th and 31st to 36th decades. He further noted that a dry spell of 60 days from the 13th to 18th decade was responsible for the crop failure under rainfed agriculture in Sipili area.

Water Abstraction from the Tank

The tanks were designed as open surface truncated inverted cones following the work of Helweg and Sharma (1983). Mathematical relationships relating the tank water depth (h_1) as a function of tank water volume (V) and exposed tank water area (A_e) as a function of water depth (h_1) were developed and used in determining the evaporation losses. According to Kiggundu (1998) the average family size in Sipili was 8 members and water consumption was 10 litres per person per day from the 1st to the 9th decade and 15 litres per person per day thereafter. For livestock watering, the two grade dairy cows consumed 50 litres per animal per day through the year.

The growing period of cabbage in Sipili was 120 days, which was equivalent to 12 decades inclusive of 3 nursery decades. Thus the computed water volume requirements for the first 3 decades were higher than what would actually be used since in the nursery the seedlings occupy a very small area. The crop coefficient (k_c) used were; during the initial stage 0.45 (25 days), crop development stage 0.75 (35 days), mid-stage 1.025 (40 days) and late-stage 0.95 (20 days). For a given crop area and planting decade, the irrigation requirements were determined using methods proposed by Doorenbos and Kassam (1979).

Tank Simulation

A computer model was developed under “Microsoft Excel Visual Basic Programming” environment to carryout tank simulations. For each simulation run, the assigned parameters were; tank capacity, crop area and planting decade. The other parameters like the design rainfall

at 67 percent probability level, evaporation amount, catchment area and runoff coefficient were input once during the simulation preparatory stage. The tank capacities selected were 50, 100, 150, 200 and 250 m³.

The following considerations were made;

- i. pan evaporation coefficient was 0.8.
- ii. the tanks were lined and therefore, seepage losses were zero.
- iii. since the rainfall onset occurred during the 10th decade, the starting point for each simulation was the 10th decade and ended on the 9th decade of the following year.

For each decade period a water balance analysis as given in equation (1) was carried out to establish whether the available water in the tank was adequate for the abstraction requirements set.

$$V_{t+1} = V_t + R_t * C_t * S - Q_t - V_e \quad (1)$$

Where,

V_{t+1}, V_t = Storage of the tank at time $t + 1$ and t

R_t = Rainfall during the decade t

C_t = Runoff coefficient at decade t

S = Collecting surface area

Q_t = Demand during the decade t

V_e = Evaporation losses during the decade t

Results and discussions

The results given in Table 1 were the maximum possible cropped area up to maturity of the cabbage crop, which was 12 decades in consideration of other farmstead water needs, which were water for domestic and livestock use. Although each decade had an attached cropped area, planting was only possible in a sequence of 12 decades. This implied that if planting was done during the 1st decade, the next planting would only be possible starting from the 13th decade. Different tank sizes were considered so as to cater for all farmers in the area. Although the tank sizes were in steps of 50 m³ from 50-250 m³, in case of farmers with tank capacities lying between any two given tanks, the cropped area would be obtained by interpolation.

The maximum cropped area was achieved when planting was done during the 14th decade (Figure 1b). The cropped area increased from the first decade up to the 14th decade and thereafter it decreased. Although the general concept is that farmers should plant immediately the rains come, with supplemental irrigation, planting would be shifted from the time of rainfall onset, which was the 10th decade to the 14th decade in order to achieve a bigger cropped area. This implied that for farmers who wished to grow cabbage all the year round, planting would be done during the 2nd, 14th and 26th decades, for tank sizes of 50, 100 and 150 m³ and on the 1st, 13th and 25th decades for 200 and 250 m³ tanks. Thus, for a given tank size and a preferred time of planting, the cropped area could be read from Table 1.

Table 1 Maximum cropped area for cabbage per decade for 5 different tank capacities

	Maximum cropped area in m ² for different tank capacities in the range of 50 – 250 (m ³)				
	50	100	150	200	250
Decade					
1	70	205	340	485	600
2	90	260	435	590	725
3	110	320	535	750	920
4	150	425	715	930	1150
5	220	645	940	1225	1510
6	365	985	1400	1820	2255
7	670	1515	1710	1880	2050
8	1300	1480	1685	1850	2020
9	1250	1455	1665	1870	2080
10	1350	1565	1790	2010	2240
11	1430	1680	1920	2165	2375
12	1500	1825	2080	2345	2600
13	1800	2100	2400	2700	3000
14	2015	2345	2680	3020	3360
15	900	1550	2025	2315	2600
16	750	900	1240	1600	1850
17	400	650	860	1100	1345
18	390	620	840	1050	1230
19	365	595	820	1030	1210
20	365	590	820	1010	1185
21	400	645	890	1080	1265
22	450	715	965	1170	1375
23	500	810	1050	1270	1490
24	580	860	1195	1450	1700
25	600	900	1320	1620	1900
26	275	550	1270	1070	1335
27	190	375	805	760	950
28	135	280	420	565	710
29	100	215	335	450	570
30	80	180	285	390	495
31	60	155	250	340	435
32	48	135	218	300	385
33	50	135	225	310	400
34	50	145	240	330	425
35	55	155	260	360	460
36	60	170	285	405	520

The first peak in Figure 1b did not occur at the same time as compared to the other two peaks. This was because of the long dry spell that starts from the 36th decade of a previous year to the 7th decade of the following year. This implied that a bigger tank would have more water stored after the 36th decade as compared to the smaller one. Thus, for a 50 m³ tank the first peak occurred at the 8th decade when the tank had received some inflow, for the 100, 150 and 200 m³ tanks it occurred at the 7th decade and for the 250 m³ it occurred at the 6th decade.

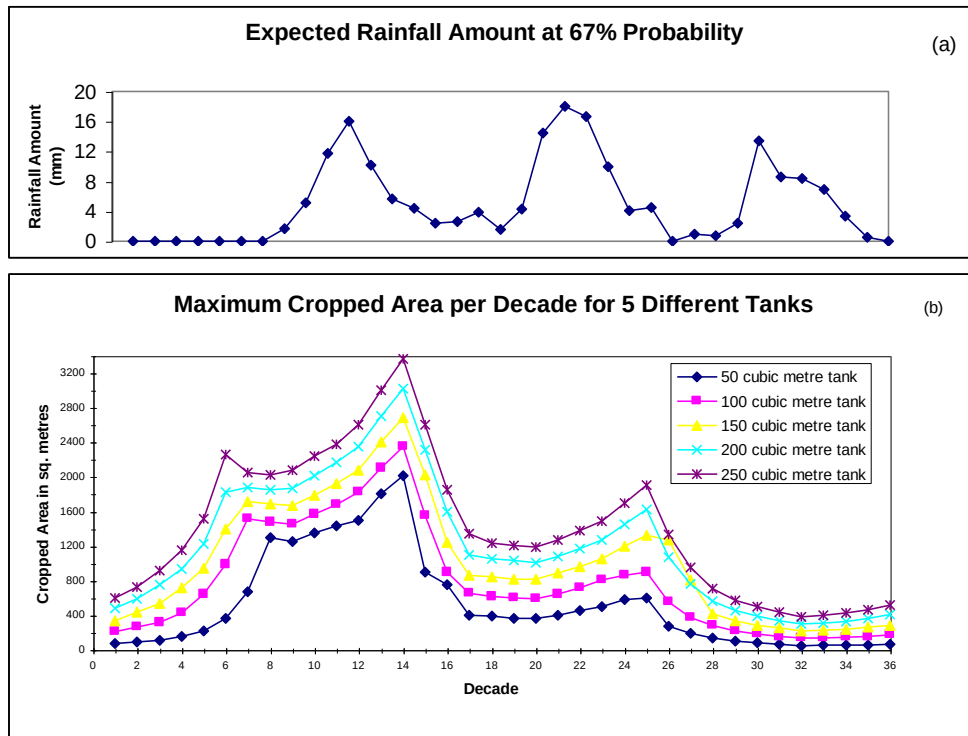


Figure 1 Expected rainfall at 67 percent probability (a) and cropped area per decade for five tank sizes (b)

The peak on the 14th decade was attributed to the fact that the crop entered its mid-stage, which ran from the 20th to 23rd decade at the time when the inflow into the tank and the available soil moisture were abundant as a result of the second wet spell, which resulted into a bigger cropped area. Both the crop's mid-stage and the wet spell started at the same decade and lasted for almost the same duration. The decline in the cropped area for planting done on the 15th decade was attributed to the fact that for the last decade of the crop's mid-stage the water was limiting and therefore a reduction in the cropped area in order to match the demand with the supply. This implied that any planting done such that the crop's mid-stage coincided with the dry spell resulted into a smaller cropped area and thus a sharp decline in the cropped area for planting done during the 16th, 17th and 18th decades. The decline in cropped area corresponded with the number of decades the mid-stage coincided with the dry spell.

The peak at the 25th decade was a result of water availability in the tank during the mid-stage of the crop that occurred from the 31st to 34th decade. The decline in the cropped area thereafter was attributed to the dry spell. The lowest cropped area occurred when planting was done during the 32nd decade mainly due to the high water requirements and low or no rainfall from the 32nd decade to the 6th decade of the following year.

Conclusion

Due to occurrence of long dry spells during the crop growing season rain-fed agriculture becomes highly unreliable in Sipili area. The crops that receive adequate rainfall during the initial stages are hindered from further growth by the long dry spell and unless there is supplemental irrigation or any other method of conserving soil moisture, crop failure may be inevitable. Although the general concept in agriculture is that farmers should plant immediately the rains come, with supplemental irrigation in Sipili, planting could be shifted from the time of rainfall onset (10th decade) to the 14th decade in order to achieve a bigger cropped area. For farmers who wished to grow cabbage all the year round, planting would be done on the 2nd, 14th and 26th decades for 50, 100 and 150 m³ tanks and on the 1st, 13th and 25th decades for 200 and 250 m³ tanks. With rainwater harvesting, planting would be done at anyone preferred time. This gives the farmer a chance to target for maximum market prices such that crop harvest is done when the crop is on high demand or going in for a bigger crop yield. Thus, a farmer would become self-reliant and carries out farm activities without being worried about water scarcity.

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Anticipatory conservation based drought management of water supply reservoirs

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Abstract

A new methodology has been developed and evaluated for making long-term forecasts for the dry and wet period phenomenon. This study emphasizes the use of actual data as opposed to synthetic data. This is extremely valuable for the reservoir water manager dealing with the actual data as opposed to artificial data, which may or may not be materialized. Utilization of the method significantly improves storage reservoir management and also acts as a valuable tool in sizing the needed capacity of the existing or non-existing reservoir systems.

Introduction

Extreme hydrologic variation often has significant effects on man and his society. Drought episodes are one type of hydrologic variation which can cause significant technical, management, economic, and social problem. The impact of severe drought in arid and semiarid areas which are agriculturally productive is quite apparent.

Traditionally, reservoir development coupled with conservation strategies has been utilized to minimize the adverse effect of drought. As a consequence, the engineer has had to determine the size of reservoirs to be constructed to provide adequate water supplies during future drought of unknown magnitude and duration.

Now the question arises: how adequate is the plan that incorporates information on potential severity and duration of the drought for dealing with the adverse consequences of a drought?

Method and Approach

The present methodology utilizes historical stream flow data based on water year discharge. Each transformed set of data (annual flow for each river reduced to unit mean and summed) is plotted in the form of cumulative departure from cumulative mean flow. Then, in relation to the long term storage capacity phenomenon (Hurst, 1951) The range statistic is formed as a boundary range curve and ultimately intersected with the linear model which already has been fitted to the regions of the realization curves. The linear model is based upon the existing correlation between duration and severity of events (wet–dry period) in every sequence of data. The intersection points are in fact the theoretical location of the diversion points on the realization curve. Implementation of this process by the means of the two above functions (i.e. boundary range curve and the linear model) along the path of the realization curve makes it feasible, even if only approximately, to predict the future pattern of the cumulative sum inflow into an existing or hypothetical reservoir.

Generally speaking, the uniqueness of each trend line and the diversion points will be powerful enough to act as a driving force to construct a linear extrapolation model for wet and

dry periods separately in the set of data. In other words, the combination of the linear model and the boundary range curve will provide forecast information to determine an extreme event of the realization curve as described in terms of its magnitude and duration. Therefore, this procedure acts as a long - term anticipatory draught tool that incorporates both stochastic and deterministic features.

The stochastic nature of a random variable such as river flow can not be ignored. Therefore, no one can speak to the storage problem of a reservoir in a purely deterministic way. Each transformed data set represents one of the stochastic realizations of the potential multi – realization of stream flow. Analysis of such a sequence as a time series on a basis of only one realization is analogous to analyzing the properties of a random variable on the basis of a single observation. Due to this fact, the proposed method is considered to be a combination of stochastic and deterministic features. However, this work will not lead to the conventional time series approach.

It is important to clarify that by the method developed in this research no attempt has been made to establish a method based on a drought probability distribution function (pdf) or a combination of Monte Carlo simulation techniques which requires a huge number of synthetic data. On the contrary, the present method tries to address the problem by describing what really does occur over a single realization curve in the future. The answer, i.e. the time and magnitude of the extreme event, is single and specific. Remember, this realization is the one which is actually occurring and the proposed answer is unique.

Range statistic

Initially consider a hypothetical reservoir whose volume is to be determined. For a sequential data set , say, of annual stream flows, $Z_1, Z_2, Z_3, \dots, Z_N$, the k th partial sum, S_k , ($k=1, 2, 3, \dots, N$) , is defined as

$$S_k = S_{k-1} + (Z_k - \alpha' Z_N) = \sum_{i=1}^k Z_i - \alpha' k Z_N \quad (1)$$

$\alpha' Z_N$ is the reservoir draft and α' , ($0 \leq \alpha' \leq 1$) is a proportionally constant. The physical interpretation of α' in Equation (1) was discussed by McLeod and Hipel (1978). When $\alpha' = 1$, the proportionality constant between storage and draft is the largest and the water in the inflowing river would be used to its full potential.

The maximum value of S_k from all N years over the entire record is called the maximum partial sum, M_N , or maximum surplus. The minimum value of S_k in the same sequence is called the minimum partial sum, m_N , or maximum deficit.

The cumulative range R_N , is defined as

$$R_N = M_N - m_N \quad (2)$$

where, $M_N = \max(0, S_1, S_2, \dots, S_N)$, for the maximum surplus, and $m_N = \min(0, S_1, S_2, \dots, S_N)$, for the maximum deficit, i.e.,

$$R_N = \max\{0, S_1, S_2, \dots, S_N\} - \min\{0, S_1, S_2, \dots, S_N\} \quad (3)$$

Note that R_N is a non- decreasing function over N years (see Figure 1)

The Hurst Phenomenon

Even though the behavior of the range statistic itself is not particularly useful for storage analysis (Sen 1997b), the idea of incorporation of the sample standard deviation with the range statistic was a striking discovery by Harold Edwin Hurst in 1951. He suggested a simple formula based upon long-term dependency of hydrologic sequences and the actual difference between the maximum and minimum cumulative flow from the historical mean flow.

Basically, Hurst's empirical finding leads to

$$(R_N/s_N) \approx R(N) \quad (4)$$

where the function $R(N)$ is the range statistic and s_N is the sample standard deviation with

$$s_N = N^{-\frac{1}{2}} \left\{ \sum_{i=1}^N (Z_i - \alpha \bar{Z}_N)^2 \right\}^{\frac{1}{2}} \quad (5)$$

The importance of the range statistic is this. Hurst's work and those who followed him demonstrated that for very long geophysical sequences such as rainfall and stream flow , R_N/s_N varies as a power, h , of N . This power h , is the Hurst coefficient and is generally found to be about 0.73 with a standard deviation of 0.09 in the many sequences examined by Hurst (Kottegoda, 1980).

Focusing on the Hurst coefficient h , finally it appears in the well known relationship developed by Hurst(1951) as

$$(R_N/s_N) = (N/2)^h \quad (6)$$

in which s_N is the sample standard deviation and h is the Hurst Coefficient.

If one wants to summarize all the research results by now, for the short-term persistent processes the value of h tends to be 0.5 and for long-term persistent processes the value is

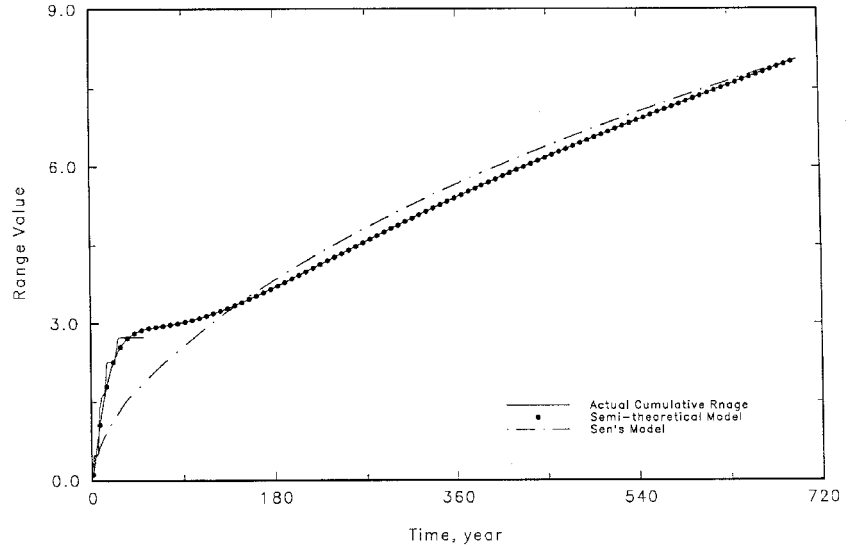


Figure 1. Expected value for range for Niger River

$0.5 < h < 1$. The value of $h=0.5$ is a result of purely random normal process and quite firm in theory. However, the value of $h=0.73$ is also a well-documented empirical figure in hydrology (Kottegoda, 1980; Wallis and Matalas, 1970; Sen, 1977; Klemes, 1974) that does not support the theoretical value of 0.5. This difference, or discrepancy, is considered "The Hurst Phenomenon."

In the literature, two different estimators have been discussed for the population Hurst coefficient h . One is k , originally used by Hurst (1951), with the explicit form of

$$k = \log(R_N / s_N) / \log(N/2) \quad (7)$$

The other estimator is designated as H , (Wallis and Matalas, 1970; Mandelbrot and Wallis, 1969). H and k are biased estimators, both asymptotically approaching 0.5 when the sample size is extremely large (Lawrence and Kottegoda, 1977; Sen, 1977a).

Estimate of the Hurst Coefficient h

It is evident that the present method must utilize annual long-term stream flow data. The Niger River in Africa with data from 1906 to 1956 was selected as a typical river to develop and illustrate the proposed methodology.

Based on a Gaussian assumption for the pdf for the stream flow, Sen(1977a) presented a theoretical expression to determine the k value. One may ask what would be a proper k magnitude without resorting to any pdf assumption. Clearly, a more appropriate model for k would be the one based on actual data reflecting the actual Hurst effect rather than one based on an Gaussian assumption behavior.

Following this direction of thought, one might first evaluate the Hurst coefficient through the observed data. Since

$$R_N = (N/2)^k * s_N \quad (8)$$

then

$$\log(R_N / s_N) = k \log(N/2) \quad (9)$$

$$k = \frac{\log(R_N / s_N)}{\log(N/2)} \quad (10)$$

where (R_N / s_N) is the adjusted re-scaled range, N is the sample size, and s_N is the standard deviation for the entire sample size. Equation(10) yields a series of k values because R_N and N are both known values from the historical record. By plotting the logarithm of k versus time and establishing a linear regression model, the natural behavior of k with respect to time, as reflected in the slope of the data, is demonstrated. The exponential form of the linear regression line is defined by

$$\log k = b - aN \quad (11)$$

$$\frac{k}{k_0} = e^{-aN} \quad (12)$$

where $b = \log k_o$ and $k = k_o$ at $N = 0$.

It was found for the Niger River data, in taking the result from Equation (11) and applying it to Equation (8), that a poor fit was obtained to the range data. In other words, keeping track of the path of the actual cumulative range curve will not work well unless Equation (12) is modified. This modification, is based on the desired asymptotic behavior with trail and error refinement, is shown below in Equation (13). With the constraint of $k_o = 0.6$ at N approaching infinity, the modified equation works quite well. The modified equation is

$$\log(k - 0.6) = b - aN \quad (13)$$

It is interesting to note that Sen's theoretical work (1977a) shows a similar behavior on his graphical presentation of expected values of k .

In summary, the above simple model conveys the following features: (1) the general behavior of the k values can be described by a modified exponential equation; and, (2) the lower bound on k found by trail and error to be 0.6 is consistent with the minimum possible value of 0.5.

Fitting model with constant coefficient

The practical significance of the real range evidenced in a data set is that it defines the minimal necessary reservoir volume to supply a demand equal to the mean flow over a drought period.

The range values are readily determined through long-term annual stream flow records. Mathematically describing the cumulative range values eventually leads to a model for the expected value of the range which is the required information for the prediction of reservoir requirements.

The key factor in accomplishing this task is the identification of a proper k value for the empirical range equation found by Hurst (1951). A sequence of k values based on Equation (13) provides a satisfactory result for describing the range behavior (see Figure 1). Thus, the two step procedure for defining a range model is: (1) make a regression analysis for k , using the modified exponential Equation (13); and (2) substitute that k into the empirical range equation. The final form will be

$$R_N = \left[\left(N/2 \right)^{\{k_o + 10^{-[a \cdot N - b]}\}} \right] * s_N \quad (14)$$

where N is time from the beginning of the record, $k_o = 0.6$ an empirical value which is the initial value of estimator of h , s_N is the standard deviation of the streamflows, and a and b are the regression coefficients for the modified k model.

The above version of the range equation furnishes a reasonably well-fitting model to the observed range data for the Niger River (see Figure 1) as well as the 9 other rivers selected from three different parts of the world for analysis. However, the model need not necessarily be a perfect fit. Figure (1) shows the observed range curve has a stair-case type of upward movement which is not making such a perfect fit; but the underlying idea is merely to find the trend of the actual data.

Because Equation (14) can empirically describe the range phenomenon as based on the Hurst empirical theory and is also consistent with the theoretical results shown by Sen (1977a), it can be called a semi-theoretical model for range calculation.

The semi-theoretical model serves as a theoretical boundary limit for the maximum-minimum variation (largest deficit and surplus) of the realization curve. Therefore, the term “boundary range curve” will be used interchangeably for semi-theoretical model. Figure (2) illustrates the boundary range curve for the Niger with the historical data of 50 years.

The realization curve

In order to prepare the realization curve defined earlier, one may calculate annual stream flows reduced to unit mean, summed them, and then subtract from each flow the mean flow based on the summed total (a process of normalization) to produce the curve which is deviation of flow from the mean flow.

Recognition of the features of a realization curve are important to understanding the objective of the current study. The realization curve is composed of wet and dry periods, forming a long term cyclic pattern. These are evidenced by upward or downward trends in the realization curve. For example in Figure (3), there is a short term upward fluctuation from point F to G which is embedded in the long-term trend from A to B in region one of the curve. These long-term trends such as from A to B, B to C, and to D on figure (3) define major wet and dry periods upon which reservoir design must be based. Since reservoirs are designed to yield water over long periods, particularly during the course of multiyear drought periods. Therefore, prediction of such long term hydrologic trends on a realization curve is important.

As a result of the normalization process, every realization curve contains at least one minimum or one maximum global point

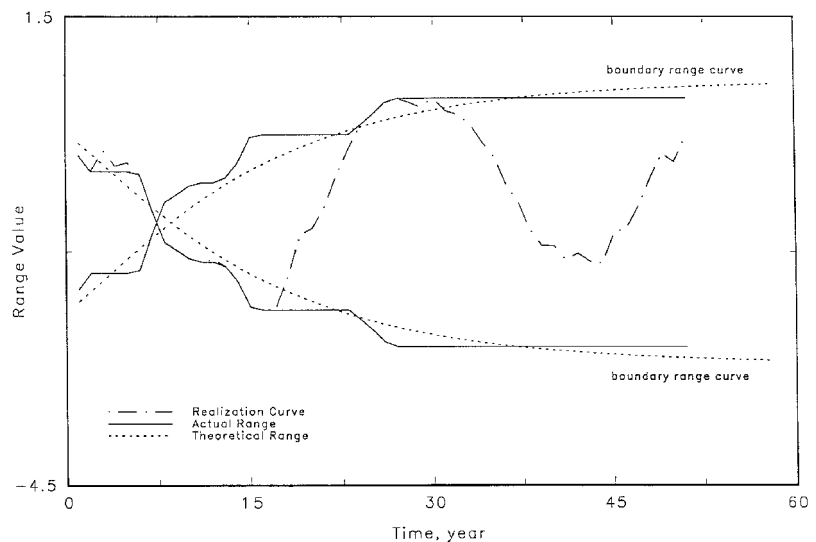


Figure 2. Boundary range curves for Niger River

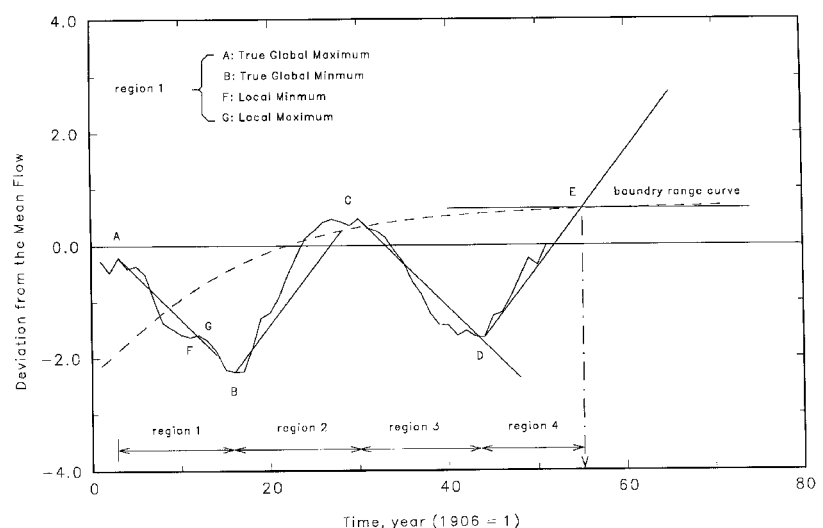


Figure 3. Forecasting for Niger River

(i.e., it has at least one half cycle if a full cycle incorporates wet-dry-wet-dry regions). For the Niger River as well as seven other rivers the realization curve reaches zero at least only after one full cycle (see the realization of figure 3). Reoccurrence of the next half cycle is expected to follow the continuation of the pattern. Sadeghipour and Dracup (1982) mentioned that drought events in a homogeneous region usually occur at the same period for each stream; this is consistent with the cyclic behavior of the realization pattern.

References

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Balanço Hídrico Seriado de Petrolina, Pernambuco

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Resumo

Para qualquer necessidade de uso dos recursos naturais de uma região, torna-se necessário o conhecimento dos regimes térmico e hídrico e da interação entre estes. Uma maneira eficaz de se obter essa interação, é com a realização do balanço hídrico climático. Este se baseia na contabilidade da precipitação pluvial com os valores correspondentes da evapotranspiração potencial. O objetivo desse trabalho foi fazer o balanço hídrico seriado para a região de Petrolina-PE, utilizando-se dados diários de precipitação e temperatura do ar da estação agrometeorológica da Embrapa Semi-árido. Determinaram-se os períodos de deficiências e excedentes hídricos e uma tendência destes para os próximos anos foi observada.

INTRODUÇÃO

Segundo NIMER (1979), excluindo as áreas de altitudes elevadas, todo o sertão de Pernambuco apresenta médias anuais de temperatura superiores à 24°C, ultrapassando os 26°C nas depressões de 200 à 250 metros de altitude (vale do Rio São Francisco). Apesar da amplitude térmica ser pequena, as temperaturas mais elevadas de verão são muito significantes, uma vez que nesta época do ano ocorre maior déficit hídrico, pela intensificação do processo evapotranspiratório.

A homogeneidade térmica, contrasta com a heterogeneidade espacial e temporal do regime pluviométrico. O principal período da estação chuvosa do semi-árido nordestino estende-se de fevereiro a maio, e pode ser influenciada pelos oceanos tropicais e por fatores de circulação atmosférica de escala global e regional. A deficiência hídrica se sobressai como o maior problema da região semi-árida. A altura média de precipitação no Nordeste do Brasil se distribui decrescendo bruscamente do litoral para o interior.

Para se ter uma idéia mais aproximada das reais disponibilidade de água em qualquer região e em particular no Semi-árido, onde o problema do déficit hídrico provoca grandes impactos sociais, não basta apenas que se conheça o regime pluviométrico. Torna-se necessário a realização do balanço hídrico. O balanço hídrico climático é um método climatológico introduzido por Thornthwate (1948), e aprimorado por Thornthwate & Mather (1955) que consiste em se efetuar a contabilidade de água em relação a uma dada superfície vegetada, computando-se, sistematicamente, todos os ganhos e perdas. São considerados ganhos as contribuições devido à precipitação pluviométrica e as perdas são ocasionadas pela evapotranspiração real.

O objetivo desse trabalho foi realizar o balanço hídrico seriado para região Petrolina-PE, para estimativa dos totais de deficiências e excedentes hídricos para o período de 1974 a 1998,

gerando uma idéia do que acontece com boa parte da região semi-árida, no que diz respeito a disponibilidade de água.

MATERIAL E MÉTODOS

Foram utilizados dados de temperatura média e totais de precipitação mensais durante o período de 1974 a 1998, da Estação Agrometeorológica do campo experimental da Embrapa Semi-árido da Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), em Petrolina-PE (latitude: 09°09' S, longitude: 40°22' W e altitude: 365,5m).

Considerou-se a capacidade de armazenamento do solo de 125mm obtida em Choudhury & Millar (1981), e realizou-se o balanço hídrico climático para o ano de 1974. Observou-se que no mês de abril do referido ano o solo estava plenamente abastecido, sendo a partir daí iniciado o balanço hídrico seriado até dezembro de 1998.

A evapotranspiração potencial (*EP*) foi calculada, mensalmente, pelo método de Thornthwaite (1948). Contabilizando-se a precipitação e a evapotranspiração potencial (Thornthwaite & Mather, 1955), estimaram-se a evapotranspiração real (*ER*) a deficiência hídrica (*DEF*) e o excedente hídrico (*EXC*) para cada ano. De posse dos valores desses últimos parâmetros, obtiveram-se o índice hídrico (*IH*), índice de umidade (*IU*) e o índice de aridez (*IA*) pelas seguintes expressões:

$$IH = (100EXC - 60DEF) / EP \quad (1)$$

$$IU = (100EXC) / EP \quad (2)$$

$$IA = (100DEF) / EP \quad (3)$$

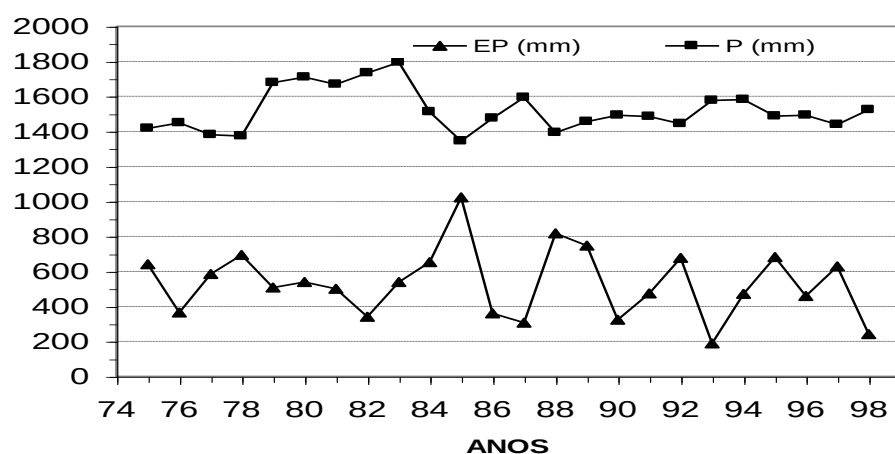
RESULTADOS E DISCUSSÃO

A variação anual e os parâmetros estatísticos da precipitação pluviométrica (*P*) e evapotranspiração potencial (*EP*), bem como evapotranspiração real (*ER*), excedentes (*EXC*) e deficiências (*DEF*) hídricas e os índices hídrico (*IH*), de umidade (*IU*) e de aridez (*IA*) são apresentados na Tabela 1, onde *M* é o valor médio, *S* o desvio padrão, *CV* o coeficiente de variação, *MAX* o valor máximo e *MIN* o valor mínimo.

Com relação a precipitação (*P*) e a evapotranspiração potencial (*EP*), elementos contabilizados no balanço hídrico, percebe-se a extrema variedade da primeira, como mostra o coeficiente de variação de 36%. Já o segundo parâmetro apresenta uma pequena variabilidade anual, com exceção do período entre 1978-85, quando ocorreram valores mais elevados (Tabela 1 e Figura 1). A amplitude térmica local normalmente varia pouco devido à baixa latitude, que proporciona uma pequena variação da incidência de radiação solar, consequentemente, produzindo pequena variação em *EP* (*CV* = 7,9%). Pela Figura 1 percebe-se uma tendência a uma simetria nos valores desses dois parâmetros, ou seja, a uma diminuição da precipitação corresponde um aumento na evapotranspiração potencial, e vice-versa, o que favorece ainda mais o déficit hídrico.

Tabela 1. Parâmetros estatísticos da precipitação anual, evapotranspiração de referência e elementos do balanço hídrico climático pelo método de Thornthwaite & Mather (1955).

ANO	<i>P</i>	<i>EP</i>	<i>ER</i>	<i>EXC</i>	<i>DEF</i>	<i>IH</i>	<i>IU</i>	<i>IA</i>
75	640,4	1416,9	638,2	2,2	778,7	-32,8	0,2	55,0



76	364,2	1449,0	364,3	0,0	1084,6	-44,9	0,0	74,9
77	584,5	1382,0	584,6	0,0	797,4	-34,6	0,0	57,7
78	694,3	1372,7	577,0	11,1	795,6	-26,2	8,5	58,0
79	508,5	1679,5	508,7	0,0	1170,8	-41,8	0,0	69,7
80	538,8	1710,6	532,0	6,9	1178,7	-40,9	0,4	68,9
81	500,1	1669,8	431,4	69,0	1238,7	-40,4	4,1	74,2
82	341,9	1733,7	341,9	0,0	1391,8	-48,2	0,0	80,3
83	540,0	1795,5	540,0	0,0	1255,5	-42,0	0,0	69,9
84	653,9	1510,9	602,5	50,9	908,3	-32,7	3,4	60,1
85	102,5	1344,4	915,5	86,1	428,9	-12,7	6,4	31,9
86	361,4	1474,5	383,7	0,0	1090,9	-44,4	0,0	74,0
87	306,9	1594,2	306,9	0,0	1287,3	-48,4	0,0	80,7
88	817,3	1392,7	684,2	98,0	708,5	-23,5	7,0	50,9
89	746,3	1455,1	565,9	90,5	889,2	-30,4	6,2	61,1
90	324,8	1492,3	449,8	0,0	1042,5	-41,9	0,0	69,9
91	474,7	1483,9	474,7	0,0	1009,2	-40,8	0,0	68,0
92	678,2	1442,7	620,1	58,0	822,5	-30,2	4,0	57,0
93	187,8	1577,0	187,9	0,0	1389,2	-52,9	0,0	88,1
94	471,1	1581,5	471,1	0,0	1110,4	-42,1	0,0	70,2
95	681,5	1488,0	681,4	0,0	806,7	-32,5	0,0	54,2
96	459,7	1491,9	459,8	0,0	1032,1	-41,5	0,0	69,2
97	629,2	1439,4	576,0	53,1	863,4	-32,3	3,7	60,0
98	242,4	1523,8	242,5	0,0	1281,3	-50,5	0,0	84,1
M	532,1	1520,9	505,8	26,3	1015,1	-37,9	1,8	66,2
S	191,6	119,8	155,0	38,7	235,1	9,1	2,7	12,1
CV	36,0	7,9	30,6	146,9	23,2	-24,2	149,5	18,2
MAX	1023,5	1795,5	915,5	117,1	1391,8	-12,7	8,5	88,1
MIN	187,8	1344,4	187,9	0,0	428,9	-52,9	0,0	31,9

Como a evapotranspiração real (ER) depende da existência de água no solo, e esta por sua vez é suprida pela chuva, a primeira acompanha a extrema variabilidade da última, com $CV = 30,6\%$.

Fig. 1. Precipitação Pluviométrica (P) e Evapotranspiração Potencial (EP) no período de 1975 a 1998 em Petrolina-PE.

A deficiência hídrica, diferença entre EP e ER ., também mostra extrema variabilidade temporal, com $CV = 23,2\%$ (Tabela 1). No período estudado, o maior espaço de tempo com deficiências acima de 900mm ocorreu 1978 e 1985 (Figura 2). No restante dos anos ocorreram no máximo dois anos seguidos acima desse valor. De acordo com a simetria da Figura 1, e a situação no final de 1998 para o início de 1999, existe uma tendência de haver vários anos seguidos com elevadas deficiências hídricas ($DEF > 900\text{mm}$) como ocorreu no final de 1978.

Em toda série de dados (24 anos), mais da metade dos anos não apresentou excesso hídrico algum ($EXC = 0$), o que é mostrado na Figura 3.

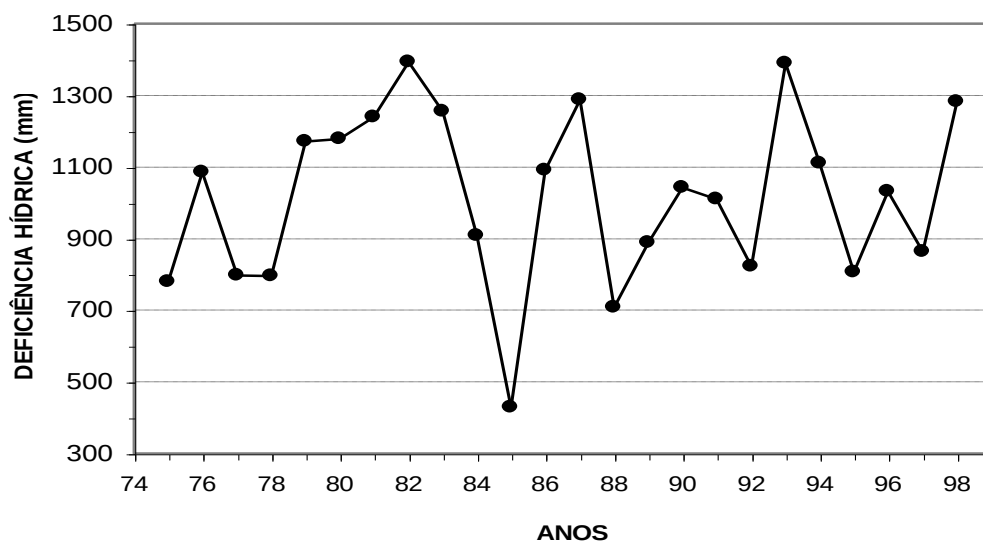


Fig. 2. Deficiência hídrica no solo no período de 1975-98 em Petrolina-PE.

O mesmo é válido para o índice de umidade (*IU*). Devido a esse fato esses dois elementos foram os que apresentaram maior *CV* (Tabela 1). É importante notar, que mesmo em anos em ocorrem elevadas deficiências hídricas, ocorrem meses com excedente hídrico (Figuras 2 e 3), o que torna mais importante o desenvolvimento de técnicas de captação de água da chuva.

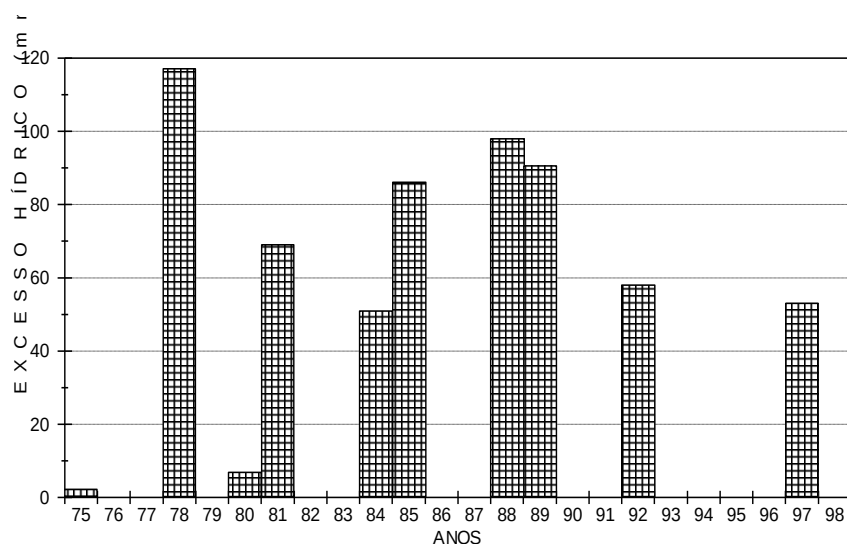


Fig. 3 Excesso hídrico no período de 1975-98 em petrolina-PE.

Comparando-se as figuras 2 e 3 percebe-se que dispendo só de valores de *DEF* ou de *EXC*, não se obtém uma idéia completa do grau anual de umidade do clima. Por exemplo, no ano

de 1978 houve maior *DEF* que em 1985 e 1988, porém apresentou maior *EXC*. A Figura 4, que apresenta a variação anual de *IH*, reflete todas as condições verificadas durante os anos, abrangendo períodos de umedecimento e ressecagem do solo.

Devem ser estudados a *DEF* e o *EXC* para intervalos menores que o mensal e, em virtude de existirem duas estações (uma seca e outra de chuvas irregulares) deve ser considerada apenas a quadra chuvosa. Ao incluir todo o ano todo no cômputo de tais índices, não se obtém uma visão mais detalhada das limitações hídricas do local, principalmente no que concerne a produção agrícola.

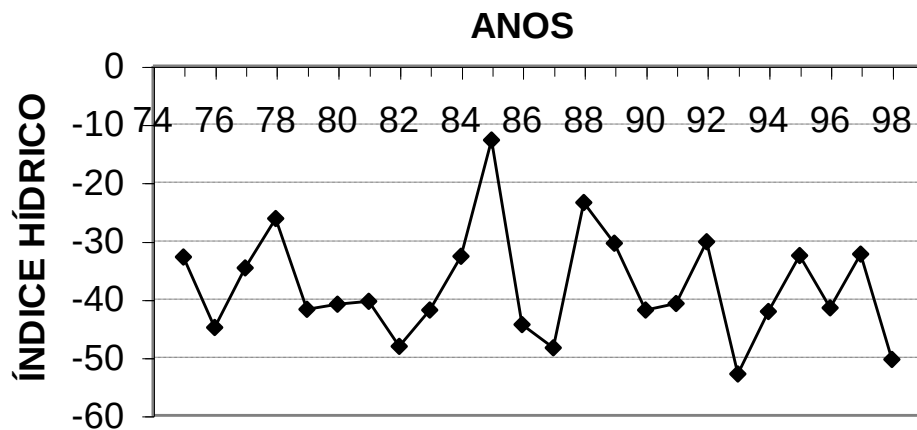


Fig. 4. Índice hídrico de Thornthwate do período de 1975-98 em Petrolina-PE

Pela Figura 4 e percebe-se que o *IH* tem uma variabilidade interanual semelhante a *DEF*, com $CV = 24,2\%$. O ano mais úmido coincide com o período mais chuvoso (1988). Porém há casos em que um ano é mais chuvoso do que outro porém apresenta um *IH* menor e vice-versa, dependendo do potencial térmico (Tabela 1).

CONCLUSÕES

- 1) As variações anuais da precipitação pluvial e evapotranspiração potencial em Petrolina-PE, ocorrem de maneira inversa, aumentando ainda mais o problema da irregularidade das chuvas e baixos índices pluviométricos na região.
- 2) Dos elementos do balanço hídrico climático, o Índice hídrico de Thornthwate (*IH*) é o que mais representa as condições hídricas em Petrolina-PE.
- 3) Há uma possível tendência de simetria nas curvas de precipitação (*P*) e evapotranspiração potencial (*EP*), havendo possibilidade de repetição de vários anos com altos valores de deficiência hídrica a partir de 1998 na região.

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Rainfall Harvesting for Indigenous Health in Australia

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Abstract

Australia is a dry country, particularly in the inland areas. The poor quantity and quality of water available to many Indigenous Australians living in rural and remote locations contributes to their poor health status relative to other Australians. Rainfall harvesting from the roofs of houses and buildings in Indigenous communities can provide a valuable source of potable water, but this harvesting is often inefficient. We report a study of two remote and diverse locations in areas where Indigenous Australians have water supply problems. The first is Giles in central Australia (25.04°S, 128.29°E) with a median annual rainfall of 119mm, and the second is Thursday Island in the Torres Strait (10.35°S, 142.22°E) with a median annual rainfall of 1718mm. We describe a means of correlating rainfall records with collecting roof areas, water storage capacity, house occupancy rates, and water consumption rates using a computer program. We determine the optimum match between these factors and the total collectable rainfall for the best, worst, and median years based on historical rainfall records for each location. This quantitative approach to rainfall harvesting could significantly improve the security of potable water supplies for many Indigenous communities in Australia, and thus contribute towards an improvement in Indigenous health.

Introduction

Australia is a dry country with limited water resources. Whilst there is considerable spatial and temporal variation in the hydrological characteristics of Australia, overall, rainfall and surface runoff is low and variable, evapotranspiration is high, and groundwater recharge is low (Smith 1998). Figure 1 shows the average annual rainfall and open-water evapotranspiration for Australia.

The Australian population (18.3 million in 1996) is concentrated in urban areas in the wetter parts of the country. Forty-seven per cent of the population lived in the wettest 10% (>881mm average annual rainfall) and 0.1% lived in the driest 10% (<186mm average annual rainfall) of the country in 1991 (ABS 1996). The Indigenous population¹ of Australia (comprising 2.1% of the total population in 1996) has a different demography compared to that of the total population, with a higher proportion (69.7%) living in smaller urban, rural and remote locations than the total population (37.3%) (ABS 1998a). More than 10% of the Indigenous population lived in the driest half of Australia (<303mm average annual rainfall) in 1991 compared with less than 2% of the total population (ABS 1996).

The health status of Indigenous Australians is poor, with a life expectancy at birth 18-19 years less than other Australians (AIHW 1998). Poor living conditions, including

¹ Indigenous refers to Aboriginal and Torres Strait Islander people.

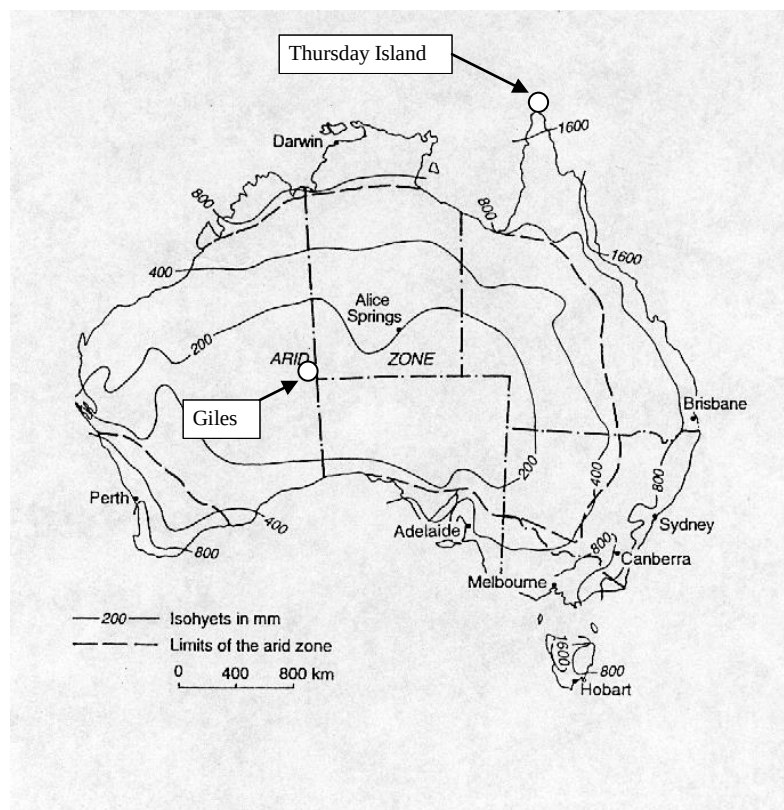
poor water supplies in rural and remote areas, contribute to this health inequality (FRDC 1994; ABS & AIHW 1997).

Mains/town water was the predominant water source for 93% of households across Australia in 1998, with only 17% of households using rainwater tanks, and 5% using bores or wells as one of their sources of water (ABS 1998b). Bore water is the main source of water for Indigenous Australians in rural and remote communities, with rainwater tanks ranking second in importance (Hearn et al 1993). The quality of this bore water is often poor and may also be detrimental to Indigenous health (NHMRC & ARMCANZ 1996; Hostetler et al 1998).

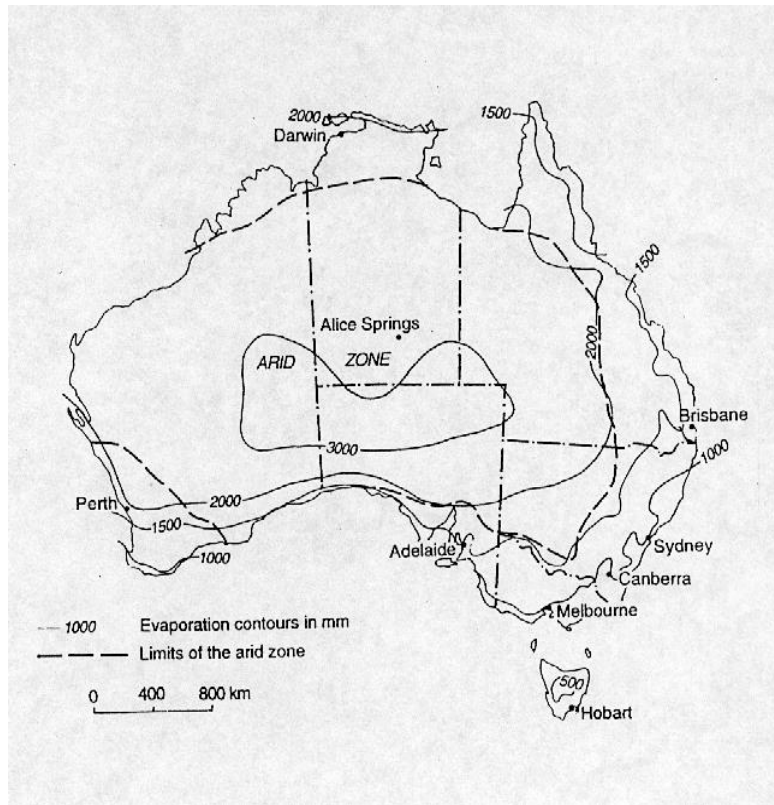
The objective of our study is to improve the efficiency of rainwater harvesting in Indigenous communities so that rainwater tanks can provide a more reliable source of potable water and thus help alleviate the overall problem of poor water supplies in many locations. Importantly, this has required close and ongoing consultation with communities in a number of locations.

Figure 1 Average annual rainfall and open-water evapotranspiration for Australia*

(a) Rainfall



(b) Evapotranspiration



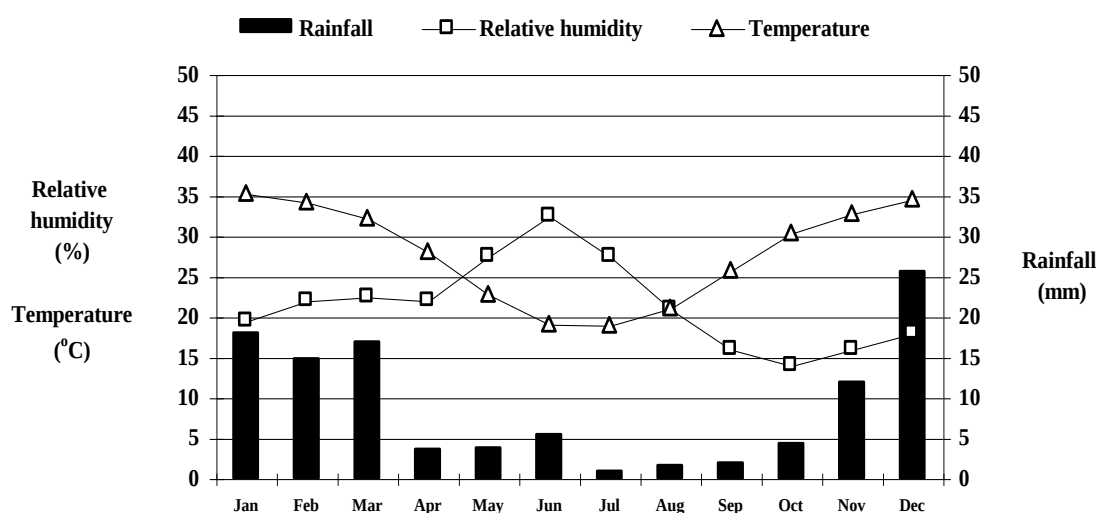
* Source: Smith (1998). Reproduced with permission of the author. The study locations Thursday Island and Giles are shown in Figure 1a.

Methods

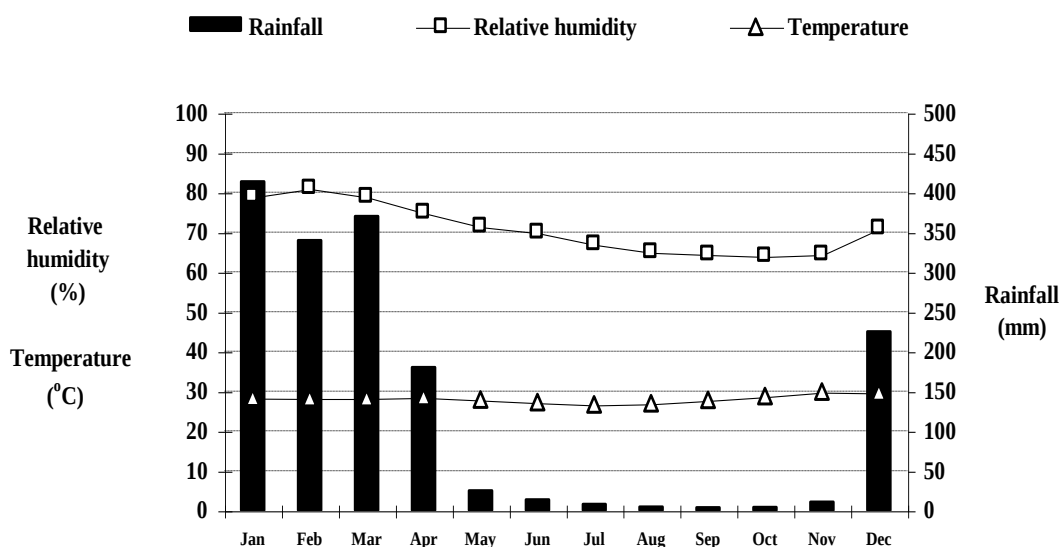
For this study we used two widely different geographical locations with extended historical rainfall records. Chosen rainfall regions (refer to Figure 1a) are occupied by Indigenous communities. Giles (25.04°S , 128.29°E , height above sea level 598 m, rainfall record 42 complete years, from 1.1.1957 to 31.12.98) is a small government meteorological station located in an arid area of central Australia with a median annual rainfall of 119 mm. Thursday Island (10.35°S , 142.22°E , height above sea level 8.0 & 57.6 m [two rainfall recording stations], rainfall record 84 complete years [1.1.1906 to 31.12.1957 and 1.1.1993 to 31.12.1995 for station 1 and 1.1.1958 to 31.12.1992 for station 2]) is a small town located in tropical northern Australia with a median annual rainfall of 1718 mm. Historical rainfall data was provided by the National Climate Centre, Bureau of Meteorology, Melbourne. Figure 2 shows some general features of the climate in both locations.

Figure 2 Median monthly rainfall, temperature, and relative humidity for Giles and Thursday Island*

(a) Giles



(b) Thursday Island



- Source of data: National Climate Centre, Bureau of Meteorology, Melbourne, 1999. Relative humidity and temperature were recorded at 3 pm.

The roof areas, tank sizes, and house occupancy rates used in this study are based on data from Indigenous communities in the two regions. All roof catchments are corrugated sheet metal. We received permission from Nganampa Health Council and the Torres Strait & Northern Peninsula Area District Health Council to use this information in our paper.

We employed a modified version of the CSIRO RAINCATCH program to model tank water balance (Wall & McCown 1989). Rainfall data was entered, checked for its integrity, and years with incomplete data were discarded. No adjustment was made for runoff coefficients less than one, described by Pacey & Cullis (1986), but this could be factored in as a later refinement were this to significantly affect prediction of supply reliability.

It is important to point out that there are many important health factors related to the use and maintenance of rainwater tanks. However, although these have been noted (Cunliffe 1998, SAHC 1995), these factors are not discussed: time and resource restraints prevented their incorporation into the scope of this study.

Results

The graphs show: the total collectable rainfall per year as a function of roof area (Figure 3); and two case scenarios of roof size, house occupancy rate, tank capacity and water consumption for each location using the Raincatch computer program (Figure 4(a) and (b)). These case scenarios were chosen in order to represent a situation typical of each region.

Figure 3 Computer analysis of total collectable rainfall per year (kilolitres) as a function of roof area in Giles and Thursday Island for the best, median, and worst rainfall years

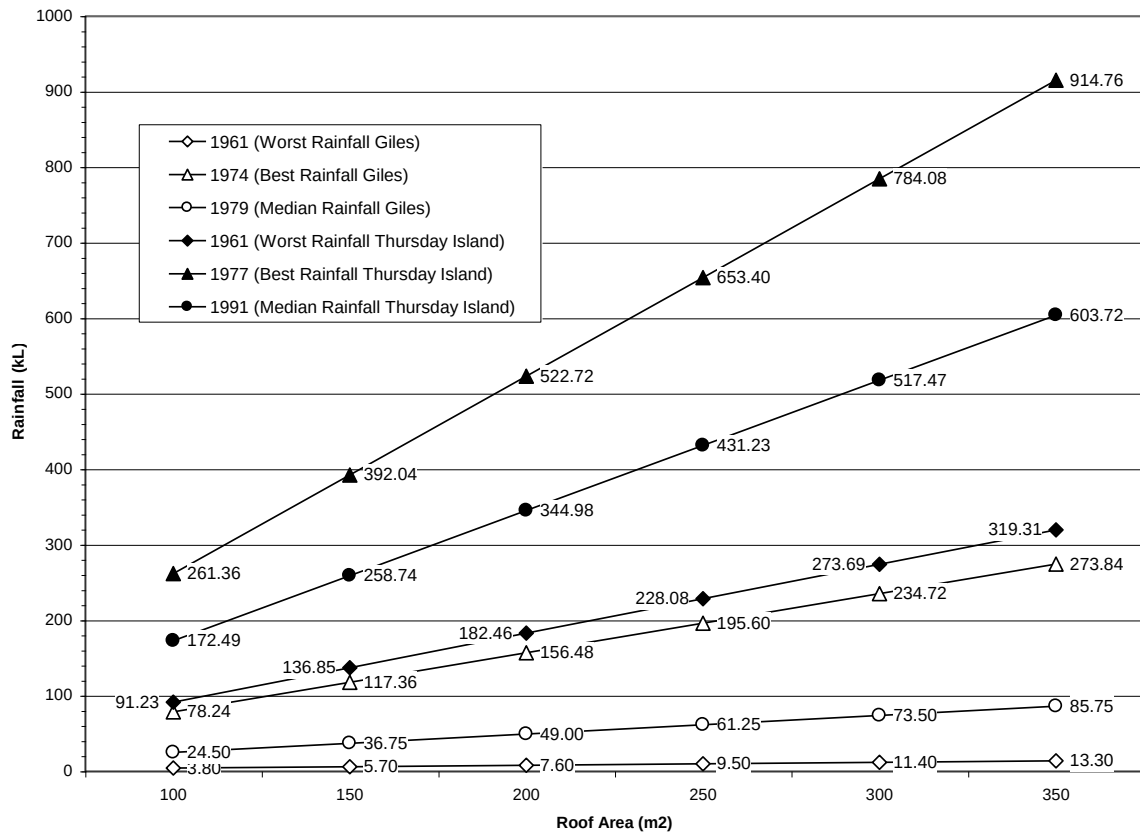
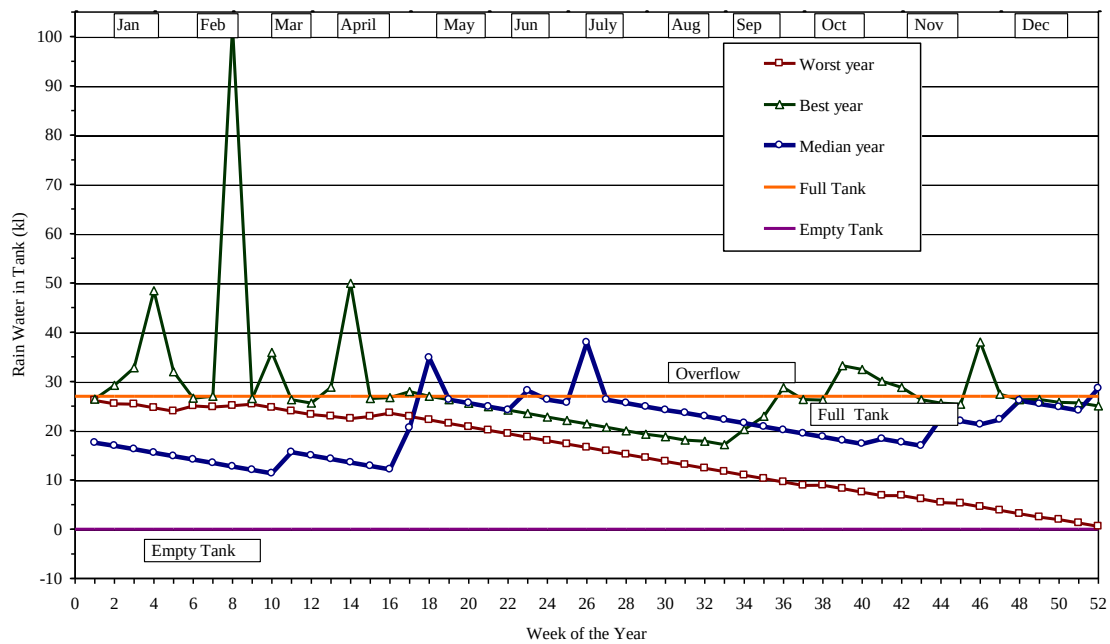
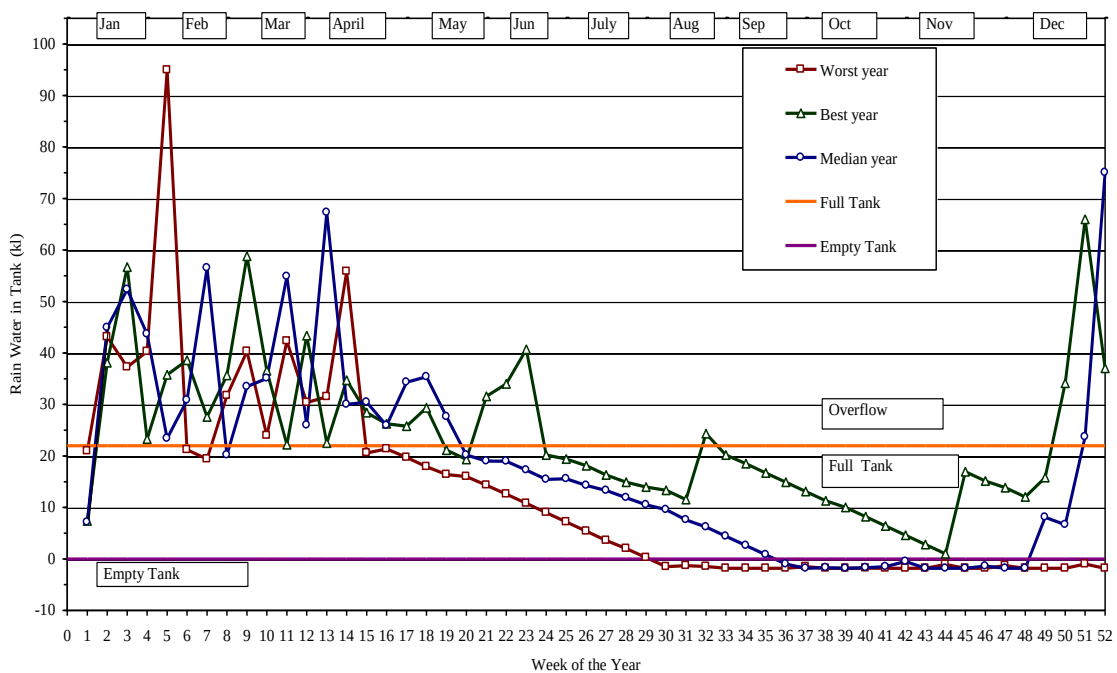


Figure 4 Computer analysis of rainfall harvesting for domestic water supply as a function of roof area, tank storage capacity, house occupancy, and consumption rate in Giles and Thursday Island

(a) Giles – 266 m² roof area, 27 kl tank storage capacity, and ten persons using 10 litres/person/day



(b) Thursday Island – 200 m² roof area, 22 kl tank storage capacity, and six persons using 50 litres/person/day



Discussion

The arid and central areas of Australia are often labelled as dry and with insignificant rainfall. In the past this has influenced decisions such as the chosen capacity for installed rainwater tanks, if their installation were even considered. However, Figure 3 shows that, even in arid locations such as Giles, roofed areas have the potential to collect significant amounts of rainwater. A 250 m² Giles house for instance can be used to collect 61.25 kl (61,250 l) in a median rainfall year. This can provide 10 people can be provided with 16.78

l of water per person every day. The case is even more significant for Thursday Island where in a median year the same size roof could potentially collect 431.23 kl (431,230 l) of rainwater, resulting in a supply of 118 l per person per day.

In Figure 4, the importance of correlating roof area to tank storage size and consumption rate is illustrated. Considering 4(a) [Giles], a house with a 266 m² roof could provide 10 people with 10 litres of rainwater per person per day even in the worst year on record, providing a tank with a capacity of 27 kl was utilised. However, even in a median rainfall year it can be seen that overflow results from a 27 kl storage tank, suggesting that for this house occupancy and consumption rate, a larger tank size would be more beneficial.

The situation for a tropical Thursday Island is shown in Figure 4(b). A consumption rate of 50 litres of rainwater per person per day was used to account for the comparatively larger rainfall. Only during the best years on record is this water consumption rate sustainable for a 200 m² roofed house linked to a 22 kl rainwater tank. It can be also seen from Figure 4(b) that, using this size tank, a large amount of overflow results between the months of January and April, and so it seems a much larger collection tank would better utilised in this area.

Conclusion

A significant amount of rainwater can be harvested even in the most arid regions of Australia. It can be used as a reliable source of potable water or as a valuable water supplement in many cases. Rainwater harvesting can be better optimised using computer analysis programs such as Raincatch. The importance of correctly matching historical rainfall, roof size, house occupancy with water consumption rates has been illustrated. In comparison, guess work may result in the loss of valuable potable water resources (tank overflow), an unreliable rainwater supply for part of the year (empty tank), or an over allocation of scant resources arising from oversizing of tank systems.

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Formas de Credito Alternativo para a Construção de Cisternas Familiares no semi-árido da Paraíba, Brasil

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Resumo

Em pleno Semi-Árido do estado da Paraíba, a organização não-governamental italiana Progetto Mondialità está realizando, desde 1996, um Programa de Credito Alternativo para a Construção de Cisternas Familiares, com financiamento da Cooperação Italiana. O objetivo geral do Programa é aumentar a capacidade de captação e armazenamento de água potável nas comunidades rurais.

A opção pela construção de cisternas se deu pelas muitas características positivas que elas apresentam. A principal delas é que as cisternas representam os reservatórios mais apropriados para o armazenamento de água potável.

Durante os dois anos e meio de atividade, o Programa idealizou e conseguiu implementar um Fundo Rotativo entre os comunitários atendidos, o qual já permitiu a construção de 157 cisternas familiares, e viabilizará a construção de mais 50 cisternas familiares por ano.

Basicamente, trata-se de uma aplicação inicial - a fundo perdido - de uma quantia de recursos financeiros que seja suficiente para dar início à primeira etapa de construção de cisternas. Os comunitários trabalham em mutirão na construção de suas próprias cisternas. Ao mesmo tempo, eles vêm resgatando os custos das cisternas através de módicas prestações mensais. À medida que os recursos financeiros aplicados inicialmente retornam ao fundo criado, outras novas comunidades passam a montar o seu próprio plano de construção.

Além do benefício principal, representado pelas cisternas, o projeto gera emprego para um assistente técnico a cada 25 cisternas construídas por ano, e torna-se um verdadeiro curso profissionalizante para os comunitários beneficiários.

Depois de quase três anos de atividades, o Fundo Rotativo já demonstrou ser plenamente auto-sustentável e, portanto, facilmente reproduzível nas condições similares dos outros municípios do Semi-Árido brasileiro.

1. Introdução

O município de Barra de Santa Rosa, na região do Curimataú do estado da Paraíba, tem uma superfície de 768 km² e uma população de cerca de 16.500 habitantes. Apresenta uma precipitação média anual de 369,7 mm (SILVA, F.B.R. et al., 1993), com estação chuvosa de março a junho e cerca de oito meses de estação seca. Os recursos hídricos superficiais e subterrâneos são escassos e as águas apresentam freqüentemente salinidade elevada, reduzindo ainda mais a disponibilidade hídrica para o consumo humano.

Na área rural domina a dicotomia entre latifúndios e minifúndios. As pequenas propriedades não conseguem produzir uma renda suficiente para a sobrevivência das famílias

de agricultores e conseqüentemente torna-se necessária a saída de alguns membros, geralmente os jovens de sexo masculino, a procura de fontes de renda alternativas.

No que diz respeito ao abastecimento hídrico, a população rural depende tradicionalmente dos reservatórios a céu aberto, naturais ou artificiais, espalhados pelo território. Estes reservatórios recolhem água durante a estação chuvosa e a armazenam por períodos variáveis, mas que raramente chegam a cobrir a estação seca por inteiro. Desta forma, na medida em que eles secam, as famílias tem que procurar quotidianamente a água cada vez mais longe de casa.

Durante as cíclicas secas prolongadas que afetam o Nordeste, a totalidade dos pequenos e médios reservatórios a céu aberto fica sem água e as comunidades rurais que deles dependem devem ser abastecidas pelas autoridades públicas, através de carros-tanques que distribuem a água proveniente das fontes ainda disponíveis. Na ausência de reservatórios apropriados, a água dos carros-tanques é deixada a céu aberto onde é rapidamente consumida pela evaporação e infiltração, com enorme desperdício de um recurso tão escasso. Esta situação continua se repetindo ano após ano.

A falta de vontade política parece ser o obstáculo maior para a solução do problema do abastecimento hídrico no Semi-Árido nordestino. No município de Barra de Santa Rosa, em pleno Semi-Árido do estado da Paraíba, a organização não-governmental italiana *Progetto Mondialità*, está implementando desde 1995 um Projeto Hídrico, Sanitário e Social, com financiamento da Cooperação Italiana.

Progetto Mondialità é uma ONG de cooperação ligada à Igreja Católica e veio ao Brasil a pedido da Diocese de Campina Grande. Nos anos oitenta, técnicos da ONG conjuntamente com colegas brasileiros elaboraram o Projeto Hídrico, Sanitário e Social, cujo objetivo principal era o de melhorar as condições de abastecimento hídrico, assistência sanitária e social da população carente do município de Barra de Santa Rosa. Este projeto foi apresentado para aprovação e financiamento ao Ministério das Relações Exteriores da Itália e foi aprovado em novembro de 1994, depois de quase dez anos da realização do estudo prévio.

2. Objetivos

O objetivo principal do Setor Hídrico do Projeto é aumentar a capacidade de captação e armazenamento de água de chuva nas comunidades rurais, onde as condições de abastecimento hídrico são extremamente precárias.

Inicialmente a solução prevista pelo Projeto para alcançar estes objetivos era a construção de quatro pequenas barragens para o abastecimento de comunidades rurais isoladas e carentes.

Devido ao atraso na aprovação, quando se iniciaram as atividades do Projeto, em 1995, tornou-se necessária uma nova avaliação, que levasse em consideração as grandes mudanças acontecidas ao longo da década e individuasse as ações mais apropriadas para a nova realidade.

3. Metodologia

Para identificar as prioridades de ação e as soluções mais eficazes para alcançar o objetivo principal do Setor Hídrico, foi realizada uma avaliação articulada em três etapas principais:

- 1 Análise da situação do abastecimento hídrico no município;
- 2 Escolha das soluções mais apropriadas e viáveis (sistema de captação, tecnologia e custo de implantação do sistema);
- 3 Escolha do modelo de gestão econômico-financeira para a realização do Projeto.

Através de reuniões nas comunidades rurais e urbanas foram identificadas as principais necessidades da população em relação ao abastecimento hídrico, foram propostas soluções possíveis, avaliando as características de cada uma delas.

Foram realizados levantamentos de campo para uma avaliação direta da realidade da região.

Foi avaliada a atuação da administração pública local e do setor privado no que se refere à questão do abastecimento hídrico e foram analisadas as ações de entidades governamentais e não governamentais atuantes na região.

4. Sistema de captação

A avaliação realizada mostrou que a construção de pequenas barragens não representa uma solução viável ao problema do abastecimento hídrico das comunidades rurais do Curimataú. Muitas barragens de pequeno e médio porte foram construídas na região e a maioria delas sofreu um rápido processo de salinização. Além disso, as águas armazenadas a céu aberto, facilmente acessíveis aos animais domésticos e selvagens, apresentam níveis de poluição microbiológica que as tornam impróprias para o consumo humano. Mesmo assim a maioria da população continua consumindo-as sem nenhum tipo de tratamento.

Entre os sistemas de captação utilizados na região, selecionou-se a construção de cisternas familiares como a forma mais eficiente de se aumentar a disponibilidade de água potável nas comunidades rurais.

Isto pelas muitas características positivas que as cisternas apresentam. Elas representam reservatórios mais apropriados para o armazenamento de água potável. Elas recolhem as chuvas que caem nos telhados das casas, aproveitando as águas que iriam se perder, aumentam a capacidade global de armazenamento d'água e tornam as famílias auto-suficientes no que diz respeito ao problema do abastecimento hídrico. Além disso, nas emergências hídricas causadas pelas secas prolongadas, as cisternas podem receber a água de açudes, poços ou dessalinizadores, sendo transportada por carros-tanques, o que minimiza as perdas. Elas melhoram a qualidade de vida das famílias, ao eliminarem o trabalho cotidiano de buscar e transportar por vários quilômetros a água, geralmente realizado por mulheres e crianças; melhora a qualidade da água consumida, reduzindo os riscos de doenças que têm causado altos índices de mortalidade infantil por todo o Semi-Árido; ao mesmo tempo, torna possível, através da instalação de uma bomba e de uma caixa d'água, canalizar a água para a cozinha e o banheiro das casas. Isso tudo representa uma melhoria das condições de vida nessas comunidades rurais que, agindo em conjunto com outras fontes (eletrificação rural, acesso à educação básica e à saúde, aos meios de transporte, etc.) pode provocar uma redução do êxodo rural.

5. Tipologia e técnica de construção

Em Barra de Santa Rosa existe uma tradição antiga de construir cisternas para armazenar água. A tipologia tradicional difundida na região é a de planta quadrada ou retangular, com paredes de tijolos maciços rebocadas internamente com argamassa de cimento. Esta tipologia passou ao longo do tempo por melhorias, como a introdução de reforços estruturais constituídos por colunas e vigas de concreto armado ou a construção de coberturas de laje premoldada. Desta forma diminuíram os perigos de aparecimento de rachaduras e vazamentos, principalmente nos cantos entre as paredes que representam os pontos mais fracos das cisternas de planta quadrangular. A técnica de construção desta tipologia de cisterna é complexa e lenta. Requer mão de obra qualificada e muitos materiais para que a segurança da estrutura seja garantida. Por isso o custo de construção é elevado.

Outra tipologia de cisterna que foi introduzida no Semi-Árido nordestino alguns anos atrás por projetos de entidades públicas, é a que utiliza lona plástica tanto para impermeabilizar o reservatório cavado no chão, quanto para constituir a cobertura, que tem também a função de área de captação. A lona é material rapidamente perecível quando exposto ao sol e portanto não se adapta às condições do Semi-Árido. Além disso, a lona utilizada por esse fim não se encontra facilmente no comércio das pequenas cidades e, quando se encontra, tem preço muito alto. A manutenção torna-se portanto cara e muitas vezes fora do alcance da população rural. Por isso este tipo de cisterna não conseguiu superar a avaliação do tempo e a maioria das que foram construídas no Curimataú está hoje abandonada.

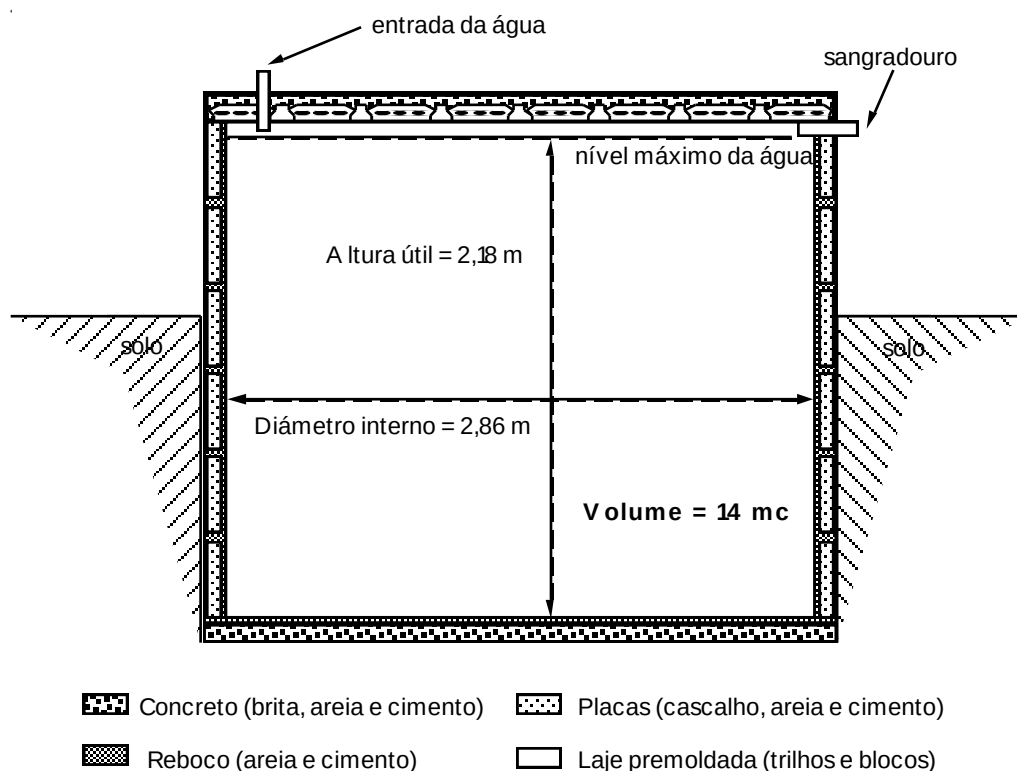


Fig. 1 - Seção vertical da cisterna de placas: esquema da estrutura e medidas principais.

No Nordeste brasileiro foi desenvolvida uma tipologia de cisterna que apresenta inúmeras vantagens em relação às demais: a bem conhecida cisterna de placas de planta circular. O próprio formato redondo faz com que esta tipologia apresente uma maior resistência e durabilidade, pelo fato do peso da água estar distribuído uniformemente na superfície da única parede. Consequentemente a estrutura pode ser menos reforçada, minimizando o uso de materiais. Além disso, a técnica de construção é mais simples e rápida.

Esta tipologia foi introduzida no Semi-Árido da Paraíba pela ONG de Campina Grande PATAAC, que divulgou a técnica de construção em muitas comunidades da região.

Progetto Mondialità resolveu adotar esta tipologia de cisterna e introduziu algumas mudanças técnicas para tornar ainda mais simples e mais rápido o trabalho de construção. Entre elas a cobertura original de placas e vigas de concreto armado fabricadas no local utilizando formas especiais, que representava a parte mais complexa e demorada da construção, foi substituída por uma cobertura de laje premoldada, disponível no mercado de Barra de Santa Rosa e da maioria das cidades do Curimataú.

A Fig. 1 da página 3 representa a seção vertical da cisterna de placas construída pelo *Progetto Mondialità*, indicando as partes que compõem a estrutura e as dimensões principais.

6. Crédito alternativo

O custo de uma cisterna tradicional de planta quadrangular com capacidade para 8 m³ para o setor privado (500,00 R\$ em dezembro de 1998), compreensivo de materiais de construção, escavação do buraco, mão de obra e lucros, é o mesmo de uma cisterna cilíndrica de placas com capacidade para 16 m³. Por isso, com a divulgação de suas características positivas em Barra de Santa Rosa pelo *Progetto Mondialità*, a nova tipologia de cisterna foi adotada pela maioria das pequenas empresas.

Da iniciativa privada surgiu a primeira tentativa de facilitar o acesso da população urbana de renda média ao benefício que a cisterna representa. Um pequeno empresário da construção civil idealizou um esquema de "Consórcio de cisternas" que encontrou boa aceitação na cidade e viabilizou a construção de mais de 100 cisternas em três anos de atividade. Segundo este sistema, as famílias beneficiárias, reunidas em grupo, pagam a cada mês em conjunto o valor de uma cisterna. Através dum sorteio todo mês é escolhida a casa onde será construída a cisterna e assim por diante até que todas as cisternas do grupo sejam construídas e pagas.

Numa economia estável este tipo de consórcio elimina a necessidade de juros e atualização do valor das prestações. O pequeno empresário pode começar a nova atividade sem necessidade de capitais iniciais e ao mesmo tempo a população pode adquirir uma cisterna com maior facilidade. O valor da prestação deste tipo de consórcio (50,00 R\$ por mês em dezembro de 1998) está porém ao alcance duma fração de população que ainda representa uma minoria na região de Barra de Santa Rosa.

Para atingir os objetivos do Setor hídrico, Progetto Mondialità idealizou e implementou um Programa de Crédito Alternativo para a Construção de Cisternas Familiares através de um Fundo Rotativo ao qual pudesse ter acesso a maioria da população da região. Portanto a necessidade prioritária foi diminuir o valor da prestação mensal.

Para isso, o custo de construção da cisterna foi reduzido (360,00 R\$ em dezembro de 1998) da seguinte forma: introduzindo, desde a escavação até o acabamento final, o trabalho em mutirão dos próprios beneficiários sob a assistência técnica de um pedreiro especialmente treinado; aproveitando alguns materiais disponíveis nas comunidades, como brita e areia; eliminando os lucros. No cálculo do custo foram incluídos os materiais (cimento, cascalho, ferro, laje premoldada, zinco e canos), a cota anual de reposição das ferramentas, a assistência técnica e o transporte.

Além disso foi prolongado para 02 anos o período de devolução, aumentando para 24 o número das mensalidades. O valor da prestação mensal ficou assim ao alcance da maioria da população (15,00 R\$ em dezembro de 1998).

O montante de recursos financeiros a disposição do Setor hídrico (18.000,00 R\$) era suficiente para a construção de 50 cisternas. No primeiro ano de atividade foram portanto beneficiadas pelo Fundo Rotativo 50 famílias. Todas elas iniciaram a pagar a prestação mensal a partir do primeiro mês de trabalho. No prazo de seis meses todas as cisternas foram construídas. Depois de mais seis meses (doze desde o começo das atividades) já estava acumulada no Fundo Rotativo uma importância igual aos 50% do valor do investimento inicial e as famílias já tinham pago metade da dívida. Foi começado um novo ciclo e cinquenta novas famílias foram beneficiadas e começaram a pagar as prestações. Com 100 famílias pagando, os 50% que faltavam para financiar as novas cisternas foram recolhidos durante os seis meses de construção e dentro de mais seis meses o Fundo Rotativo tinha novamente o capital para recomençar o ciclo. Dessa forma todo ano o Fundo Rotativo dispõe de recursos suficientes para a construção de 50 novas cisternas.

A Fig.2 ilustra o Fluxograma financeiro, analisando o andamento das entradas, das saídas e do saldo do Fundo Rotativo durante os primeiros 36 meses de atividades.

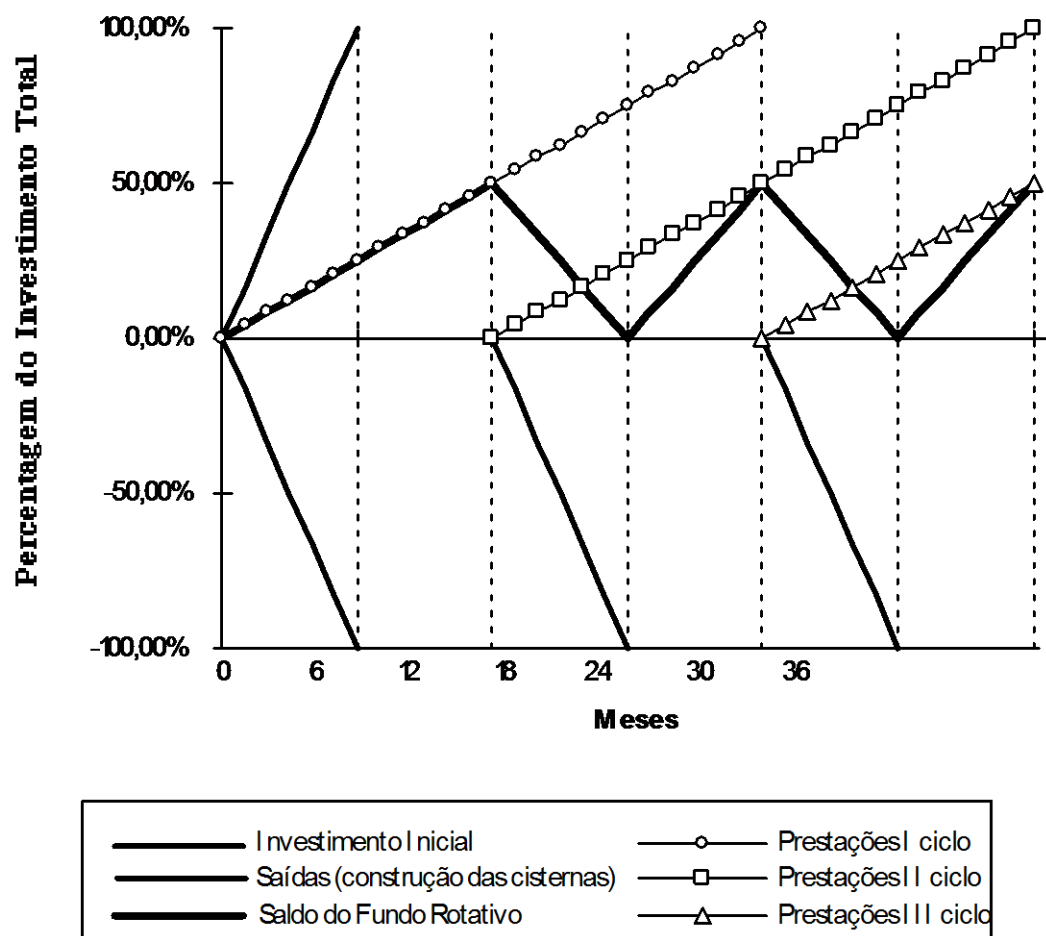


Fig. 2 - Fluxograma financeiro do Fundo Rotativo durante os primeiros 36 meses de atividades.

7. Resultados alcançados

Durante três anos de atividade do Programa de Crédito Alternativo para a Construção de Cisternas Familiares já foram construídas mais de 150 cisternas de placas, e o Fundo Rotativo constituído viabilizará a construção de mais 50 cisternas familiares por ano, por um número indefinido de anos (possivelmente até que todas as famílias da região possuam uma cisterna), pelas comunidades rurais de Barra de Santa Rosa. Isso beneficiou e beneficiará diretamente um igual número de famílias e, com um investimento inicial bastante baixo, já vem garantindo capacidade para armazenar todo ano mais de 2 milhões de litros de água potável.

Para o sucesso do Programa mostrou-se mais importante do que tudo a capacidade de mobilizar os comunitários para a iniciativa, ganhar a confiança deles para o empreendimento e merecer o respeito dos mesmos na hora de resgatarem os débitos assumidos.

Além do benefício principal, representado pelas cisternas, o Fundo Rotativo gerou e continua gerando três empregos para a equipe que realiza o Programa (02 Assistentes técnicos e 01 Coordenador), e torna-se um verdadeiro curso profissionalizante para os beneficiários, os quais aprendem as técnicas de construção das cisternas ganhando a chance de um novo espaço no mercado de trabalho.

Depois de três anos de atividades em Barra de Santa Rosa, o Fundo Rotativo para a Construção de Cisternas Familiares já demonstrou ser plenamente auto-sustentável e, portanto,

facilmente reproduzível nas condições similares dos outros municípios do Semi-Árido brasileiro.

Os resultados conseguidos foram de grande monta e atraíram a atenção de várias entidades, governamentais e não governamentais. Em 1997, o Programa de Estudos e Ações para o Semi-Árido, da Universidade Federal da Paraíba (PEASA/UFPB), propôs-se para uma parceria que tinha como objetivo a divulgação da metodologia do Fundo Rotativo para a construção de cisternas familiares em outras regiões do Semi-Árido paraibano, através da realização de Cursos de construção de cisternas (com financiamento do SINE-PB) nas comunidades rurais. Infelizmente a parceria não teve os resultados esperados e até hoje o PEASA/UFPB não conseguiu implantar novos Fundos Rotativos. Todavia, sob a orientação do *Progetto Mondialità*, tanto o Programa de Pequena Tecnologia Apropriada (PPTA) do Governo do Estado da Paraíba quanto a Universidade Federal da Paraíba passaram a divulgar em todo o Estado a técnica construtiva da cisterna de placas.

Só foi possível implementar um novo Fundo Rotativo, para a construção de 30 cisternas por ano, em 1998 nas comunidades rurais do município de Araruna, graças a uma parceria com a Diocese de Guarabira e ao financiamento do Serviço Alemão de Cooperação Técnica e Social (SACTES-DED).

8. Considerações finais

Os resultados positivos do Programa mostram que é possível melhorar as condições de abastecimento hídrico das comunidades rurais do Semi-Árido nordestino com módicos investimentos, utilizando tecnologias simples e autóctones e formas de crédito alternativas, como os Fundos Rotativos ou os Consórcios, bem aceitas pela população.

Programas do tipo aqui ilustrado podem muito facilmente ser realizados, com mínimos ajustes, por Associações, Sindicatos, Prefeituras e outras entidades similares, utilizando ou recursos próprios ou financiamentos recebidos a fundo perdido ou empréstimos bancários com taxas de juros reduzidas. Na conclusão do Programa, depois de atingidos os objetivos desejados, no Fundo Rotativo estará novamente acumulada uma importância equivalente ao valor do capital inicialmente investido, atualizado segundo a inflação acumulada durante o período de realização. Esta atualização não descende da cobrança de juros, mas do ajuste anual das prestações dos novos beneficiários que entram no Programa ao novo custo de construção da cisterna. A entidade promotora poderá portanto utilizar esta importância para devolver a dívida ou para outros fins, no caso de recursos próprios ou recebidos a fundo perdido.

Este sistema funciona bem em época de estabilidade econômico-financeira. No caso de retorno da instabilidade e da inflação alta, o valor da prestação mensal pode variar em função do preço de uma quantidade fixada de um material (por exemplo: o valor da prestação igual ao preço de 2,5 sacos de cimento). Assim se consegue, de forma simples e facilmente compreensível e sem utilizar complicadíssimas fórmulas para o cálculo dos juros, manter o valor do investimento atualizado.

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Formas de Crédito Alternativo para a Construção de Cisternas Familiares no semi-árido da Paraíba, Brasil

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Resumo

Em pleno Semi-Árido do estado da Paraíba, a organização não-governamental italiana Progetto Mondialità está realizando, desde 1996, um Programa de Crédito Alternativo para a Construção de Cisternas Familiares, com financiamento da Cooperação Italiana. O objetivo geral do Programa é aumentar a capacidade de captação e armazenamento de água potável nas comunidades rurais.

A opção pela construção de cisternas se deu pelas muitas características positivas que elas apresentam. A principal delas é que as cisternas representam os reservatórios mais apropriados para o armazenamento de água potável.

Durante os dois anos e meio de atividade, o Programa idealizou e conseguiu implementar um Fundo Rotativo entre os comunitários atendidos, o qual já permitiu a construção de 157 cisternas familiares, e viabilizará a construção de mais 50 cisternas familiares por ano.

Basicamente, trata-se de uma aplicação inicial - a fundo perdido - de uma quantia de recursos financeiros que seja suficiente para dar início à primeira etapa de construção de cisternas. Os comunitários trabalham em mutirão na construção de suas próprias cisternas. Ao mesmo tempo, eles vêm resgatando os custos das cisternas através de módicas prestações mensais. À medida que os recursos financeiros aplicados inicialmente retornam ao fundo criado, outras novas comunidades passam a montar o seu próprio plano de construção.

Além do benefício principal, representado pelas cisternas, o projeto gera emprego para um assistente técnico a cada 25 cisternas construídas por ano, e torna-se um verdadeiro curso profissionalizante para os comunitários beneficiários.

Depois de quase três anos de atividades, o Fundo Rotativo já demonstrou ser plenamente auto-sustentável e, portanto, facilmente reproduzível nas condições similares dos outros municípios do Semi-Árido brasileiro.

1. Introdução

O município de Barra de Santa Rosa, na região do Curimataú do estado da Paraíba, tem uma superfície de 768 km² e uma população de cerca de 16.500 habitantes. Apresenta uma precipitação média anual de 369,7 mm (SILVA, F.B.R. et al., 1993), com estação chuvosa de março a junho e cerca de oito meses de estação seca. Os recursos hídricos superficiais e subterrâneos são escassos e as águas apresentam freqüentemente salinidade elevada, reduzindo ainda mais a disponibilidade hídrica para o consumo humano.

Na área rural domina a dicotomia entre latifúndios e minifúndios. As pequenas propriedades não conseguem produzir uma renda suficiente para a sobrevivência das famílias

de agricultores e conseqüentemente torna-se necessária a saída de alguns membros, geralmente os jovens de sexo masculino, a procura de fontes de renda alternativas.

No que diz respeito ao abastecimento hídrico, a população rural depende tradicionalmente dos reservatórios a céu aberto, naturais ou artificiais, espalhados pelo território. Estes reservatórios recolhem água durante a estação chuvosa e a armazenam por períodos variáveis, mas que raramente chegam a cobrir a estação seca por inteiro. Desta forma, na medida em que eles secam, as famílias tem que procurar quotidianamente a água cada vez mais longe de casa.

Durante as cíclicas secas prolongadas que afetam o Nordeste, a totalidade dos pequenos e médios reservatórios a céu aberto fica sem água e as comunidades rurais que deles dependem devem ser abastecidas pelas autoridades públicas, através de carros-tanques que distribuem a água proveniente das fontes ainda disponíveis. Na ausência de reservatórios apropriados, a água dos carros-tanques é deixada a céu aberto onde é rapidamente consumida pela evaporação e infiltração, com enorme desperdício de um recurso tão escasso. Esta situação continua se repetindo ano após ano.

A falta de vontade política parece ser o obstáculo maior para a solução do problema do abastecimento hídrico no Semi-Árido nordestino. No município de Barra de Santa Rosa, em pleno Semi-Árido do estado da Paraíba, a organização não-governmental italiana *Progetto Mondialità*, está implementando desde 1995 um Projeto Hídrico, Sanitário e Social, com financiamento da Cooperação Italiana.

Progetto Mondialità é uma ONG de cooperação ligada à Igreja Católica e veio ao Brasil a pedido da Diocese de Campina Grande. Nos anos oitenta, técnicos da ONG conjuntamente com colegas brasileiros elaboraram o Projeto Hídrico, Sanitário e Social, cujo objetivo principal era o de melhorar as condições de abastecimento hídrico, assistência sanitária e social da população carente do município de Barra de Santa Rosa. Este projeto foi apresentado para aprovação e financiamento ao Ministério das Relações Exteriores da Itália e foi aprovado em novembro de 1994, depois de quase dez anos da realização do estudo prévio.

2. Objetivos

O objetivo principal do Setor Hídrico do Projeto é aumentar a capacidade de captação e armazenamento de água de chuva nas comunidades rurais, onde as condições de abastecimento hídrico são extremamente precárias.

Inicialmente a solução prevista pelo Projeto para alcançar estes objetivos era a construção de quatro pequenas barragens para o abastecimento de comunidades rurais isoladas e carentes.

Devido ao atraso na aprovação, quando se iniciaram as atividades do Projeto, em 1995, tornou-se necessária uma nova avaliação, que levasse em consideração as grandes mudanças acontecidas ao longo da década e individuasse as ações mais apropriadas para a nova realidade.

3. Metodologia

Para identificar as prioridades de ação e as soluções mais eficazes para alcançar o objetivo principal do Setor Hídrico, foi realizada uma avaliação articulada em três etapas principais:

- 1 Análise da situação do abastecimento hídrico no município;
- 2 Escolha das soluções mais apropriadas e viáveis (sistema de captação, tecnologia e custo de implantação do sistema);
- 3 Escolha do modelo de gestão econômico-financeira para a realização do Projeto.

Através de reuniões nas comunidades rurais e urbanas foram identificadas as principais necessidades da população em relação ao abastecimento hídrico, foram propostas soluções possíveis, avaliando as características de cada uma delas.

Foram realizados levantamentos de campo para uma avaliação direta da realidade da região.

Foi avaliada a atuação da administração pública local e do setor privado no que se refere à questão do abastecimento hídrico e foram analisadas as ações de entidades governamentais e não governamentais atuantes na região.

4. Sistema de captação

A avaliação realizada mostrou que a construção de pequenas barragens não representa uma solução viável ao problema do abastecimento hídrico das comunidades rurais do Curimataú. Muitas barragens de pequeno e médio porte foram construídas na região e a maioria delas sofreu um rápido processo de salinização. Além disso, as águas armazenadas a céu aberto, facilmente acessíveis aos animais domésticos e selvagens, apresentam níveis de poluição microbiológica que as tornam impróprias para o consumo humano. Mesmo assim a maioria da população continua consumindo-as sem nenhum tipo de tratamento.

Entre os sistemas de captação utilizados na região, selecionou-se a construção de cisternas familiares como a forma mais eficiente de se aumentar a disponibilidade de água potável nas comunidades rurais.

Isto pelas muitas características positivas que as cisternas apresentam. Elas representam reservatórios mais apropriados para o armazenamento de água potável. Elas recolhem as chuvas que caem nos telhados das casas, aproveitando as águas que iriam se perder, aumentam a capacidade global de armazenamento d'água e tornam as famílias auto-suficientes no que diz respeito ao problema do abastecimento hídrico. Além disso, nas emergências hídricas causadas pelas secas prolongadas, as cisternas podem receber a água de açudes, poços ou dessalinizadores, sendo transportada por carros-tanques, o que minimiza as perdas. Elas melhoram a qualidade de vida das famílias, ao eliminarem o trabalho cotidiano de buscar e transportar por vários quilômetros a água, geralmente realizado por mulheres e crianças; melhora a qualidade da água consumida, reduzindo os riscos de doenças que têm causado altos índices de mortalidade infantil por todo o Semi-Árido; ao mesmo tempo, torna possível, através da instalação de uma bomba e de uma caixa d'água, canalizar a água para a cozinha e o banheiro das casas. Isso tudo representa uma melhoria das condições de vida nessas comunidades rurais que, agindo em conjunto com outras fontes (eletrificação rural, acesso à educação básica e à saúde, aos meios de transporte, etc.) pode provocar uma redução do êxodo rural.

5. Tipologia e técnica de construção

Em Barra de Santa Rosa existe uma tradição antiga de construir cisternas para armazenar água. A tipologia tradicional difundida na região é a de planta quadrada ou retangular, com paredes de tijolos maciços rebocadas internamente com argamassa de cimento. Esta tipologia passou ao longo do tempo por melhorias, como a introdução de reforços estruturais constituídos por colunas e vigas de concreto armado ou a construção de coberturas de laje premoldada. Desta forma diminuíram os perigos de aparecimento de rachaduras e vazamentos, principalmente nos cantos entre as paredes que representam os pontos mais fracos das cisternas de planta quadrangular. A técnica de construção desta tipologia de cisterna é complexa e lenta. Requer mão de obra qualificada e muitos materiais para que a segurança da estrutura seja garantida. Por isso o custo de construção é elevado.

Outra tipologia de cisterna que foi introduzida no Semi-Árido nordestino alguns anos atrás por projetos de entidades públicas, é a que utiliza lona plástica tanto para impermeabilizar o reservatório cavado no chão, quanto para constituir a cobertura, que tem também a função de área de captação. A lona é material rapidamente perecível quando exposto ao sol e portanto não se adapta às condições do Semi-Árido. Além disso, a lona utilizada por esse fim não se encontra facilmente no comércio das pequenas cidades e, quando se encontra, tem preço muito alto. A manutenção torna-se portanto cara e muitas vezes fora do alcance da população rural. Por isso este tipo de cisterna não conseguiu superar a avaliação do tempo e a maioria das que foram construídas no Curimataú está hoje abandonada.

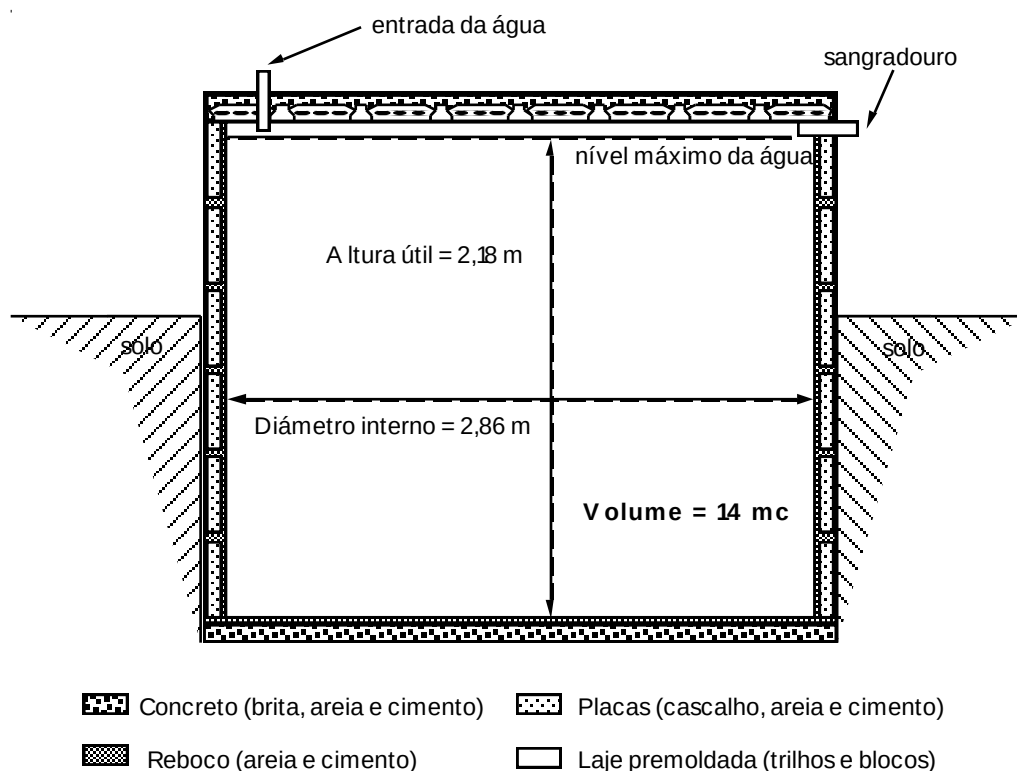


Fig. 1 - Seção vertical da cisterna de placas: esquema da estrutura e medidas principais.

No Nordeste brasileiro foi desenvolvida uma tipologia de cisterna que apresenta inúmeras vantagens em relação às demais: a bem conhecida cisterna de placas de planta circular. O próprio formato redondo faz com que esta tipologia apresente uma maior resistência e durabilidade, pelo fato do peso da água estar distribuído uniformemente na superfície da única parede. Consequentemente a estrutura pode ser menos reforçada, minimizando o uso de materiais. Além disso, a técnica de construção é mais simples e rápida.

Esta tipologia foi introduzida no Semi-Árido da Paraíba pela ONG de Campina Grande PATAAC, que divulgou a técnica de construção em muitas comunidades da região.

Progetto Mondialità resolveu adotar esta tipologia de cisterna e introduziu algumas mudanças técnicas para tornar ainda mais simples e mais rápido o trabalho de construção. Entre elas a cobertura original de placas e vigas de concreto armado fabricadas no local utilizando formas especiais, que representava a parte mais complexa e demorada da construção, foi substituída por uma cobertura de laje premoldada, disponível no mercado de Barra de Santa Rosa e da maioria das cidades do Curimataú.

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Da iniciativa privada surgiu a primeira tentativa de facilitar o acesso da população urbana de renda média ao benefício que a cisterna representa. Um pequeno empresário da construção civil idealizou um esquema de "Consórcio de cisternas" que encontrou boa aceitação na cidade e viabilizou a construção de mais de 100 cisternas em três anos de atividade. Segundo este sistema, as famílias beneficiárias, reunidas em grupo, pagam a cada mês em conjunto o valor de uma cisterna. Através dum sorteio todo mês é escolhida a casa onde será construída a cisterna e assim por diante até que todas as cisternas do grupo sejam construídas e pagas.

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Para atingir os objetivos do Setor hídrico, Progetto Mondialità idealizou e implementou um Programa de Crédito Alternativo para a Construção de Cisternas Familiares através de um Fundo Rotativo ao qual pudesse ter acesso a maioria da população da região. Portanto a necessidade prioritária foi diminuir o valor da prestação mensal.

Para isso, o custo de construção da cisterna foi reduzido (360,00 R\$ em dezembro de 1998) da seguinte forma: introduzindo, desde a escavação até o acabamento final, o trabalho em mutirão dos próprios beneficiários sob a assistência técnica de um pedreiro especialmente treinado; aproveitando alguns materiais disponíveis nas comunidades, como brita e areia; eliminando os lucros. No cálculo do custo foram incluídos os materiais (cimento, cascalho, ferro, laje premoldada, zinco e canos), a cota anual de reposição das ferramentas, a assistência técnica e o transporte.

Além disso foi prolongado para 02 anos o período de devolução, aumentando para 24 o número das mensalidades. O valor da prestação mensal ficou assim ao alcance da maioria da população (15,00 R\$ em dezembro de 1998).

O montante de recursos financeiros a disposição do Setor hídrico (18.000,00 R\$) era suficiente para a construção de 50 cisternas. No primeiro ano de atividade foram portanto beneficiadas pelo Fundo Rotativo 50 famílias. Todas elas iniciaram a pagar a prestação mensal a partir do primeiro mês de trabalho. No prazo de seis meses todas as cisternas foram construídas. Depois de mais seis meses (doze desde o começo das atividades) já estava acumulada no Fundo Rotativo uma importância igual aos 50% do valor do investimento inicial e as famílias já tinham pago metade da dívida. Foi começado um novo ciclo e cinquenta novas famílias foram beneficiadas e começaram a pagar as prestações. Com 100 famílias pagando, os 50% que faltavam para financiar as novas cisternas foram recolhidos durante os seis meses de construção e dentro de mais seis meses o Fundo Rotativo tinha novamente o capital para recomençar o ciclo. Dessa forma todo ano o Fundo Rotativo dispõe de recursos suficientes para a construção de 50 novas cisternas.

A Fig.2 ilustra o Fluxograma financeiro, analisando o andamento das entradas, das saídas e do saldo do Fundo Rotativo durante os primeiros 36 meses de atividades.

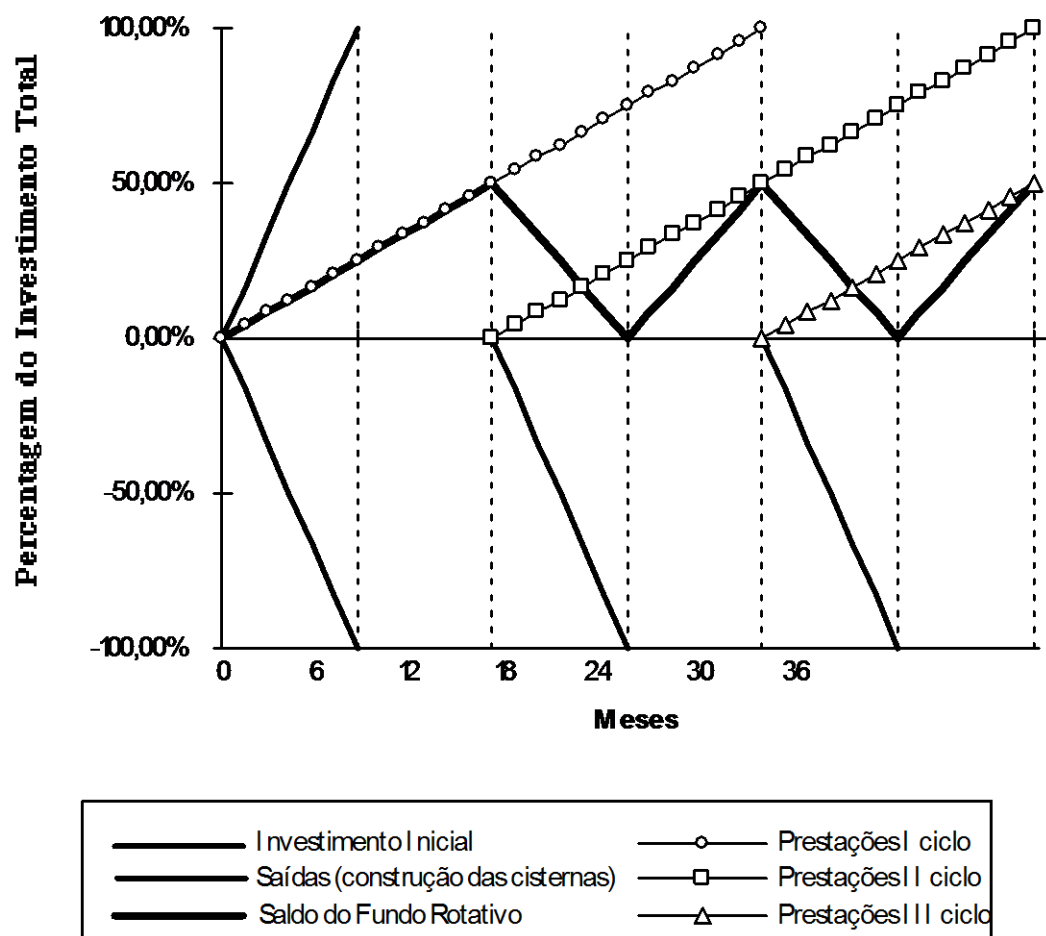


Fig. 2 - Fluxograma financeiro do Fundo Rotativo durante os primeiros 36 meses de atividades.

7. Resultados alcançados

Durante três anos de atividade do Programa de Crédito Alternativo para a Construção de Cisternas Familiares já foram construídas mais de 150 cisternas de placas, e o Fundo Rotativo constituído viabilizará a construção de mais 50 cisternas familiares por ano, por um número indefinido de anos (possivelmente até que todas as famílias da região possuam uma cisterna), pelas comunidades rurais de Barra de Santa Rosa. Isso beneficiou e beneficiará diretamente um igual número de famílias e, com um investimento inicial bastante baixo, já vem garantindo capacidade para armazenar todo ano mais de 2 milhões de litros de água potável.

Para o sucesso do Programa mostrou-se mais importante do que tudo a capacidade de mobilizar os comunitários para a iniciativa, ganhar a confiança deles para o empreendimento e merecer o respeito dos mesmos na hora de resgatarem os débitos assumidos.

Além do benefício principal, representado pelas cisternas, o Fundo Rotativo gerou e continua gerando três empregos para a equipe que realiza o Programa (02 Assistentes técnicos e 01 Coordenador), e torna-se um verdadeiro curso profissionalizante para os beneficiários, os quais aprendem as técnicas de construção das cisternas ganhando a chance de um novo espaço no mercado de trabalho.

Depois de três anos de atividades em Barra de Santa Rosa, o Fundo Rotativo para a Construção de Cisternas Familiares já demonstrou ser plenamente auto-sustentável e, portanto,

facilmente reproduzível nas condições similares dos outros municípios do Semi-Árido brasileiro.

Os resultados conseguidos foram de grande monta e atraíram a atenção de várias entidades, governamentais e não governamentais. Em 1997, o Programa de Estudos e Ações para o Semi-Árido, da Universidade Federal da Paraíba (PEASA/UFPB), propôs-se para uma parceria que tinha como objetivo a divulgação da metodologia do Fundo Rotativo para a construção de cisternas familiares em outras regiões do Semi-Árido paraibano, através da realização de Cursos de construção de cisternas (com financiamento do SINE-PB) nas comunidades rurais. Infelizmente a parceria não teve os resultados esperados e até hoje o PEASA/UFPB não conseguiu implantar novos Fundos Rotativos. Todavia, sob a orientação do *Progetto Mondialità*, tanto o Programa de Pequena Tecnologia Apropriada (PPTA) do Governo do Estado da Paraíba quanto a Universidade Federal da Paraíba passaram a divulgar em todo o Estado a técnica construtiva da cisterna de placas.

Só foi possível implementar um novo Fundo Rotativo, para a construção de 30 cisternas por ano, em 1998 nas comunidades rurais do município de Araruna, graças a uma parceria com a Diocese de Guarabira e ao financiamento do Serviço Alemão de Cooperação Técnica e Social (SACTES-DED).

8. Considerações finais

Os resultados positivos do Programa mostram que é possível melhorar as condições de abastecimento hídrico das comunidades rurais do Semi-Árido nordestino com módicos investimentos, utilizando tecnologias simples e autóctones e formas de crédito alternativas, como os Fundos Rotativos ou os Consórcios, bem aceitas pela população.

Programas do tipo aqui ilustrado podem muito facilmente ser realizados, com mínimos ajustes, por Associações, Sindicatos, Prefeituras e outras entidades similares, utilizando ou recursos próprios ou financiamentos recebidos a fundo perdido ou empréstimos bancários com taxas de juros reduzidas. Na conclusão do Programa, depois de atingidos os objetivos desejados, no Fundo Rotativo estará novamente acumulada uma importância equivalente ao valor do capital inicialmente investido, atualizado segundo a inflação acumulada durante o período de realização. Esta atualização não descende da cobrança de juros, mas do ajuste anual das prestações dos novos beneficiários que entram no Programa ao novo custo de construção da cisterna. A entidade promotora poderá portanto utilizar esta importância para devolver a dívida ou para outros fins, no caso de recursos próprios ou recebidos a fundo perdido.

Este sistema funciona bem em época de estabilidade econômico-financeira. No caso de retorno da instabilidade e da inflação alta, o valor da prestação mensal pode variar em função do preço de uma quantidade fixada de um material (por exemplo: o valor da prestação igual ao preço de 2,5 sacos de cimento). Assim se consegue, de forma simples e facilmente compreensível e sem utilizar complicadíssimas fórmulas para o cálculo dos juros, manter o valor do investimento atualizado.

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Rainwater Collection: An Easy Way to Overcome the Chronic and Growing Shortage of Water of the Albanian Rural Family

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Abstract

Albania has abundant rainfall (722-2747 mm/year), but mostly concentrated in the rainy season (October - April). During the dry summers, water levels are often at a critical low. During the past 50 years, rainwater catchment has been used to irrigate 50 - 60 % of the land, but little has been done to supply clean, safe drinking water for the people. Among the 2800 villages only 450 (16%) have aqueducts. During the summer only 5-10 liters of water per capita /day are available in some villages. Since the current government seems to be unable to supply the rural population with access to safe drinking water, the NGO *Rain & Rural Family* was founded in 1997 to study the possibilities of promoting roof rainwater catchment. The study states that each house with a roof of 50-100 m² could collect enough water to provide 6 people with an average water supply of 60- 130 liters for 90 days. The cost to build a reinforced concrete cistern would come to 590.000 leke (about US\$ 3,000). *Rain and Rural Family* aims to: 1) popularize the concept of rainwater harvesting, 2) inform the public about the tradition of rainwater collecting and 3) to establish rainwater collection as a national priority.

Introduction

Water, this basic living element of our planet, is to be found in abundance in Albania. Rainfalls constitute the main source, varying from 722 to 2747 mm/rainfall per year. By calculating an average of 1200 mm rainfall on a territory of 28.000km², Albania could theoretically collect 33.6 billion m³ of rainwater. This water could then be used for farming. The 700.000 ha of farmland need 7 billion m³ of water. The population of 3.5 million would need about 252 million m³ of water per year for personal use.

These two basic items of water usage consume 2,5 % of the annual reserve, even if one applies maximal standards of 10.000m³/ha of water per capita. It is understood that in this balance sheet rainfall represents one of the main reserves and could be an asset for the country providing energy resources and food for the population.

Not too many countries have the same rainwater collecting potential. The rainfalls in Albania are seasonal. More than 80 to 85 % fall between October and April. During the summer months (June-August, sometimes September) rainfall does not exceed 4-10% of the annual volume. The temperatures during this period are between 30-40 degree C. Thus Albania is the European country with the driest summer and people, plants and animals suffer from a lack of water. (see index 1-5)

Over the last 50 years many useful artificial reservoirs for rainwater collection have been built. The water from these reservoirs is mostly used for the irrigation of land. In regards to meeting peoples needs nothing has been done, and people have been left with empty political promises. During the summer months, about 60% of the arable land is under irrigation, while all the large urban centers, including the capital, as well as most of the rural areas (60% of the population lives in the countryside), are suffering from the seasonal summer draught. Of the 2800 villages in the country, only 450 (16%) have aqueducts, most of which are not capable of supplying 10-30 liters of water per capita/day. Hence we are facing a paradox, we have and do not have water. This ranks us indisputably, as the continent's most backward country.

The situation has turned into a daily torture. Every morning people in the cities have to carry water to the upper floors of their buildings. In the countryside, peasants carry water themselves or use animals, walking several hundred meters, often even kilometers, to transport water from the springs to their homes. They carry between 5 to 20 liters of water per capita/day. During the summer the lack of abundant water, does not allow for maintaining high hygienic standards. This results in

- infectious diseases and parasite insects
- poor health of the population, particularly of women and children.
- an unpleasant environment, taking into consideration that rural families keep their domestic animals near them. The stink, from the manure and lack of water help to increase the number of black flies and other insects, which are not only annoying, but also dangerous as bearers of infections.
- The decrease of agricultural and livestock products. There are fewer vegetables as well as less milk.

To certain degree the past political regime can be blamed for the current situation, but there is also no tradition for collecting rainwater or to develop any strategies in this respect. Given Albania's rocky terrain and the make up of its villages-- houses are usually built at a certain distance from each other the cost of an aqueduct is very high. It costs from US\$ 5,000-10,000 per house (taking into account water intake, channels, pipes, hydraulic equipment, energy for construction and maintenance). This would require a considerable government contribution, but given the political and financial situation of Albania, it would take another four to five decades to build such a system.

At some point in the future the government will have to build such complex water supply systems. Nevertheless following the 8th IRCSC, we founded the *Shi & Fa* Association (Rain and Family Association), a registered NGO with its seat in Tirana. *Shi & Fa's* goal is to provide a faster, cheaper solution for the needs of water, particularly for the rural family.

At *Shi & Fa's* request a group of specialist studied the rainfall ratio and the roof surfaces in rural areas, figuring out the volume of water that can be collected to cover the needs during the dry and hot summer months. They arrived at the following conclusion:
Every rural family with 6-7 members and a roof of 100m² (a roof surface common in Albania) might collect 30-70 m³ rainwater. Given an average of 2000 mm annual rainfall, they can easily collect enough water to take them through the summer. The cost pro cistern will be between US\$1,000-1,500 (see page Nr. 1 and Nr. 2).

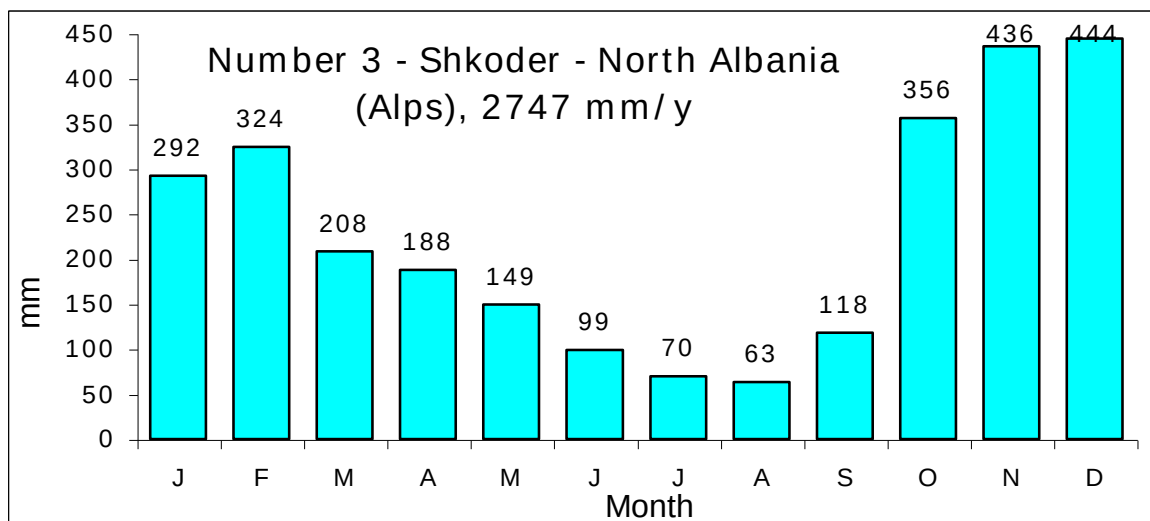
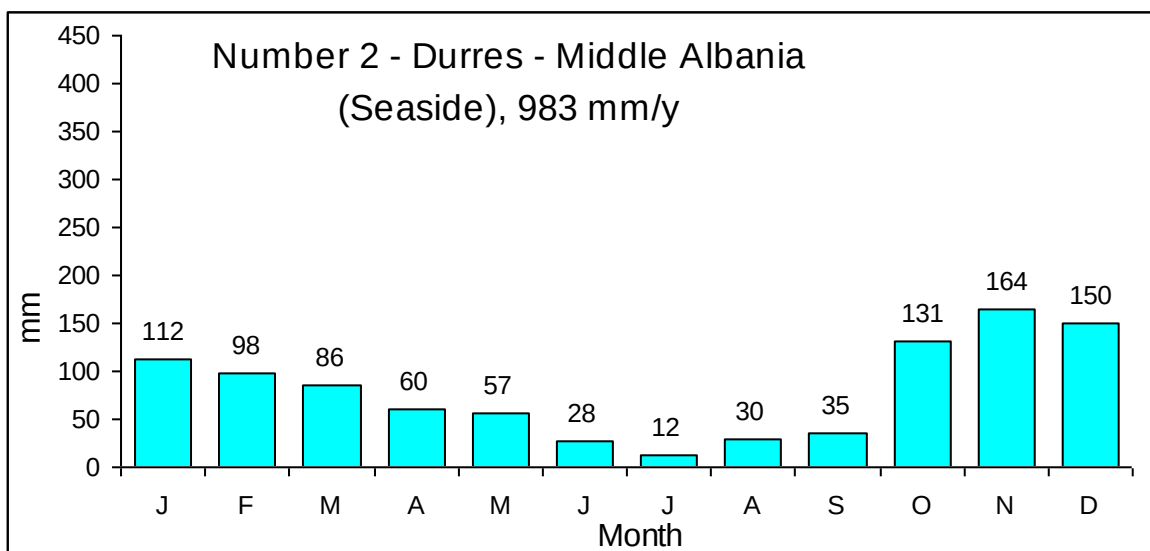
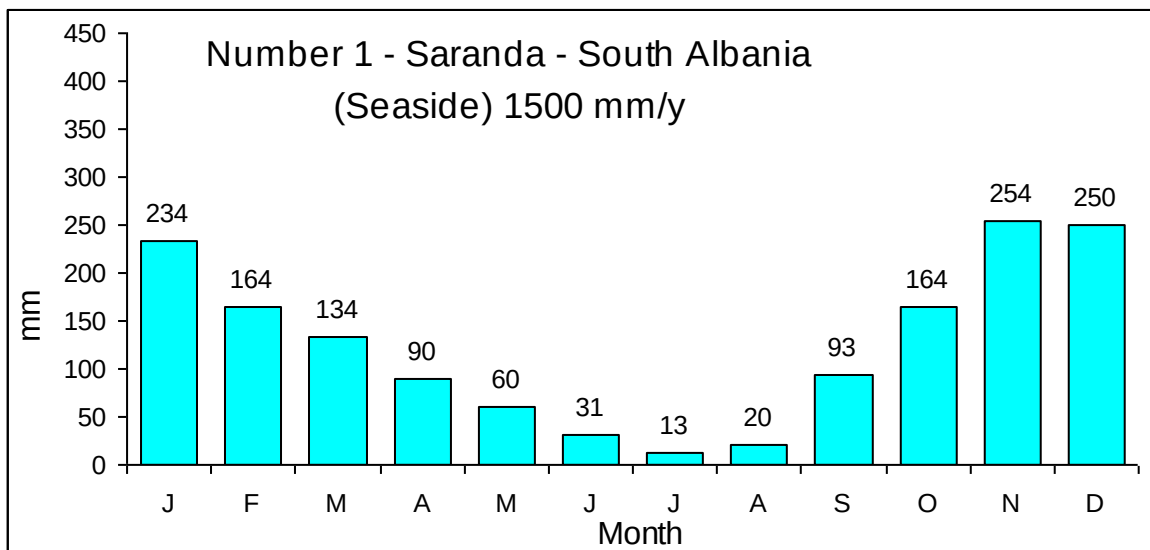
If the peasant family supplies some of the materials or if they use plastic tanks instead of iron-concrete ones, the cost might be reduced to US \$500- 750. There exists a vast possibility of choices depending on the purpose and economic power of each rural family. Theoretically they could collect 90 –100m³ of water, taking into consideration that they have 100m² of roof surface. If the roof surface increases, the volume of water collected increases too. This implies that during the rainy season (October- April) every house in the countryside can collect a volume of water ensuring no less than 60-130 liters of water/person/day for the dry season of 90 days.

At the beginning we thought that only 20-30% of the farmers might be willing to make such an investment on their own. With some aid from the state or a donor organization the percentage might increase to 50%. Within 1 to 2 months, the time needed to build a reservoir, a century-old problem could be solved. But the project's most important aspect is not its cost, but to allow individuals that they can do something to change their situation. It will allow each of us to come up with a strategy and one that's within our means.

It is high time for us to realize that the rainwater from our roofs without any costs for energy, without any need for pumps, pipes and hydraulic parts has been forgotten. Albania used to have a tradition called *Gjirokastra* for collecting rainwater. We should study it and spread its knowledge throughout the country as an appropriate regional method.

The *Shi & Fa* Association has as its main goal to remind people that rainwater is a natural product like wheat, fruits, etc., which should be collected and used according to need. In order to achieve this goal, it is striving to build 5 to 10 iron concrete reservoirs in various parts of the country and to launch within the next 2 or 3 years a national movement.

The members of the *Shi & Fa* Association also keep the poet Noli's lines in mind: "Under the light unnoticed, close to the sea unwashed." These lines should not hold true in the future, it's better if they pertain to Albania's past.



OFFER (translation from Albanian)

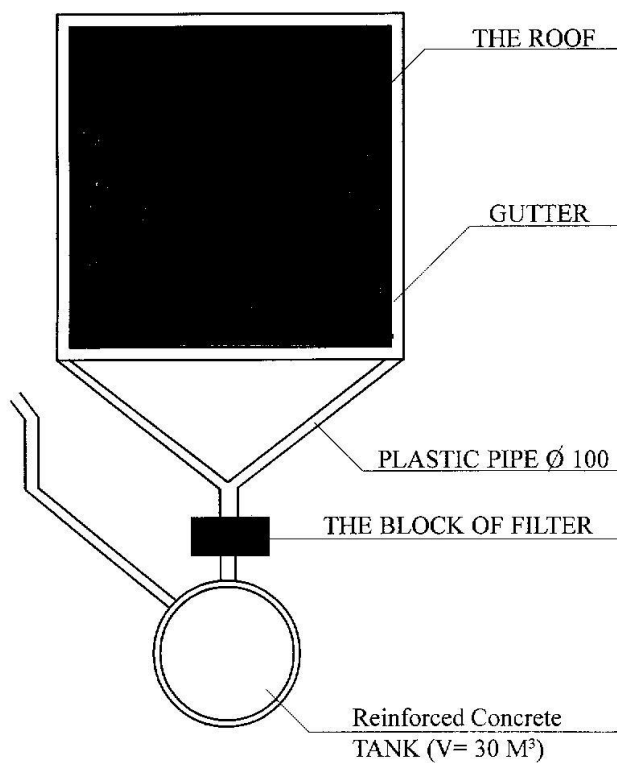
For the construction of a concrete water tank with a volume of 30 m³ covering the need of one family with living surface of 100 m².

1. Digging	m ³	8 x 4.000	=	3.200
2. Basement of stones t= 20 cm	m ³	3 x 840	=	2.520
3. Basement of concrete M200 t=15cm	m ³	2.2 x 8.500	=	18.700
4. Concrete wall M200 t=20cm	m ³	7.9 x 15.000	=	118.500
5. Concrete wall for filtering unit	m ³	1.2 x 15.000	=	18.000
6. Covering roof concrete M200	m ³	2 x 13.000	=	26.000
7. Stones covering for filter	m ³	0.5 x 1.000	=	500
8. Steel	kg	1.000 x 100	=	100.000
9. Finishing with isolation material	m ²	70 x 400	=	28.000
10. Plastic tubes for gathering	kg	170 x 280	=	47.000
11. Tube of concrete 200 mm	ml	2 x 800	=	1.600
12. Zinc tubes	kg	10 x 270	=	<u>2.700</u>
		Subtotal 1		367.320
		Expenses for small mat. 11 %		<u>40.405</u>
		Subtotal 2		407.725
		Net profit 15 %		<u>61.158</u>
		Subtotal 3		468.883
		VAT 20 %		<u>93.776</u>
		Subtotal 4		562.659
		Reserve		<u>27.341</u>
		TOTAL		590.000
				(about 3000 USD)

The physical external volume of the tank will be of 37 m³

June 1998

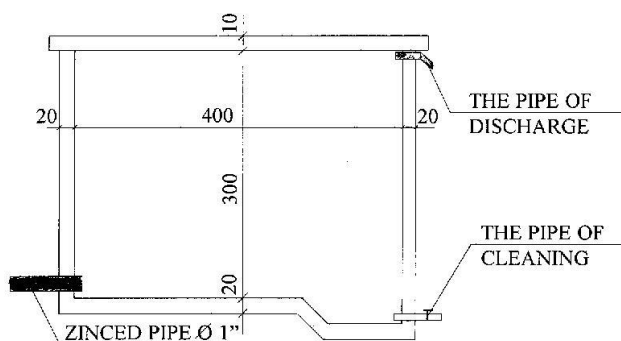
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Ing. Islam Zhupa
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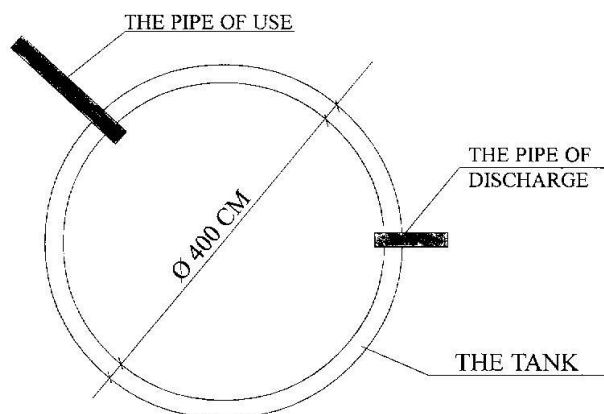
THE PLAN OF THE RAINWATER IMPIANT

(FOR ONE FAMILY)

$h_{mm} \geq 1000 \text{ MM/Y}$



THE TANK OF THE RAINWATER



$V = 30 \text{ M}^3$

Rainwater Catchment: Women and Gender Participation in Zimbabwe

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Abstract

Rainwater catchment and storage have been successfully utilized by people all over the world. Any form or size of container has been used to harvest and store water from roofs made of iron sheets, asbestos and grass thatch. Many systems of rainwater catchment have been designed over the years. These systems however can work well only when they are adapted to suit specific environments in which they are placed. Experience has shown that no one technical solution can be applied throughout one country. Technical solutions must be adapted to suit local environments and local financial resources and also suit traditional skills in construction and facility use behavior of the population. The following paper shows how these questions were solved in the towns of Beitbridge, Plumtree and Mberengwa in Zimbabwe.

1. Introduction

Water is essential to all life: animal, human and vegetation. It is therefore important that adequate water supplies be developed to sustain such life. However the development of water supplies should be undertaken in a way that will preserve the hydrological balance and the biological functions of ecosystems.

2. The Situation in Zimbabwe

Zimbabwe is a landlocked country in Southern Africa with approximately 389.000 square kilometers. The driest region of the country is the Lowveld, covering the area below 600 meters above sea level and consisting mainly of the Zambezi, Limpopo and Save Valley. The two other regions the Middle Veld and the High Veld have more water and are not in need of rainwater harvesting methods.

Zimbabwe as a country has a policy on "Water and Sanitation." In spite of the above policy, only three percent of households categorized as "very poor" have access to piped water in Zimbabwe's communal areas, according to a 1995 poverty assessment study. Figures are even worse for the Save-Limpopo basin in the southern part of the country. The average rainfall in these areas is normally around or below 600mm per year and at times as little as 295 mm per year.

On many occasions, boreholes sunk in these areas by the government and NGOs, do not yield sufficient water and frequently the water drawn is saline. In Zimbabwe, like in most countries, the woman is the beast of burden. She has many roles to play in the home. She is the mother, organizer, teacher, health worker, etc. She goes to the field with the husband and she also has to look for firewood, catch water and cook for the husband and children. She is the first to get up in the morning and the last to go to bed.

In most rural areas of Zimbabwe, women spend many hours a day walking to the boreholes which may be 3 to 5 km away. Or they take water from earth dams, which are also used by domestic animals. To help women get out of this terrible situation, the Zimbabwe Council of Churches has embarked on a rainwater harvesting program for individual households.

3. Case studies from Beitbridge, Plumtree and Mberengwa

I am going to describe the experiences gained during the planning and implementation of rainwater harvesting projects in the districts of Beitbridge, Plumtree and Mberengwa in the Zimbabwean provinces of Matebeleland South and Midlands. The rainwater harvesting project in these areas demonstrate that a well planned project, with community participation, can bring about a sustainable development to communities in isolated and marginal areas far away from river water sources.

3.1 Beitbridge-Tongwe and Dumba Villages

Prior to the initiation of the rainwater harvesting project, the majority of people in the Dumba and Tongwe villages did not have access to clean water. They got their water from earth dams situated far away and which are also used to provide water for livestock. The boreholes were another source, which would dry up quickly or produce salty water. The overall situation at the homesteads was that of despondent dependency, desperation and insecurity. Many of the subsistence farmers as well as youth abandoned their homes and went to South Africa to search for employment, leaving behind women and children.

In September 1995, an officer from the Zimbabwe Council of Churches (ZCC) visited the area after having attended a workshop on rainwater harvesting in Mbarara, Uganda. Participatory Rural Appraisal (PRA) was used as the method for identifying the major problems. PRA involved the villagers, in their majority women.

Water was identified as the community's top priority. Women were spending considerable time fetching small quantities of water. The community asked for more bore holes to be drilled despite the fact that 95% of the existing boreholes had dried up. Discussions continued and an example of a bank was used whereby if the banker continued to withdraw money without depositing any, there would be no more money. In the same way the underground source would dry up should more boreholes be sunk. The villagers then suggested the harvesting of water through building of tanks at household level and also earth dams.

Community participation is necessary for a sustained system. Initiation of a project is the most critical phase in the entire process. People themselves must identify and define their perceived needs and aspiration. If the idea and the request for assistance for rainwater catchment is perceived as an external intervention, it will not receive the necessary community support in the subsequent operation and maintenance.

The community feared that the program would not succeed as they claimed that they had received empty promises from previous donors. Nobody thought that women could build a water tank. There was no trust that a woman officer would successfully manage such a huge project. However 19 women from the two villages gave it a first try.

Water development usually requires external inputs in terms of essential physical, material and technical advice. Although the community is the recipient of such assistance, it should own the project. The community should not be simply viewed as provider of free labor. It should be actively involved in all aspects of planning, implementation and management of the intended project. Staff should consider themselves as facilitators in the development of a community concerned water project.

From the onset of the project women made up their constitution which would help them working together. They formed committees and led them. A joining fee of Z\$2 was paid by each member as commitment to the project.

Community participation can in practice be achieved through holding of meetings with all beneficiaries of the project. A "participatory approach" in which the water users assume a leading role, as the true owners of the project should be applied in making decision affecting the project. Let them take the leadership role. PRA methodologies are most fundamental for the successful implementation and sustainability of any project that promotes self-reliance. Communities as key actors and role players should provide apart from labor, locally available materials, to strengthen project ownership.

The groups were also assured that the process was their responsibility. This included planning, maintenance of records, control of stock, reporting, monitoring progress and on-going evaluation. ZCC facilitates and provides technical advice and skills. The Blair Research Laboratory Institute belonging to the Ministry of Health was invited to provide the technical skills for the women. A number of structures were discussed and women finally opted for the brick tank. The women themselves contributed labor, river sand, pit sand, concrete stones, hard core and water. Outside assistance consisted of cement brick-force and technical advice.

The participatory approach usually takes time to implement but if correctly applied it has the advantage of bringing together the eventual beneficiaries in such a manner that everybody becomes a stakeholder by agreeing to the objectives of the project and on how best to achieve them. Each member of the community clearly understands his/her role in the construction and management of the water resources. Once general consensus is achieved, no problems would be anticipated during the implementation, management and maintenance phases.

The two villages (Tongwe and Dumba) constructed 100 household tanks and 4 big tanks at their two schools. The household tanks hold about 6000 cubic liters of water (30 drums) each. If carefully used, it supplies a family of 8 members with 4 liters of water for 250 days. Collected water usually lasts less time because families also use the water for other purposes.

Training communities to construct their own water facilities lowers costs and promotes project sustainability. Women are the majority of population and the users of their own water supply system. They are responsible for its maintenance and therefore they need to be trained to gain all necessary skills. They also control the use of water and try to avoid misuse.

Once given the skills, the communities can implement the project while staff only supervises. The fact that they have built the resources themselves instills possessive spirit in them. They will also share the skills with other communities at little or no cost unlike the engagement of the expensive water engineers, thereby also increasing their knowledge of the project.

The choice of an appropriate and acceptable technology for communities is crucial for success. Indigenous ideas presented by the user-groups, when carefully assessed on technical grounds and supported by training, should result in projects manageable and maintainable by the communities themselves with minimum backstopping by technicians. This means to say that their participation in the choice of what technology to use is necessary and this could be eased by involving the community as early as the making of the budget.

Impact of Rainwater Harvesting

- Women do no longer need to walk long distances for water, giving them more time for other household chores.
- Participation of women in community decision making has improved.
- Since women get together regularly, they interact in an informative manner, exchanging ideas and learning from each other.
- The project has changed men's attitude to the capabilities of women in the community. Women's contribution to decision making and to community affairs has increased.
- Women have gained tank building skills.
- The health of family members, particularly of the children, has improved due to the acquisition of clean water.
- Women have grown in confidence and self-esteem through running the village water committees and through the gender discussion series.

3.2 Plumtree District

In Plumtree 96 household tanks have been constructed. As in Beitbridge, the PRA methodology was used to mobilize communities. It was not easy for the community to visualize how women would build tanks. Two women from Beitbridge were the animators for the Plumtree group. It was easy for the women to instruct and then teach the people of Plumtree how to construct tanks. We did not need the Blair Research team to provide technical advice since we had the Beitbridge activists and the assistance of the ZCC officer. Unlike in Beitbridge, men in Plumtree have become very active and are participating in the project. The women are still taking the leadership in the rainwater harvesting committees. Work in Plumtree is still in progress. The target is to build a total of 150 household tanks.

3.3 Mberengwa District

In this district a different tank is used: the ferrocement tank. John Mbugua and Isaac Kariuki from Kenya came in for consultations and demonstrations of how to build ferrocement tanks. Rainwater harvesting is making a deep impact on the communities. In Mberengwa, women, men and youth (boys and girls) participate in the implementation of the project. When the program in this district was started, the drinking water situation was very bad. Women added ashes to the dirty dam water in order to purify it for drinking.

The program in Mberengwa commenced on the February 1, 1999 and six weeks after its start 32 household tanks have been constructed as well as 5 big tanks for schools and clinics. The target number for phase one in this district is 150 tanks. Hopefully phase one will be concluded by the end of September 1999.

4. Conclusion

For the success of a rainwater harvesting program community participation is necessary from the beginning, through the implementation and for continued maintenance.

Programa de Cisternas Caseiras no Brasil Semi-Árido da Cáritas Brasileira: Iniciativas Simples, Grandes Soluções

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Resumo

Tentaremos demonstrar a importância das pequenas iniciativas, destacando entre estas a importância das cisternas caseiras, que a Cáritas Brasileira vem desenvolvendo junto às famílias rurais no Semi-Árido brasileiro, e que já data de longos anos, porém, acentuada de maneira incisiva a partir de 1998. A técnica, as dimensões, a forma mais adequada e os cuidados necessários para que a cisterna caseira garanta água para o uso doméstico, já são de amplo conhecimento da Cáritas e das ONGs que trabalham no Semi-árido brasileiro. A cisterna de placa para a captação da água da chuva é uma das iniciativas essenciais para recuperar a capacidade de conviver com o semi-árido, captando a água boa e em quantidade para o consumo humano.

O princípio fundamental é a participação e a organização da comunidade. E é aqui que desejamos introduzir no debate o que consideramos essencial: as políticas de promoção da convivência com o Semi-Árido brasileiro só terão sucesso se seguirem uma metodologia participativa e de valorização dos costumes e da cultura de cada localidade.

Entendemos que todas as iniciativas de captação, conservação e uso de água, bem como todas as demais políticas necessárias para promover uma convivência saudável e feliz com o Semi-Árido brasileiro, incluída a reforma agrária e as políticas de irrigação, só terão sucesso se forem implementadas de forma democrática, com participação e com promoção da cidadania de todos que habitam nesta região.

Introdução

O Brasil tem quase 10% de sua população vivendo na região semi-árida. São mais de 14 milhões de pessoas, espalhadas numa área de quase um milhão de quilômetros quadrados, cobrindo parte dos territórios dos seguintes estados: Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia, Minas Gerais e Espírito Santo.

Um Semi-Árido desconhecido - Pode-se dizer com segurança que a maioria da população brasileira não tem conhecimento de que existe uma região semi-árida em seu país, e muito menos ainda consciência das características próprias deste Semi-Árido. Por interesses das oligarquias locais e regionais, e por seu poder de comprometer os responsáveis pela política estadual e nacional, a idéia e a imagem que a população tem desta região é de uma *região seca*. Esta raiz estrutural tornou possível a formulação, prática e teórica, da chamada *indústria da seca*: atração de recursos e concessão de privilégios de toda ordem em favor dos grandes proprietários e das elites ligadas a eles *utilizando os períodos de estiagem* para caracterizar a região como frágil e carente de apoios externos permanentes. Até mesmo a industrialização da região foi implementada tendo como base estes privilégios.

A pobreza e a miséria da maioria da população deste Semi-Árido não é fruto *natural* dos seus limites, mas consequência da implantação e da reprodução de oligarquias privilegiadas e poderosas. Por outro lado, os povos indígenas deste Semi-Árido, que o conheciam e viviam

nele há mais de 10 mil anos, ou foram dizimados ou impedidos de viver como povos. A consequência mais grave deste genocídio e etnocídio tem sido a falta de uma cultura característica desta região, implicando em relações que tornam cada dia mais frágil o seu ecossistema. Além disso, torna-se mais complicada a formulação de práticas econômicas e políticas alternativas adequadas a este Semi-Árido, por relativa *falta de história*.

Água e dívidas sociais - “Não é livre quem depende de um prefeito até para beber um copo d’água”. A luta pela água é uma questão essencial de cidadania e liberdade. As manobras das elites brasileiras e nordestinas que instrumentalizam a fome e a sede do povo sertanejo em favor de seus interesses políticos, não é apenas uma questão de injustiça e negação de direitos, como um genocídio constante. A seca, a fome e a miséria, é uma dívida social de ontem, de hoje, e de amanhã.

O Brasil possui 8% da água doce mundial, mas só 3% das águas brasileiras estão na região Nordeste. Não é à toa que a ONU prevê, para a próxima década, disputas acirradas pelo controle dos mananciais no mundo inteiro. No Brasil, um exemplo claro dessa disputa é a privatização do Rio São Francisco, onde o adquirente iria controlar 90% da água desse rio. A pluviosidade nordestina e do norte de Minas Gerais é irregular e diferenciada; a água do subsolo, quase sempre salobra; a maioria do solo não oferece condições para a perfuração de poços profundos; há poucos rios, na realidade, existem apenas duas grandes bacias: a do São Francisco e a do Parnaíba. Nesta circunstâncias, torna-se inadiável a busca de soluções alternativas e a criação de uma nova mentalidade, uma nova cultura e adaptação ao meio ambiente semi-árido.

Resgate das dívidas - Mesmo assim, é muito rica a história das lutas populares em favor de sua vida, de sua cultura, de sua cidadania, implicando lutas pela terra, pela água e por iniciativas econômicas ecologicamente adequadas. Pode-se afirmar com segurança que existem, e por mérito da população, iniciativas e conhecimentos tecnológicos capazes de embasar um projeto de desenvolvimento alternativo, favorável à população e recriador do meio ambiente no Semi-Árido brasileiro.

As saídas para o resgate da dívidas sociais é antes de tudo uma questão política, que passa necessariamente pela luta por criação de iniciativa popular, que conquiste democraticamente planos municipais de água que priorizem as tecnologias simples e eficientes, de fácil domínio público, e custos reduzidos.

Tem sido uma constante o empenho das organizações não-governamentais, sindicatos, igrejas e pastorais sociais na luta em busca de alternativas, para fazer valer o preceito legal previsto na lei de recursos hídricos, de janeiro de 1997, que institui o sistema nacional de gerenciamento de recursos hídricos, estabelecendo a água como *bem de domínio público* e como *recurso natural limitado dotado de valor econômico*. Ainda estabelece essa legislação que, em situação de escassez, é prioritário o *uso dos recursos hídricos para o consumo humano e a dessedentação dos animais*.

A ação Cáritas: apoio à construção de cisternas caseiras – É opção política da Cáritas Brasileira atuar no Semi-Árido, com prioridade para a construção de cisternas que assegurem a convivência pacífica e possível da população sertaneja em suas próprias localidades e em condições humanas dignas, com água de boa qualidade para o consumo humano. Esta opção se insere num contexto maior, dentro do seu *Programa de Convivência com o Semi-Árido*, com abrangência regional.

O Programa, que teve início em maio de 1999, com uma grande campanha emergencial de arrecadação de bens e recursos financeiros em todo Brasil, tendo em vista a calamidade anunciada pelo fenômeno *El Niño*, tem como meta construir, a curto prazo, com o apoio financeiro de pessoas e instituições de boa vontade, do Brasil e do exterior, cerca de oito mil cisternas de placa para a captação e armazenamento de água da chuva.

Sem entrar no detalhamento das linhas constitutivas deste programa como um todo, limitaremos nosso olhar ao que se refere à água, de modo especial à captação, conservação e utilização da água gerada pelas chuvas. Mesmo neste particular, destacaremos a importância das *cisternas caseiras*.

Temos todo um conhecimento sobre o tamanho, a forma mais adequada e os cuidados necessários para que a cisterna caseira garanta água para o uso doméstico. Ela é, então, uma das iniciativas essenciais para recuperar a capacidade de conviver com o semi-árido captando a água das chuvas.

Temos também experiência em relação aos custos de cada cisterna: a mais acessível não passa de 400 reais, em média - ao preço atual do real, mais ou menos 220 dólares. Mas a mesma cisterna chega a custar, em se tratando de programas governamentais, R\$ 3.000,00 (1.660 dólares). O mais desafiador é que a maioria das cisternas construídas ao custo de 3 mil reais não chega a funcionar, enquanto praticamente a totalidade das que custam 400 reais são valorizadas e mantidas pelas famílias.

É aqui que desejamos introduzir um debate que consideramos essencial. Formulada como tese, a questão poderia ter a seguinte redação: *as políticas de promoção da convivência com o Semi-Árido brasileiro só terão sucesso se seguirem uma metodologia participativa e de valorização dos costumes e da cultura de cada localidade*.

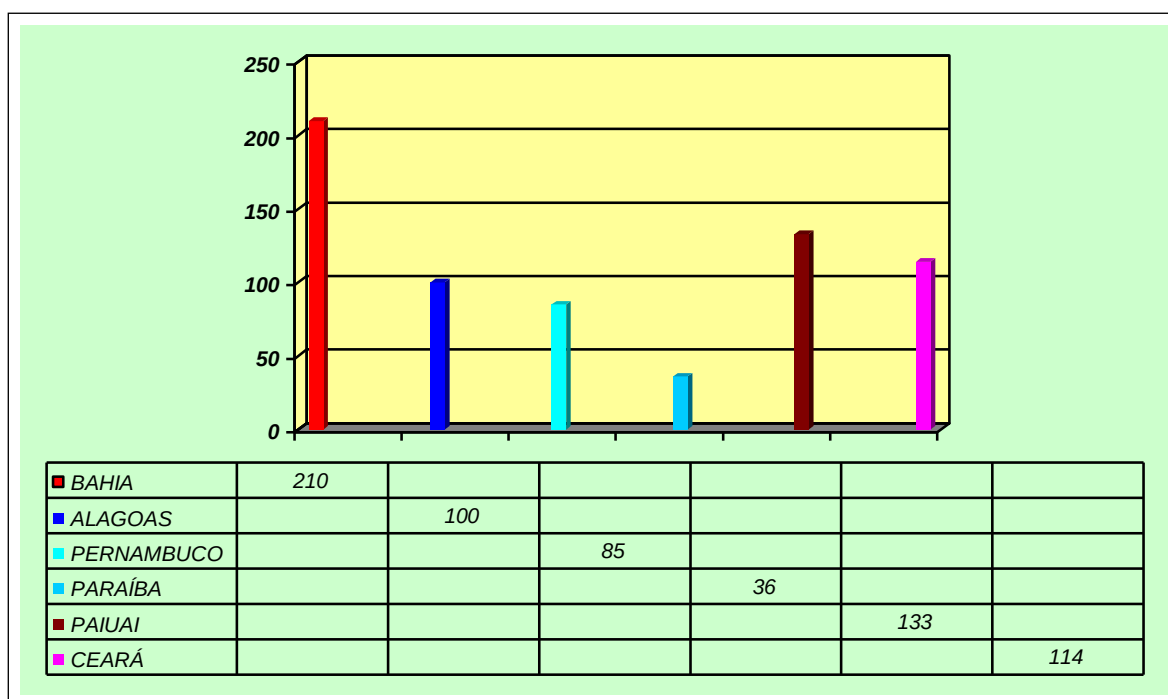
É isso que explica tanto a possibilidade da popularização das cisternas por meio do baixo custo, como a geração do interesse pela sua utilização e boa manutenção familiar. A prática das entidades da sociedade civil – entre elas, a Cáritas Brasileira – é implementada sempre em diálogo e em cooperação com as pessoas, as famílias e as comunidades locais. Isso possibilita a) o debate sobre a importância da cisterna, apresentando, entre outros dados, experiências bem sucedidas; b) a tomada de decisão coletiva sobre a construção e sobre o tamanho necessário, a depender do número de usuários em cada casa; c) o treinamento de pedreiros para coordenarem a construção coletiva das cisternas; d) o treinamento para manutenção da qualidade da água e sobre o seu uso mais adequado; e) o reforço ou nascimento da organização comunitária, como garantia da iniciativa assumida por todos.

Além disso, a perspectiva assumida nestas iniciativas é politicamente mais ampla em relação à prática da cidadania: procuram estimular a luta organizada, para exigir do Estado políticas públicas que favoreçam a vida de todos que vivem na região. Estas políticas devem, obviamente, ser implementadas em conjunto e em cooperação com as comunidades, a partir da prática que demonstra ser possível melhorar a convivência com o semi-árido, sem grandes obras e grandes custos.

Na maioria dos casos, as ações implementadas por projetos governamentais seguem um caminho contrário. Na palavra de uma nordestina: *“agora eu aprendi: se a gente não se organiza, vocês vão embora; no caso dos governos, quando a gente se organiza, eles vão embora”*. Desse modo, agindo sem diálogo, em geral por meio de empresas contratadas, que agem apenas com critérios econômicos e desrespeitam as famílias, estas cisternas custam muito e não são assumidas pelas famílias.

Entendemos que todas as iniciativas de captação, conservação e uso de água, bem como todas as demais políticas necessárias para promover uma convivência saudável e feliz com o semi-árido brasileiro, incluída a reforma agrária e as políticas de irrigação, só terão sucesso se forem implementadas de forma democrática, com participação e com promoção da cidadania de todos os *semi-aridinos*.

Gráfico 1 - Construção de cisternas apoiadas por Cáritas (out/98 a maio/99)



Fonte: Cáritas

Rainwater Catchment in Brazil's Rural Semiarid Tropics: A Grassroots' Approach

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Abstract

During the past decade, NGOs and grass-root organizations working in Brazil's semiarid tropics have focused on rainwater catchment systems as an essential contribution to people's survival under the region's climatic conditions. Awareness about the possibilities of the semi-arid region had to be raised. The main necessities are adequate education at all levels, therefore organizations working in the Northeast dedicate most of their efforts on this aspect. The organizations not only teach appropriate technologies, but first speak about an appropriate understanding of the semiarid climate and then introduce rainwater catchment systems and look at the socio-economic and cultural conditions of the people involved. There has to be a political willingness to create an infra-structure such as access to land, animal raising, rain-fed agriculture, water supply, education, health service, streets and commercialization of local products. Once these aspects are taken into consideration, the future of the rural population in the Brazilian semiarid region will be more certain.

Introduction

The semi-arid tropics or so-called "drought stricken polygon" in Brazil's Northeast is a region extending over about one million square kilometers and peopled by about 15 million inhabitants. Every couple of years the rural population is faced with a drought and not able to cope with it. Each year the people till the soil and plant corn hoping for sufficient rainfall. But regular and sufficient precipitation is the exception rather than the rule in a semiarid climate. Thus a bad harvest seems to be programmed in advance..



Map of Brazil showing the semi-arid tropics or dry polygon in the Northeast.

For most politicians - from the simple county counselor to congress representatives - dry years mean a guaranteed election victory. State funds are being manipulated as election baits and water trucks

for the thirsty cows catch the votes of a whole village. The rich flow of funds from the capital Brasília is not channeled to the needy people but ends up in the hands of corrupt politicians. The so-called "labor front against the drought" and well digging programs are being used by big landowners for their own benefit. The politicians earn lots of money with each drought and therefore they have no interest in taking preventive measures for the next draught period.

History

Between 1981 and 1983 the area was once again drought stricken. Vast parts of northeastern Brazil were affected and the people were completely unprepared. The Brazilian government had received previous information about the coming drought from meteorologists. However, this information did not reach the people. As a result, many migrated to the big cities, others were forced to sell their land to big landowners and irrigation farmers for a ridiculous price.

For the people affected it seemed like an organized attempt at genocide. Those strong enough to organize and resist, got together to develop strategies of dealing with the politics of drought. "No Nordeste não falta água, falta justiça!" ("In Brazil's Northeast there is no lack of water, there is a lack of justice!"), was one the main slogans of that time.

Some people working with NGOs, grass-root organizations and communities realized that besides the importance of a land reform and political organizing, there was also the need to develop a well-structured education program for peasants. At the beginning there were only some isolated experiences centered around communal water management, communal fields, manioc mills, bee keeping, communal tractors, bore wells, deposits for water from rainfalls, avoiding slash and burn farming, refusing chemical pesticides, etc.

Later on, three main topics were developed geared at guaranteeing the peoples' survival in Brazil's Northeast:

- Climate and water management: How does the semiarid climate work and what consequences does it have for agriculture. Establish preventive measures such as rainwater catchment in order to have water reserves for the dry periods.
- Animal husbandry: Keeping small animals, especially sheep and goats, adapted to the semiarid climate; provision of fodder for the dry months, de-worming, etc.
- Dry land farming: harvesting in years with poor rainfalls; which plants are best suited for a semiarid climate.

IRPAA (Regional Institute for Appropriate Smallholder Farming and Animal Husbandry) is focusing on these above mentioned topics. Founded in 1990, it is an independent non-governmental organization with headquarters in Juazeiro (Bahia) the twin city of Petrolina (Pernambuco). Today, there are a number of other similar rural projects underway in various regions of the Northeast.

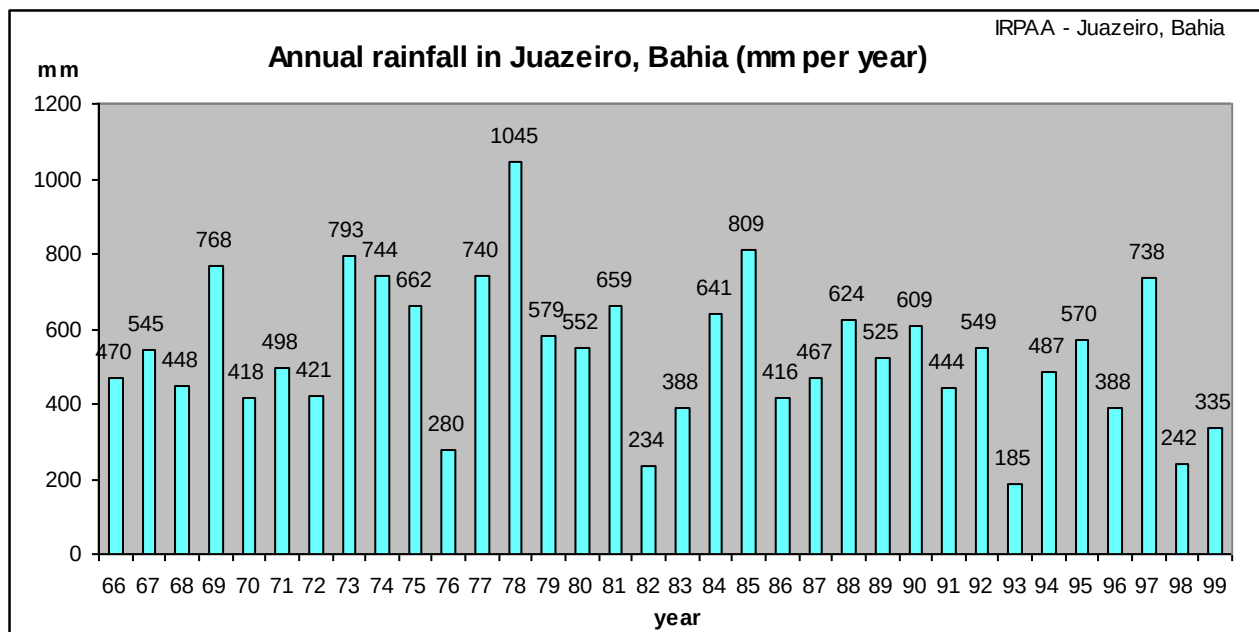
Methodology

Concerning IRPAA's methodology we tried to find a balance between theory and practice. Our job is not only technical assistance but mostly educational work, spreading knowledge through practical examples. A specific technology can never be followed blindly. It is assumed that peasants and sheep and goat breeders have been applying technologies that worked well for them. These technologies have allowed the small farmers to survive in Brazil's Northeast. Once these technologies are combined with new knowledge they are the foundation for an "appropriate" technology, enabling the rural population to live in an arid climate zone. Regarding rainwater catchment systems, we do not prescribe the kind of cistern to be built and used, but we guide and supervise people in discovering the rainwater catchment system most appropriate for their case.

Rainwater catchment adapted to specific climatic conditions

Due to the draughts occurring every couple of years, the Brazilian Northeast is often called an emergency zone. We think that this so-called emergency is man-made. If we find a way of living under these climatic conditions, then we do not need to blame "draught spells" for causing our problems.

One can change a lot, but certainly not the amount of rainfall and its distribution. We must find a way of life, a way of farming and animal husbandry that agrees with the precipitation and the type of soil. It is of no use to complain about lacking rain. For thousands of years the Northeast has known droughts and they will continue to occur for many thousand years to come.



How can we change our attitude concerning water?

In the Northeast it rains a lot. But we are careless about this gift. In the rainy season we let the water run off and some months later we have to beg the local politicians to send us water trucks.

Therefore we must build reservoirs to collect rainwater. In the first place we must calculate how much water we will need during the dry months. For example one person needs at least 14 liters of water per day, one cow 53 liters and a goat needs 6 liters a day.

We need a rainwater cistern for drinking water close to each house, a bigger pool for rainwater storage - at least 3 meters deep (because of high evaporation) - for each community for water used for washing as well as the animals and thirdly, an additional year round water source easily accessible for several communities. The latter could be a small but deep rainwater reservoir or a deep well.

These three types of water supply are called:

- family water
- community water
- water for emergencies.

We can get water from the subsoil, from rivers or from rainwater catchment. The subsoil in almost half of the semiarid region is crystalline rock. Therefore there is no suitable aquifer in this type of subsoil, because water is found only in fissures and often salty. Only near the São Francisco River and a few other perennial rivers do we have an adequate supply of piped water and irrigation. Rainwater catchment, on the other hand, is viable in every part of the semiarid region and the most appropriate solution for the area with crystalline subsoil.

At the beginning of the eighties, the farmers in the Casa Nova (Bahia) county (on the left side of the São Francisco River) were hit by a severe draught. Some people from the county remembered that in former days people used to dig "caxios" in order to collect rainwater. Caxios are rock cisterns, i. e. deep, narrow holes dug into the softer rock. People got together and started to dig. The local politicians, belonging to the old ruling families, made fun of them threatening them, "You may well die of thirst while working together. We are not going to send you a single water truck!"

The months went by and there was hardly any rain, but the people did not suffer from any water shortage as their "caxios" had filled up. And even today the people tell that those who had trusted the local politicians and their water trucks "had died of thirst".

Even in the dry years of 1993, 1995 and 1998 the "caxios" had enough water for humans and animals all year round.

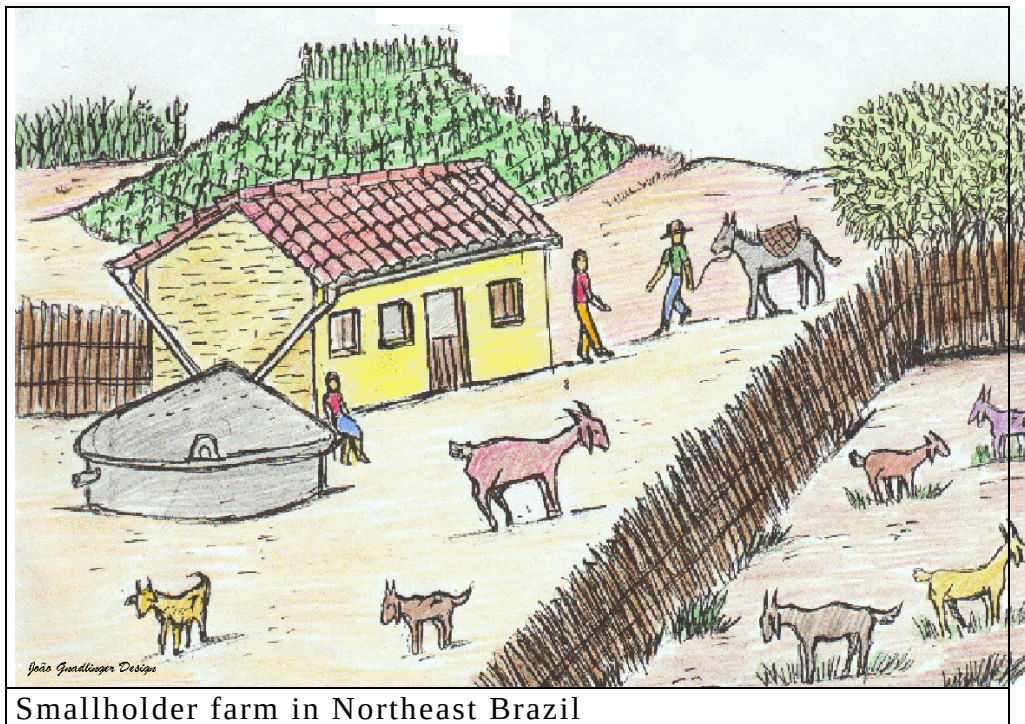
It only makes sense to dig deep reservoirs with a small surface otherwise they will be dried out by the wind and the sun.

In the region around the cities of Canudos and Campo Alegre de Lourdes (in Bahia) the communities started to collect rainwater from the roofs. They built cisterns of 15,000 l near their homes where water is collected in the gutters and brought to the cisterns. These cisterns are sealed on top to avoid evaporation and to keep out insects. To have an all year water supply, one needs to know one's water needs and the size of one's roof. With this in mind, one can build the right size cistern. The cistern must be round to avoid cracks. It can be made of concrete plates, iron cement or local materials such as bricks and lime mortar.

What do we have to change in regards to goats and sheep?

In 1993, a drought causing El Niño year, the people of Cipó village (Juazeiro County) gathered to discuss the scarcity of rain. They realized that there was hardly anything to harvest in the fields. However, the people were not discouraged, although they knew that the sheep and especially the cows would have to struggle to survive until the next rainy season. The goats posed no problem. They were healthy and had a shiny skin. In the natural thornbush vegetation goats find enough fodder and way into the dry season they would be eating the husks from the Prosopis tree and the leaves of the Opuntia cactus. This cactus is not only important as fodder for the goats, but supplies them with water. (In their trunks and leaves cacti store rainwater). Neither would people be lacking water. Along the temporary river beds they had dug shallow wells and lined them with stones.

In Jaboticaba village (Bahia) the people had planted enough draught-resistant buffalo grass for hay. In 1998, another El Niño year, people were prepared in terms of their water supplies and had stored enough fodder for the animals. One of the small farmers said: "In the past, we only thought about planting the fields without knowing whether we would harvest or not. At the time when our animals need special care we neglected them although they are our main source of income."



Smallholder farm in Northeast Brazil

What do we have to change in terms of planting?

In good years, that is years with enough rain, the farmers can even have an additional income from their harvests. But what to do to make plants survive between rains? Without regular rainfall, farmers must find methods to avoid evaporation of the soil:

- Most important, slash and burn clearing has to be stopped. Whenever farmers go out into their fields the matchbox has to stay at home. Straw and the dry leaves on the ground collect rainwater and protect the soil from the sun and loss due to evaporation. As time goes by, they rot and turn into layers of humus.

- Animals are also of great importance, since they produce manure, which can be used in the fields. The mixture of aged manure with soil is not only a good fertilizer, but more important in arid regions - it holds back humidity. Since manure collects rainwater it is the most important water reservoir for crops!

There are other rules to follow if farmers want to get a better crop. For instance, they should choose plants capable of resisting long dry periods. In many arid places sorghum is planted, rather than corn, which is still popular even in Brazil's semiarid region. Sorghum is better adapted to the semi-arid climate and yielding much more.

It is also important to plant in leveled furrows (ridge cultivation), thus avoiding soil erosion. The furrows collect runoff water and bring it to the roots of the plants.

The farmers following these rules while planting smaller plots, will harvest the same amount as they harvested with bigger fields, with the only difference, that harvest is almost guaranteed.

Women and Rainwater Harvesting

It is the women who suffer the most during draughts. They fetch the water from the nearest wells, carrying the containers on their heads. They are always trying to find ways to feed their large families. During dry years, the women make survival of their families possible. They keep a few chickens for eggs, one or two pigs are being fed with the leftovers, they use a small plot to plant vegetables, preferably near the water reservoir and watering it with a small can.

After the girls from Cicero Dantas County had received training on water supply, they demand from their future husbands to build water cisterns near their houses in order to spare their wives the daily

fetching of water. The solution of water supply during the dry season makes women's daily lives much easier. Instead of spending lots of time fetching water, women and girls can use this time to plant vegetables, to work in the community or to get further education. "The cisterns are liberating us women from the daily water fetching. At the same time they liberate our community from its dependency on the water trucks sent by our politicians", said Dalva from a village in Uauá County (Bahia).

Examples showing the practical results of this holistic approach

Alcides, a small farmer from the city of Uauá (Bahia), who used to raise goats and plant corn was about ready to migrate to São Paulo, the 2000 km distant economic capital of Brazil. Nearly half the village had moved to São Paulo in the course of the past thirty years. It was mostly men who left, while women stayed behind with their children. Many people, especially the young, are dreaming of life in the city, preferring it to work on the farm. Right at that time, Alcides' brother convinced him to participate in a course on appropriate life in an arid region.

Alcides was so enthusiastic about this course that he gave up on the idea of migrating to São Paulo. Instead he became one of the most active defenders of life in the Northeast. He built a big cistern near his home. Before the last rainy season, he marked the contour level and plowed a half acre ridge, where he planted sorghum and beans. The rain no longer washed away the soil and the water was held back in the horizontal furrows. This way of cultivating the soil prevents erosion. Next year, Alcides will be able to plant the same plot without having to burn the natural thornbush vegetation. His neighbors will follow his example.

Teachers who had participated in courses on appropriate technology in the Northeast, became aware that the books used in schools were about life in the cities in Southern Brazil and didn't reflect the reality of the rural Northeast. They thought that books should be changed according to the needs of the rural population. Thus children would not be educated for city life, but rather be prepared for life in the country side. In the county of Curaça (Bahia), the first rural communities to receive this training, primary school teachers are being instructed to make teaching about life adapted to the semiarid climate part of their curriculum. Teaching mathematics, children no longer take the examples from urban surrounding, but they calculate the amount of rainwater falling on a roof and are asked to figure out if it will be enough to supply their families with water for the dry season, given a certain water consumption. In other schools the project led to the introduction of a new curriculum for fifth to eighth grade and new teaching aids have been produced.

Evaluation and outlook

Until now there hasn't been a political will to change the situation of the people in the semiarid zones of Brazil. Normally the politicians representing the interests of the big landowners want to control the access to water sources. They have no interest in people taking their own destiny in hands. There are a handful of politicians - mostly from the opposition - who have taken an interest in learning about alternatives.

The governmental rural extension services have been mostly at the service of the big landowners and irrigation farmers. But there are some hopeful exceptions: The official Agricultural Research Center for the Semiarid Tropics (CPATSA) from the Brazilian Agricultural Research Agency (EMBRAPA) has been working with appropriate technology in rainwater catchment systems for years. For this center our experience with imparting basic knowledge among the rural people in the Northeast is important for spreading these technologies.

Usually there are no public funds for small farmers to receive further training nor is there money for projects to build cisterns on a large scale. But there are a few exemptions: In counties like Curaçá, one per cent of the local budget is used for constructing cisterns and shallow wells. In other counties, politically organized people are trying to change the local laws to guarantee the whole rural population's water supply with cisterns by the year 2005. In other villages, families received loans from aid agencies for building cisterns and paid back their loans by selling goats. This money was put in a communal fund, which was used for building more cisterns. This way thousands of cisterns were built.

There are also a number of similar rural projects like IRPAA underway in various regions of the Northeast. Some NGOs, labor unions and smallholder associations joined to a network called "mutirão" ("neighborhood help") and have taken up the same methodology, cooperating directly with small farmers, including such topics as rainwater supply and climatic conditions. All these projects have started to cooperate more closely with each other in order to work out a common strategy and program. Labor unions in some counties have made the struggle against the rural exodus part of their demands, various communities are elaborating plans to supply rural people and animals with water during the dry season. Such different organizations as UNICEF, Charities of Brazil and other church affiliated groups are engaged in these projects. A pilot project, which includes water supply, animal raising, rain-fed agriculture, commercialization, education among the rural population is planned in three counties of Northern Bahia – Curaçá, Uauá and Canudos. The positive results of this work have been an encouragement to many people in Northeast Brazil.

Families living in isolated areas with no access to an organized community might not be able to resist migration to the cities or finding employment as cheap labor in irrigation projects. On the other hand, rural people organized in grass-root communities who know about the semiarid climate and appropriate production methods will be ready to fight for just rainwater catchment systems as well as for all the other aspects facilitating and enriching life in the Northeast. Looking at the extension of the Northeast makes one realize that there is still an immense task ahead. Certainly the experiences of other countries presented at the 9th IRCS Conference will encourage us to continue on this path.

Food Security Through Rainwater Catchment

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Abstract

Harvesting rainwater, from the rooftop and on the surface, has been part of Indian social and cultural life since antiquity. A wide range of hydraulic systems to suit diverse ecological regimes exist in the country. Ancient texts, inscriptions, local traditions and archaeological remains bear testimony to a rich tradition of rainwater harvesting. Some evidence of advanced water harvesting systems can be traced from pre-historic times as well. The *Puranas*, *Mahabharata*, *Ramayana* and various Vedic, Buddhist and Jain texts contain several references to canals, tanks, embankments and wells.

With the settling societies being largely agrarian, written texts are loaded with reference to irrigation systems. Kautilya, a minister of King Chandragupta Maurya (321 – 297 BC), gave vivid reference of irrigation with water harvesting systems in his historic politico-administrative treatise called the *Arthashastra*. Kautilya's treatise is often compared to Machiavelli's *The Prince*. He pointed out that not only people were knowledgeable about water regimes and the hydrological cycle but that the state was often supportive of such ingenious local solutions.

Archaeological evidences indicate that this so-called 'water wisdom' was unique to the development of civilizations on the Indian subcontinent. It was all a case of learning to live with nature. The first humans, who came to inhabit the Indian subcontinent, must have soon realised that water was a very ephemeral resource for them. With the monsoon season being limited to three months, people knew that sustaining life will require extending the bounties of the wet to dry months. The diverse water harvesting systems, developed to suit some 15 different ecological regions, are the net result of human ingenuity.

STATE OF DECLINE

Today, this rich socio-cultural tradition of rainwater harvesting is in a state of abject neglect. At several locations, these socio-engineering structures have been reduced to objects of archaeological relevance only. Tragically, the systems that sustained societies for centuries were sacrificed in the name of 'development' during the past 200 years only.

The British, who ruled the country for little over two centuries, set the cycle of destruction in motion. In an effort to earn revenue from the society, the water management systems were brought under the control of the state. However, within few decades the results of this control started surfacing. Faced with recurrent famines, the British invited their top irrigation engineer Sir William Willcocks to advise them on why India was suffering from recurrent droughts.

To their utter surprise, Willcocks advised them to learn from the natives. But the adamant colonialists paid no heed to the advice and continued with their sinister move of applying engineering solutions to the ecological problem. The Indian bureaucracy did not learn much from the follies of their predecessors. On the contrary, it increased investment in the water sector and brought it to the present state where the number of villages suffering from water scarcity are increasing by the day. India's ability to manage water has taken a severe beating at the hands of none other than its own water bureaucracy.

Water management is a complex social exercise. It is managed by individual farmers as well as by communities in irrigation schemes and watersheds. The advent of water bureaucracies brought decline of the social institutions which, for centuries, had designed, developed, managed and protected their water systems. Unless the social institutions are revived and the control of water systems handed over to them, the poor will continue to be at the receiving end of this water crisis.

THE REGION OF HOPE

Although several attempts have been made in the past few decades in reviving the traditional water systems, one such experiment that stands out belongs to a region on the west coast of India – in the state of Gujarat. The Saurashtra region resembles an inverted saucer, surrounded on three sides by the sea. The region has about 4700 villages, nearly 25 per cent of the entire state, and a population of some one million people.

Normal monsoon brings between 300 and 500 mm of rain. If the rain gods smile, the villages get plenty of water and good crops of groundnut, cotton and millet. However, every 2 to 3 years the monsoon fails over the region. Between 1985 and 1987, the region faced the worst drought of the century. The Government of Gujarat mounted relief work – food packets were distributed and trains loaded with water were brought from adjoining districts. Lasting solutions, however, were neither developed nor found feasible in the given geo-hydrological regime of the region.

Irrigation in the region is largely done through open irrigation wells – each well has on an average a diameter of about 6 metres and contains between 350,000 to 400,00 litres of water. During the drought period, the water level in these wells receded to depths of more than 300 feet. The wells that were the most reliable source of irrigation water failed to meet the farmers' demand during the peak period. Lifting water from such depths was not only costly for the farmers but beyond their means as well. Like in other regions, the social institutions that nurtured such community irrigation systems were eroded beyond recognition for any rearguard action.

REVIVING SOCIAL INSTITUTIONS

Contrary to conventional developmental process driven by external aid and supported by new institutions, a social movement called *Swadhaya* (meaning self-study) has brought community-controlled and community-managed model of sustainable natural resource use to fore. Within less than 50 years since it was launched, the movement has focussed its attention on revitalising the dominant *Vedic* thought of *indebtedness*. Missing from the conventional development vocabulary, this thought has triggered community response to social crisis. Communities in the affected villages have embraced the thought in transforming their lives.

Swadhaya has taught people that the ultimate good of man consists in offering his most developed life at the feet of nature. Paradoxical as it may sound, self-offering is the only true freedom. To submit oneself to the sole authority of nature is to free oneself from the slavery of the world. This genuine independence removes the sense of beggary from one's mind. In *Swadhaya*, poverty is a state of mind. Through devoted self-offering, the people who practice *Swadhaya* repay their debt to nature (for granting them free access to resources like air, water, clouds, sun, sky etc). Interestingly, all the villages in Saurashtra follow this practice. In all, some 100,000 out of 550,000 villages in the country practice *Swadhaya*.

The movement has had profound impact on the social life in Saurashtra. Nurtured over the past 50 years, the movement has helped to rebuild the social institutions of mutual help and dependence. Villagers offer one day of their earnings each month to a social fund which, over the years, has grown into large deposits. It surprises visitors to discover that most villages in the region have deposits in excess of US \$ 2 million. Notably, people make the entire contribution themselves. From within the community, the custodians of this fund are chosen.

SUPPORTING INGENIOUS SOLUTIONS

With community resources and the spirit of self-offering, villages in the region have recharged over 100,000 irrigation wells and created some 1,000 large water tanks. The total investment by the communities in reviving the water harvesting systems is well over US \$ 2.5 million for well recharging and US \$ 200 million for the tanks.

The technology of recharging irrigation wells is simple. A 6 x 6 foot filter tank is dug close to the well and filled with 2-3 layers of pebbles of different sizes. The bottom of the tank is fitted with a cement pipe – about 9 inches in diameter – to guide the water into the well. Rainwater comes into the filter tank through open channels and gushes into the well through a pipe. Cost of this installation varies from location to location, on an average each installation costs around US \$ 25.

Ramjibhai Manjibhai, a small farmer of Dhoraji, is known to have conceived this simple ingenious solution. He diverted run-off water into his open well. Neighbours warned him

against silting of his well. Some silt did collect but the same led him to design a silt trap. Saurashtra has enough rain during monsoon to recharge the wells. As soon as people learnt about the success of the system, village after village adopted the system of harvesting rainwater to recharge the parched wells. Creation of large tanks in the region has further helped in increasing the water table and recharging of the wells.

The recharging method has been found suitable for the irrigation wells. If water remains in these wells during the lean season, farmers can be sure of two more crops. A study by the Department of Economics, Saurashtra University has revealed that due to revival of irrigation wells, the region could harvest crops worth US \$ 400 million each year.

CONCLUSION

Through the revival of social institution and the culture of self-help, *Swadhaya* has demonstrated that dependence brings despondency. Only by overcoming self-pity and bringing in the element of self-pride, can the communities manage and control their destinies.

Swadhaya is an unending saga of human endeavour to bring stability in thoughts and actions. Through the process of self-analysis, self-study and self-offering, it has nurtured a movement anchored by some 100 million people worldwide who have found a new meaning in living in harmony with the given situation. Drawn from different strata of society and from diverse ethnic groups, a new community is surging ahead to take control of its own destiny and bring about the much-needed social and ecological stability.

Rural People and Water Resource Management

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Abstract

In today's Iran villagers' participation is regarded as one of the most important topics in the development and transformation of certain rural regions. Explaining the necessities, policies and practical methods of villagers' participation in watershed management is regarded as a helpful and important solution for Iran's governmental organizations, such as the Ministry of Jahade Sazandegi. The purpose of this research is to evaluate people's participation in watershed management.

This study wanted to define people's participation in the programs related to water resources management. The conclusion reached was that watershed management combined with governmental support and peoples' participation is necessary to ensure sustainable development and environmental protection. It is also very important to encourage rural inhabitants to participate in watershed management programs and to establish watershed cooperative associations.

Villages in Iran

Throughout history environments have been strongly influenced by peoples' social behavior. In Iran considerable research has been carried out on watershed management but very little on the role of people.

Today, villagers' participation is regarded as one of the most important topics in the development and transformation of certain rural regions. Explaining the necessities, policies and practical methods of villagers' participation in watershed management is regarded as a helpful and important solution for Iran's governmental organizations, such as the Ministry of Jahade Sazandegi. The purpose of this research is to evaluate people's participation in watershed management.

Among the goals of this research are:

- Determining the methods of making people participate in planning, decision making and carrying out the rural development.
- Achieving a suitable system to encourage peoples' participation.
- Improving knowledge, information, and the culture of cooperation in solving the village's watershed problems.

The case study:

Fars province is located in the south of Iran. It covers 120,612 square kilometers and its population is 3,817,036, of which 41 % live in rural areas. The average altitude is from 20 to 1,500 meters above sea level and there are great climatic variations. Fars Province is one of the regions with loss of soil and water. The biological environment is worsening gradually and the land's productivity is decreasing. Based on these factors, the provincial government has been paying attention to the watershed management to control soil and water loss. The government's main target is cooperation with the rural inhabitants.

Many of the traditional projects have been working successfully on a collective base for several years.

These projects include: Irrigation channels, Qanats (Subterranean canals), flood irrigation, flood spreading farming systems and Ab-Anbars (water tanks).

With the help of a questionnaire, the villagers were asked about their role in watershed management. The questionnaire of this study consisted of 18 questions. 25 questionnaires were sent to the Jahade Sazangeji's offices. 80% of questionnaire were answered. The survey was carried out by mail between February 10, 1999 and March 10, 1999. The statistical analysis of the questionnaire is done using EXCEL.

The following questions were asked:

What are peoples' support and active participation in watershed management?

What are the practical methods in this regard?

What kind of organizations can be suggested to increase people's participation?

What is the government's role?

How to make sure that survival in the countryside is in accordance with nature and helps to protect the watersheds?

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Strategic Water Development in Rural Kenya-- The Importance of Rainwater Catchments

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Abstract

80% of Kenya's population is rural and agriculture based. The majority of rural Kenyans rely on small-scale (subsistence) farming. The economic importance of rainwater catchment combined with smallholder irrigation has not been properly evaluated for Kenya, hence the investigation presented in the present paper.

The investigation adopts a systematic, integrated and strategic approach (SISA) to evaluate the role of rainwater catchment in rural Kenya. The emphasis is on subsistence and appropriate technologies as well as management of natural resources (particularly land and water).

In conclusion, recommendations are presented on how proper strategies can result in promotion of rainwater catchment and utilisation for food security in the new millennium.

Introduction

Kenya has a territorial area of 592,000 km² of which 2% is occupied by water bodies, 15% by arable lands and 83%, classified as arid and semiarid, in other words, ASALs. The mean annual precipitation in Kenya is 621mm although some areas enjoy over 2000mm and others less than 200mm per year (JICA, 1992).

Agriculture and Food Security

Agriculture is the mainstay of Kenya's economy and accounts for 30% of its total GDP. Agricultural products earn more than 70% of its foreign exchange and this sector provides employment for 3 to 4.5 million people. Over half of the total labour force of Kenya is engaged either directly or indirectly in agriculture. Kenya has not recorded sustained growth in the agricultural sector for the last eight years and, in fact, has recorded negative growth for the first three consecutive years of this decade. A decade or so ago, 76% of Kenya's population lived in just over 10% of the land considered arable while 24% of the population lived in the ASALs making up 83% of Kenya's land mass. (MRDASW, 1992). At present, an estimated 30% of Kenya's population is living in the ASALs.

Climatic cycles frequently adversely affect crop and livestock productivity in Kenya. Rural communities, particularly in the ASALs, regularly lose their livestock (often their only source of livelihood) and their crops, to floods or severe droughts.

Irrigation and Agriculture

Kenya promotes irrigation as the main technology required to increase food production. Traditional rainwater related irrigation has been practised in Kenya for some centuries, mainly along the Tana, Kerio and Perkerra rivers. On the Tana flood plains, irrigation was and still is based on seasonal floods while furrow irrigation is practised along the Perkerra and Kerio rivers.

Formal irrigation development was started in the country by the British administration. With the construction of the Kenya - Uganda railway between 1901 and 1905, many workers were imported from India. Each of these workers was given about 30 hectares of land to produce vegetables (using surface water) for the railway crews in the Kibwezi/Makindu area. With the completion of the railway and start of the Second World War, many of these workers turned to retailing and abandoned agriculture. A second attempt at formally organised irrigation was started during the Second World War, and was concentrated in the Naivasha, Karatina and Taveta areas for horticultural products and shores of Lake Victoria for rice production. These activities necessitated by the need to feed British troops in East Africa, ceased when the war ended. (Kimani, 1984)

Between 1952 and 1960, Mwea, Ishiara, Perkerra, Hola and Yatta Irrigation Schemes were implemented under a land improvement programme which aimed to rehabilitate prisoners and/or detainees. After 1960, research findings became available on the profitability of irrigated coffee and tea production, resulting in progressive investments in sprinkler irrigation for large-scale plantations for these crops. In 1966, the Government of newly independent Kenya set up the National Irrigation Board (NIB) which arranged for small-scale tenant farmers to be allocated 1-1.6 ha of irrigated land for crop production. Investment in private small-scale irrigation on the basis of individual initiative began later as a consequence of rapid growth of urban areas that created a ready demand for fruits and vegetables. Submitting to the poor history of formal irrigation, the government finally gave approval to Small-scale irrigation in 1970s (Kimani, 1984).

Small-scale irrigation

Small-scale irrigation systems offer a way of boosting crop yields among small farmers. In mid 1980's, IFAD (International Fund for Agricultural Development) in collaboration with FAO (Food and Agriculture Organisation) investment centre conducted a review of the present state of irrigation in sub-Saharan Africa with special emphasis on small-scale water control schemes in this region (FAO, 1986). This review showed that irrigation in Kenya is not traditionally a part of the average farmer's daily life, so shortage of skills and knowledge about irrigation is a major constraint to the promotion of this technique. However, a few traditional small-scale irrigation systems including flood, swamp, surface and low-lift irrigation have been developed in Kenya, largely without government support

Importance of Small-holder Production

Table 1 shows the gross marketed production from small and large farms in Kenya between 1974 and 1991. The increasing importance of small farm crop production is clear from these statistics.

TABLE 1. GROSS SALE TO MARKETING BOARDS FROM LARGE/SMALL FARMERS (K£ x 10⁶)

Year	Large farms	Small farms	Total	% share of small farms
1974	73.4	75	148.4	50.6
1975	71.8	90.1	162	55.6
1976	122.1	128	250.0	51.2
1977	206	208.5	414.6	50.3
1978	147.2	186.2	333.4	55.8
1979	148.2	172.5	321.0	53.7
1982	216.67	232.25	448.92	51.7
1983	271.34	284.10	555.44	51.2
1984	386.22	402.53	788.94	51.0
1985	346.63	409.31	755.94	54.2
1986	515.53	422.79	938.32	45.1
1987	432.07	385.13	817.7	47.2
1988	500.41	445.33	945.74	47.1
1989	508.32	494.88	1003.20	49.33
1990	481.77	617.30	1099.07	56.17
1991	489.53	722.17	1211.70	59.60

Source: Economic survey reports of Government of Kenya for 1979, 1980, 1981, 1987, 1989, 1990, 1991, 1992.

The Ministry of Agriculture classification of land in Kenya is based on annual rainfall and comprises 4 categories as shown in Table 2.

TABLE 2. AGRICULTURAL LAND CLASSIFICATION

Item	High potential land 857.5 mm or more annual rainfall	Medium potential land 735mm to 857.5mm annual rainfall	Low potential land less than 612mm annual rainfall	Other	Total
Land area in ha x 1000	6,785	3,151	42,105	4,867	56,908
Percent of total area	11.9	5.5	74	8.6	100

Source: JICA, 1992

Lack of water and fertile land are the key constraints to food security in Kenya. Proper use of rainwater can have a positive effect on conservation of both these resources. The amount of rainfall and availability of water is the most important factor in view of agricultural production. Based on the balance between irrigation demand and mean monthly flows, according to the JICA (1992) study, Kenya has about 471,000 hectares of land available for upland crop irrigation and 340,000 hectares for lowland (paddy) crop irrigation using surface and ground waters as shown in Table 3. Significantly, rainwater harvesting for agriculture was ignored yet this is an important option for smallholders and can be linked to smallholder irrigation.

TABLE 3. IRRIGATION POTENTIAL IN KENYA

Crop	Surface water	Groundwater	Total
Upland	469,600	1,514	471,114.00
Lowland	338,300	1,038	339,338.00

Source: JICA 1992

Irrigation Strategy

The water master plan (JICA, 1992), recommends that priorities for further irrigation development should be given to:

- Small-scale irrigation (low-cost of development)
- Irrigation of areas adjoining densely populated districts (many beneficiaries)
- Water deficient areas where agriculture is not possible without irrigation (food security in strategic areas).

The proposed Water Development Plan to the year 2010 prepared by JICA, (1992) recommends development of 140 small-scale irrigation schemes covering about 7000 hectares of land. The estimated cost for irrigation development was set at US\$ 11 million for these 140 small-scale irrigation schemes. The real question here is whether more could not be achieved with the same amount of money if the emphasis was shifted to run-off farming, land reclamation in Arid and semiarid lands, floodwater harvesting, micro watershed management and other rainwater harvesting technologies?

Rainwater harvesting – a practical smallholder water option?

Well-balanced physical and economic development of Kenya calls for comprehensive, integrated and efficient water resources planning for the small landholder. Potentially, rainwater collection in agriculture has far greater importance - for more people's livelihoods – than rainwater for domestic supply

Many examples of appropriate rainwater harvesting technologies for smallholder agriculture exist. In regions with most exacting climatic conditions of limited rainfall in a hot summer season, strategies have been developed based on storing more water in the soils, and sometimes postponing crop planting until highest evaporative demand is past. This can

include building high bunds or banks along contours so that extended strips of land may be inundated to a depth of as much as a metre. This water slowly infiltrates the soil or evaporates when a crop is planted as the water subsides. By this time, the season of highest temperatures passes so the crop is able to grow under conditions where evaporative demand is relatively modest.

This technique is used in Sudan where quick maturing millet is planted immediately the water left by a storm has subsided. The crop grows and matures in 80 days, using the moisture that has been induced to infiltrate the soil behind the bunds (Wickens and White, 1978). Similar techniques are used in other tropical, arid or semiarid areas where the rains come in summer, including parts of Southern Pakistan, Iran, China and India.

With regard to runoff farming as opposed to the exploitation of floodwater, the inundation method has been developed to its highest level of sophistication. Techniques differ in detail, but the principle is to allow runoff to collect behind a bund and leave the water standing until the planting date for the crop approaches. Then the land is drained and the crop is sown.

A third way of exploiting the water is to take advantage of infiltration from the inundated land to the water table beyond the bund.

Rainwater Harvesting for Food Security in Kenya

Kenya has a well-developed agricultural extension system stretching from the Central Government to the Sub-Location level. It also has Research, Government, Inter-Governmental, Non-governmental and private organisations that are working on appropriate technologies for agriculture. In spite of this, Kenya continues to suffer serious food shortages. Clearly it is time to review present land and water use policies and seriously consider options not investigated earlier. Rainwater harvesting for conservation of natural resources and reclamation of land for food production is one of these options.

Much information on the successful use of rainwater for increased food production and effective, sustainable rainwater harvesting technologies is available. The country now needs to put in place a strategy to identify, adapt and promote the opportunities that arise from this information. Kenya receives relief food, in particular for the people of arid and semiarid lands (UNDP-GOK, 1998). The starting point for an integrated water and land use strategy might be a pilot strategy for the ASALs.

The components of an integrated system for conserving and providing water in arid lands must concentrate on meeting water demands and increasing precipitation in such areas. The matrix presented in Figure 1 contains a prioritised integrated water demand framework for the ASALs of Kenya. The distinctive characteristics affecting water/land use by pastoral communities in Kenya form the basis for this systematic and integrated framework.

Figure 1. Water and land use priorities in ASALs of Kenya

Population Group	Natural Resource Required And Priority						
	Water use			Land use			
	Domestic	Livestock	Agriculture	Human needs	Rangeland	Farming	Other/Forest
1. Traditional pastoralists	1	2	3	1	2	3	4
2. Modern sedentary pastoralists	1	2	3	1	2	3	4
3. Traditional ASAL farmers	1	3	2	1	3	2	4
4. Newly integrating groups of farmers, etc.	1	2	3	1	4	2	3

Measures that can help to increase precipitation include:

Protection and expansion of forest and plant cover to increase water storage, to control runoff and promote transformation of water into vapour.

Increased water storage through management of natural structures such as aquifers and by constructing manmade structures such as dams, rock catchments or contour bunds to harvest rainwater.

Improved irrigation efficiency by conversion /reuse of surface and ground water.

Optimisation of irrigation through efficient water distribution and use, storage before seeding as well as adjustment of irrigation times etc.

Increasing the distance of water transfer

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Captação e Aproveitamento de Água de Chuva na Produção Agrícola dos Pequenos Produtores do Semi-árido Brasileiro: O Que Tem Sido Feito e como Ampliar Sua Aplicação no Campo

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Resumo

O trópico semi-árido brasileiro ocupa uma área de aproximadamente um milhão de quilômetros quadrados onde vive vinte milhões de habitantes. A maioria dos produtores dependem da agropecuária de subsistência, caracterizada por explorar pequenas áreas, utilizar pouco capital e obter produtividade a qual é instável e baixa. Utilização errada e abusiva dos recursos naturais pode comprometer, a médio e longo prazo, a sustentabilidade da agropecuária explorada nesta região. O regime pluviométrico apresenta alta variabilidade e os solos são predominantemente pobres.

O Centro de pesquisa Agropecuária do Trópico Semi-Árido (CPATSA) foi criado pelo governo federal em 1975, e tem como objetivo desenvolver tecnologias que permitam melhorias na qualidade de vida dos habitantes desta região. Um compreensivo programa de pesquisa sobre manejo de solo e água para pequenos produtores tem estado em atividade desde 1977, o qual é apresentado neste documento. Os principais tópicos do programa são: indução de escoamento superficial, coleta de chuva, agricultura de vazante, irrigação de salvação, barragem subterrânea e cisterna para armazenamento de água para o consumo humano. Significativos avanços no desenvolvimento destas tecnologias tem sido alcançados. Todavia, existe o reconhecimento por parte do CPATSA que é necessário se trabalhar com mais eficácia na difusão de tecnologia. Além disso, se se pretende desenvolver uma agricultura de base sustentável no trópico semi-árido brasileiro, a abordagem de sistema de produção, incluindo questões sociais, ambientais e econômicas, é de fundamental importância.

Introdução

O trópico semi-árido brasileiro, perfazendo 1 milhão de km², é formado por um aglomerado de ambientes, que se diferenciam quanto aos principais componentes que constituem os recursos naturais. Nesta região, vivem mais de 20 milhões de habitantes.

Agricultura familiar de subsistência baseada na oferta de chuva, extrativismo dos recursos naturais, capital financeiro muito limitado, e quase ausência do uso de tecnologias melhoradas, são características predominantes no processo produtivo. Portanto, baixa produtividade e produção instável são os resultados alcançados pelos pequenos produtores.

Do ponto de vista dos recursos naturais, as áreas semi-áridas brasileiras apresentam solos rasos, com baixas fertilidade, infiltração, capacidade de retenção de umidade e matéria orgânica. Em adição, eles estão submetidos a chuvas de alta intensidade, intercaladas por longos períodos de estiagem, alto potencial de erosão hídrica e elevada taxa de evaporação. Na maior parte desta área, chuvas esporádicas são as únicas fontes de água para a

sobrevivência, visto que, a formação geológica que dá origem ao solo é cristalina, com baixo potencial para acumulação de água subterrânea.

Os sistemas de produção tradicionais, praticados pelos pequenos produtores do semi-árido brasileiro, compreendem cultivos de subsistência e produção animal. A consorciação de culturas é uma prática comum, cujo objetivo é reduzir os riscos de perdas. Milho e feijão estão entre os principais cultivos anuais. Para as áreas com precipitação ao redor de 400 mm por ano, a chance de colher um rendimento superior a 50% do potencial produtivo, é de apenas 30% (Porto et al, 1983). Quando se trata de milho, esta chance ainda é menor. Por estas razões, os pequenos produtores não têm conseguido nem mesmo satisfazer suas necessidades básicas.

No trópico semi-árido brasileiro, a ocorrência de secas não é novidade, existindo registro deste fenômeno desde 1559 (Medeiros Filho e Souza, 1983). Só nas últimas décadas, a região já sofreu os efeitos de quatro secas severas, sendo que uma delas durou cinco anos (1979-1983). Portanto, é necessária a introdução de tecnologias para conviver em harmonia com este cenário.

O Centro de Pesquisa Agropecuária do Trópico Semi-Árido (CPATSA) - hoje Embrapa semi-árido foi criado em 1975 e está vinculado à Embrapa, que, por sua vez, pertence ao Ministério da Agricultura e do Abastecimento. O objetivo do Centro é gerar e adaptar tecnologias que permitam melhorar a qualidade de vida dos produtores, sem, contudo, danificar o meio ambiente. Durante todos estes anos, a Embrapa semi-árido tem desenvolvido pesquisa sobre irrigação, captação e aproveitamento de água de chuva, cultivos, produção animal, mecanização agrícola, meio ambiente e sócio-economia. Atualmente, o Centro possui um grande acervo de informações geradas.

Este documento tem como objetivo apresentar, de forma resumida, a proposta de pesquisa que tem sido desenvolvida na Embrapa Semi-Árido sobre Captação e Aproveitamento de Água de Chuva, além de apresentar sugestões para que pequenos produtores possam ter mais acesso a uma agropecuária sustentável.

Captação e Aproveitamento de Água de Chuva: a base para o desenvolvimento

A necessidade de se implementarem alternativas estratégicas que possibilitem maximizar a utilização dos recursos pluviais disponíveis no Nordeste, reduzindo o elevado risco da exploração agrícola em áreas dependentes de chuva, constitui o fundamento básico para os estudos que a Embrapa Semi-Árido vem desenvolvendo.

O programa, em seu início, foi baseado em sugestões técnicas, consultorias e na literatura nacional e internacional sobre trópicos semi-áridos como: Rebouças & Marinho (1972), Duque (1973), Guerra (1975), NAC (1974), Water Harvesting Symposium (1975) e ICRISAT (1975-76). As principais técnicas estudadas têm sido: Cisterna, barreiro para irrigação de salvação, captação “in situ”, exploração de vazante e barragem subterrânea.

Tecnologias

A seguir, são apontadas as principais tecnologias trabalhadas:

Cisternas rurais

Um dos graves efeitos da seca, nas regiões áridas e semi-áridas, é a escassez de água potável para o consumo familiar. À medida que as fontes habituais de água vão se esgotando, as famílias passam a utilizar as não habituais, geralmente partilhadas com animais, agravando a situação devido à péssima qualidade da água, que contribui para uma maior incidência de doenças no meio rural.

A técnica de captação e armazenamento de água de chuva para o consumo humano na pequena propriedade rural tem sido usada secularmente nas zonas urbanas, porém foi pouco difundida no meio rural, particularmente no Nordeste Semi-Árido. Consiste em aproveitar os telhados das casas como área de captação e os depósitos ou cisternas como recipientes para armazenamento.

Os estudos sobre cisternas foram iniciados em 1979, sendo a Embrapa Semi-Árido uma das primeiras instituições governamentais a estudar cientificamente o assunto. Várias propostas de formas e tipos de materiais utilizados na construção da cisterna propriamente dita e da área de captação foram avaliadas.

Atualmente, existem várias propostas disponíveis de formas e processos utilizados para construção de cisternas. O modelo mais popular é a cisterna de placas pré-moldadas, conforme Figura 1. Várias ONGs têm programas de treinamentos para ensinar como fazer este tipo de cisterna.

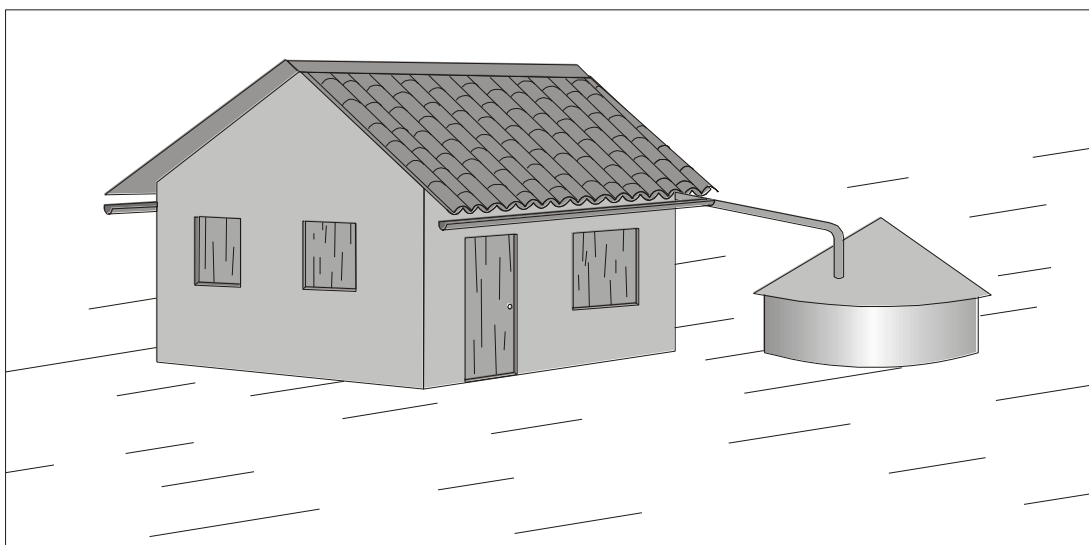


Figura 1. Desenho esquemático de cisterna de placa implementada na zona rural.

Vários governos estaduais e municipais têm hoje em seus programas de ações, a construção de cisterna para o armazenamento de água para o consumo humano das famílias que vivem na zona rural. Estima-se que nos últimos cinco anos foram construídas mais de

cinquenta mil cisternas no semi-árido. Esta tem sido uma grande conquista obtida pela Embrapa Semi-Árido.

Barreiro para “irrigação de salvação”

A captação e o armazenamento de parte do escoamento superficial que se forma quando da ocorrência de chuvas, e sua utilização posterior como irrigação de suplementação, pode reduzir, significativamente, as chances de perda das colheitas de cultivos anuais tais como milho e feijão.

Os estudos de utilização do escoamento superficial para irrigação suplementar, neste caso definida como irrigação de salvação, tiveram início em 1975 e foram a primeira linha de pesquisa desenvolvida pela Embrapa Semi-Árido. A hipótese inicial era de que com 100mm extras de água de chuva captada e armazenada, para cada hectare cultivado com o consórcio feijão e milho na proporção 2:1, as chances de colheita saíam de 10 a 30% para 70 a 80%, em áreas com totais anuais de chuva entre 400 e 500mm.

As altas taxas de evaporação reduzem a eficiência de utilização de água de chuva quando armazenada superficialmente, principalmente, para as localidades em que o período de chuva coincide com o de temperaturas elevadas. Com o objetivo de minimizar estas perdas, a Embrapa Semi-Árido introduziu, no sistema, o conceito de **reservatórios com compartimentos**. Esta idéia foi inicialmente desenvolvida por Cluff (1977) e nas condições do semi-árido brasileiro tem demonstrado ser um método eficiente para armazenamento de água em locais onde os reservatórios necessitam ter pouca profundidade. A Figura 2 apresenta uma visão esquemática do sistema.

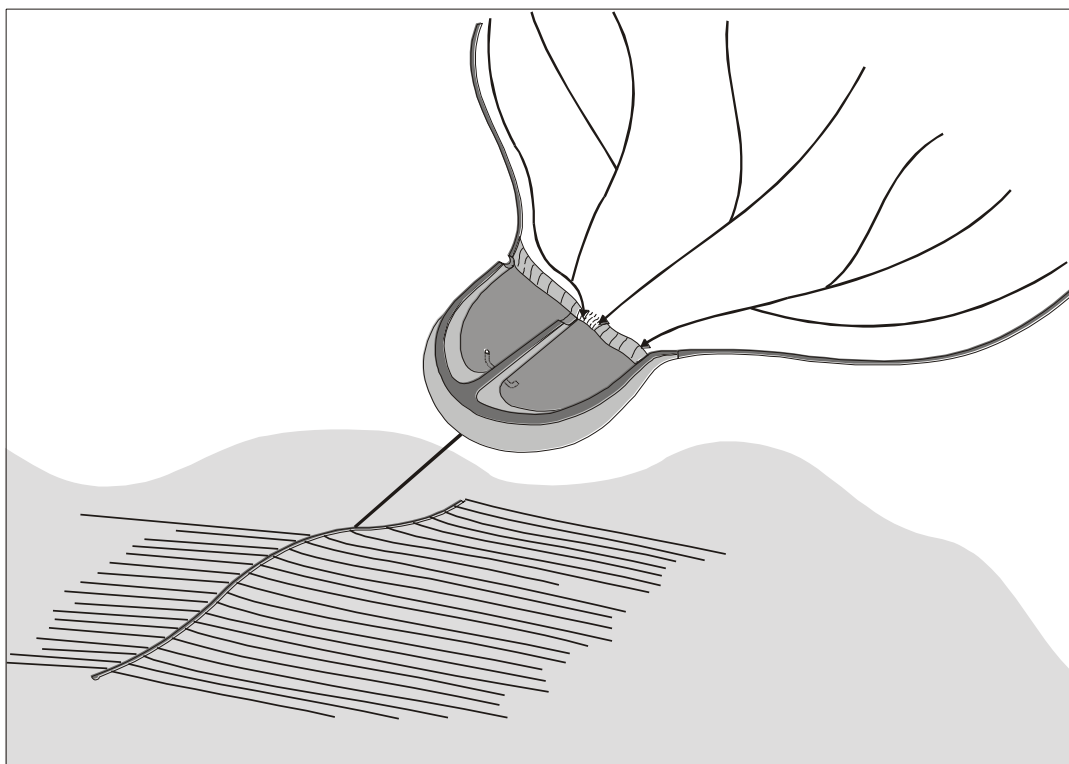


Figura 2. Desenho esquemático do sistema desenvolvido pela Embrapa Semi-Árido para irrigação de salvação.

A eficiência do barreiro para uso de irrigação de salvação tem sido comprovada através de um sistema construído na fazenda de sequeiro existente nos campos da Embrapa Semi-Árido, o qual foi construído em 1982. Desde a sua implantação, em todos os anos são realizados plantios de feijão e milho. Até o ano de 1998, ou seja, numa seqüência de 17 anos, em apenas dois anos houve frustração de safras.

Por outro lado, é importante ressaltar que até o momento não se tem informações sobre a utilização em escala desta tecnologia por parte dos pequenos produtores. As razões para isto são duas: 1. a necessidade de áreas significativas, em relação ao tamanho das propriedades dos pequenos produtores; 2. o alto custo de horas-máquinas para a construção mecanizada do sistema. Em geral, em regiões com precipitação de 400 a 500mm anuais, são necessários entre 7 e 10 hectares, e o tamanho do reservatório deve ser de, aproximadamente, 3000 m³. Isto implica num gasto de 60 a 80 horas de trator de esteira.

Captação “in situ”

Através do programa de manejo de solo e água para agricultura dependente de chuva, a Embrapa Semi-Árido tem procurado desenvolver diferentes alternativas de captação e aproveitamento do escoamento superficial, devido à grande diversidade de situações ambientais e sócio-econômicas encontradas em de campo.

Considerando que a aplicação de barreiro para irrigação de salvação apresenta exigências específicas de tipo de solo, topografia e tamanho de área da propriedade, a Embrapa Semi-Árido, a partir de 1980, utilizando os mesmos princípios que fundamentam essa tecnologia, tem desenvolvido várias configurações para captar excedente de chuva no próprio pé da planta (“in situ”). Esta linha de trabalho contempla tanto culturas anuais em fileira, como culturas perenes. A Figura 3 apresenta alguns modelos utilizados.

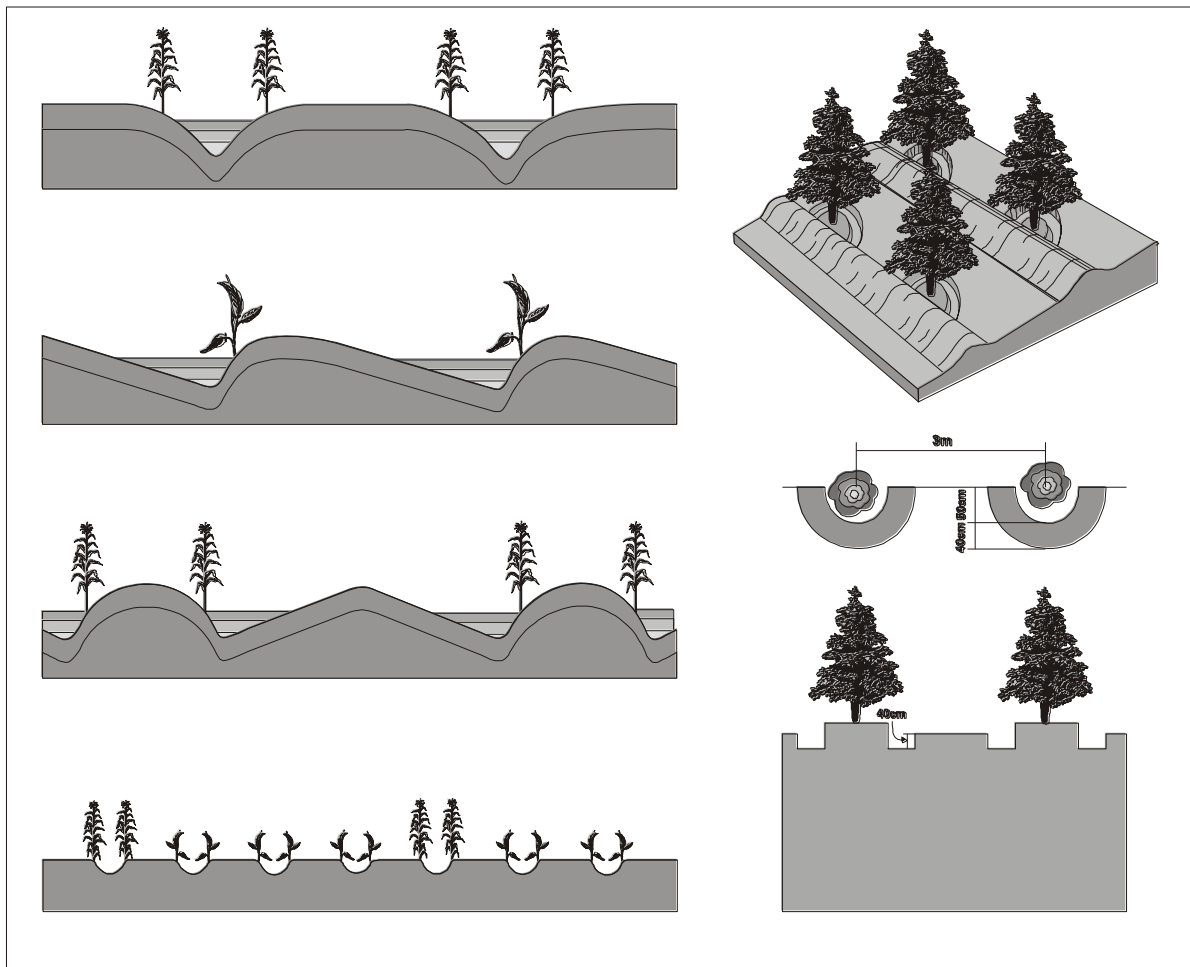


Figura 3. Desenho esquemático do sistema de captação de água de chuva “in situ” para cultivos anuais e perenes

O sistema de captação de água de chuva “in situ” consiste na modificação da superfície do solo, de maneira que o terreno entre as fileiras de cultivo sirva de área de captação. Esta área apresenta uma inclinação que intensificará a produção de escoamento, ao mesmo tempo em que o conduzirá para a porção de solo explorada pelo sistema radicular da cultura.

As principais vantagens desta tecnologia são: 1. a produção de escoamento por unidade de área é mais eficiente; 2. não requer maquinário pesado para sua implementação; 3. é de fácil construção no campo, e 4. os investimentos são baixos.

A capacidade de retenção de umidade do solo é fator extremamente importante para o sucesso desta tecnologia, pois de nada vale produzir um excedente de água, se este não for absorvido pelo solo. Portanto, textura, estrutura, porosidade e profundidade do solo são características indispensáveis no planejamento deste sistema.

Por outro lado, a adição de alguns produtos na área explorada pelo sistema radicular, tais como: adubo verde, esterco, resíduos de culturas e compostos, pode ser feita com a finalidade de melhorar a capacidade de retenção de umidade do solo.

A Embrapa Semi-Árido tem desenvolvido equipamentos simples, de tração animal, destinados ao preparo de solo para a captação de água de chuva “in situ”. Convém salientar que estes sulcos e camalhões modificados são feitos em curvas de nível com 0,4% de declividade.

Não obstante as vantagens apontadas para a captação “in situ”, as avaliações de campo demonstraram que o uso desta tecnologia pelos pequenos produtores é quase inexistente. A explicação dada por eles é a dificuldade de trabalhar com curva de nível. Portanto, há necessidade que a Embrapa Semi-Árido estabeleça estratégias prioritárias para a difusão desta tecnologia.

Exploração de Vazante

A agricultura de vazantes é uma prática típica do Nordeste Semi-Árido, cujo potencial agrícola é ainda subexplorado (Guerra 1975 e Barbosa et al., 1980). Esta técnica consiste na utilização dos solos potencialmente agricultáveis dos açudes, rios e lagos que foram cobertos pelas águas na época chuvosa (Duque, 1973 e Guerra, 1975).

As vazantes são exploradas, principalmente, por pequenos produtores, sendo as espécies mais cultivadas o arroz, o caupi, a batata-doce e o milho (Brasil.MINTER, 1973; Duque, 1973; Guerra, 1975 e Holanda et al., 1981).

A exploração de vazantes, como realizada tradicionalmente, apresenta limitações, devido a um inadequado manejo de solo e água. No que tange ao manejo de solo, o plantio das culturas é feito em covas abertas diretamente no solo, quando o teor de umidade está próximo da saturação, ocorrendo, com muita frequência, o apodrecimento da semente. Quanto ao manejo de água, o problema é o espelho d'água recuar rápido, ressecando o solo e provocando estresse hídrico para o cultivo.

Para reduzir o efeito destes problemas, os pesquisadores da Embrapa Semi-Árido desenvolveram um método simples de marcação de curva de nível, sem a ajuda de equipamento. A técnica consiste em marcar a linha de água que limita a área da bacia hidráulica do reservatório, com piquetes espaçados de 10 em 10 metros. Quando a água baixar, reduzindo a bacia, estará demarcada uma curva de nível base com muita precisão, conforme mostra o esquema da Figura 4. Em seguida, os sulcos e camalhões são abertos com enxada, acompanhando o direcionamento dado pelos piquetes.

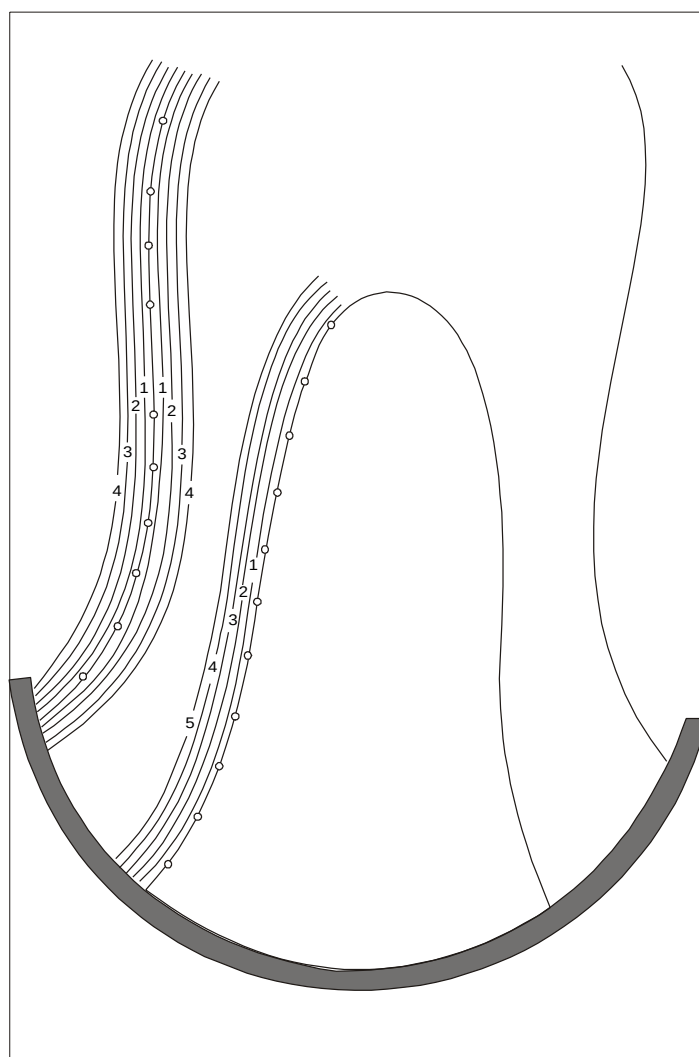


Figura 4. Desenho esquemático de exploração de vazante em açude

A utilização desta tecnologia permite que o plantio possa ser realizado mais cedo, porque os camalhões drenam o excedente da umidade da área de plantio, e o produtor poderá irrigar através dos sulcos formados entre os camalhões, caso a cultura comece a apresentar sintomas de estresse hídrico.

Não obstante os aumentos de rendimento alcançados em cultivos anuais, tem-se verificado insignificante utilização desta tecnologia por parte dos pequenos produtores. Dentre as ações apontadas para aumentar a adoção, sugere-se a necessidade da montagem de um programa de difusão de tecnologia mais agressivo, visto que nunca foi organizado um dia de campo, ou qualquer outro evento com o objetivo de difundir-la. Por outro lado, é reconhecida a relutância dos produtores do semi-árido em trabalhar com curva de nível, que também é parte integrante da tecnologia.

Barragem Subterrânea

A barragem subterrânea nada mais é do que uma estrutura construída para deter o fluxo horizontal de água subterrânea que ocorre no perfil do solo. Através do balanço hídrico, se tem conhecimento do total de chuva que chega à superfície do solo. Parte retorna para a

atmosfera, através da evaporação direta ou pela transpiração das plantas, parte escora na superfície do solo, podendo ser armazenada superficialmente, e parte se infiltra indo formar os lençóis freáticos.

O deslocamento da água, tanto na superfície como no interior do perfil do solo, se dá por conta da formação de um gradiente hidráulico, e este movimento pode se dar no sentido horizontal, vertical ou em ambos. Portanto, o fundamento básico da barragem subterrânea é a criação de um septo ou parede impermeável, transversal ao deslocamento horizontal do fluxo, conforme mostra a Figura 5.

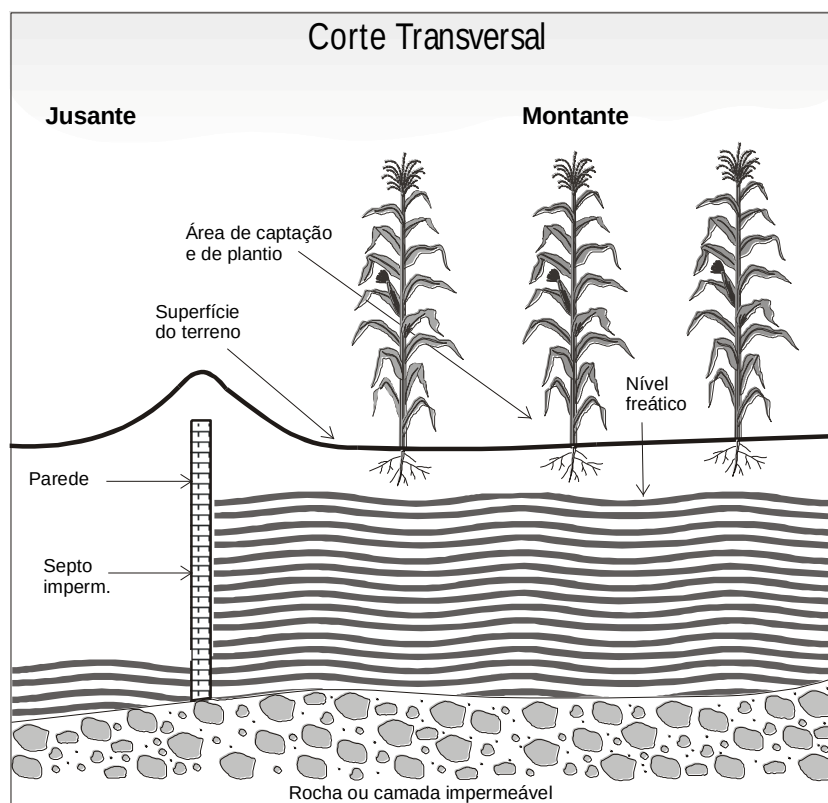


Figura 5. Desenho esquemático de exploração de barragem subterrânea.

Este tipo de barragem só deve ser construída em terrenos de aluvião. Este tipo de solo, formado pela sedimentação das partículas sólidas que são transportadas pelos escorrimentos superficiais durante o período de chuvas, é encontrado de forma irregular no semi-árido, constituindo camadas contínuas ou bolsões de largura e espessura variáveis.

O septo impermeável é o principal componente da tecnologia. Para construí-lo, abre-se uma valeta no aluvião apropriado, com largura suficiente para um homem entrar, ou da pá do equipamento utilizado. Esta valeta deve ter a profundidade limitada pela camada impermeável do perfil do solo, que geralmente é a rocha matriz. No caso do semi-árido brasileiro ela varia de 3 a 8 metros, em geral. Depois de aberta a valeta, coloca-se uma lâmina de plástico na vertical, ou constrói-se uma parede de pedra ou de argila bem compactada. A parede é construída no centro da valeta. No caso do septo feito com plástico ou de pedra, ficam espaços entre o septo e a parede do perfil do solo. Este espaço deve ser preenchido com o

material retirado da escavação. Ao nível da superfície do solo, deve-se construir uma pequena parede, com 0,5 m de altura, para reter o fluxo superficial.

Nos últimos três anos, principalmente na seca de 1998, esta tecnologia foi muito difundida no semi-árido brasileiro. Só no estado de Pernambuco, foram construídas, neste ano, mais de 200 barragens subterrâneas. Um ponto importante a ser ressaltado no projeto implementado por Pernambuco é que em todas as barragens foram construídos Poços Amazonas.

ESTRATÉGIA PARA AMPLIAR A APLICAÇÃO DE TECNOLOGIA NO CAMPO

Desempenho dos atuais sistemas de produção

Não obstante todo o esforço e probidade na geração e difusão de tecnologia levados a efeito pela Embrapa Semi-Árido, no sentido de provocar a transformação do semi-árido, no que se refere ao desenvolvimento da agropecuária dependente de chuva, tem-se verificado ser insignificante a utilização de algumas tecnologias, quando se toma como referencial os pequenos e médios produtores.

Dentre as razões apontadas para este insucesso, identifica-se a não consideração nas propostas de transformação, do conhecimento local, das características das unidades de produção agrícola, das políticas públicas, da capacidade de resposta dos ambientes e da mobilização dos produtores.

Via de regra, as políticas voltadas para exploração agrícola das unidades de produção do semi-árido dependentes de chuva, têm sido baseadas em informações com nível de detalhamento não adequado e, principalmente, não associado a uma base de dados (clima, solo e vegetação), ao perfil do produtor e ao custo dos recursos financeiros.

O ambiente tem efeito direto em qualquer tipo de atividade agropecuária. No caso do semi-árido, o clima e o solo lideram os fatores que definem o ambiente. A escassez e a variabilidade temporal dos eventos pluviais são as causas principais apontadas como obstáculos ao desenvolvimento agrícola dependente de chuva.

De acordo com Porto (1995), o desempenho dos sistemas de produção tradicionais, atualmente em uso no semi-árido brasileiro, está levando os pequenos produtores ao empobrecimento a uma taxa média de 13,5% ao ano.

Para comprovar as afirmações anteriores, é suficiente verificar os dados do último Censo Agropecuário, ou seja, no período de 1985 a 1995, cerca de 30% dos estabelecimentos agrícolas da região foram abandonados, por absoluta falta de condições de sustentação do trabalhador e de sua família. Além disso, cerca de 90% das propriedades deixam de captar crédito no mercado por insuficiência de capacidade de pagamento, à luz dos seus “modus operandi”.

Desta forma, urge que sejam desencadeadas ações governamentais, em todos os níveis, no sentido não apenas de minimizar o sofrimento do homem do campo, mas, também, e, principalmente, de viabilizar meios e mecanismos que tornem as propriedades do semi-árido sustentáveis no longo prazo. Isto será possível através da intensificação da aplicação de tecnologias.

Ações sugeridas

O semi-árido brasileiro é o tipo de ambiente em que mais ou menos alguns milímetros de chuva ou centímetros de perfil de solo podem fazer significativas diferenças no desempenho dos sistemas de produção dos agricultores. Por outro lado, as técnicas de captação e aproveitamento de água de chuva podem reduzir muito os impactos destas diferenças. Portanto, a aplicação de tecnologias que tornem a utilização das chuvas mais eficiente é fundamental.

Para ampliar a operacionalização do processo de aplicação destas e de outras tecnologias necessárias no espaço semi-árido do Nordeste, sugere-se que sejam trabalhados quatro segmentos distintos, porém complementares:

No primeiro, propõe-se que seja trabalhada a compreensão do habitat semi-árido em toda sua singularidade. Não obstante toda a fragilidade, esta região tem muito a oferecer em termos de recursos naturais, flora e fauna, podendo a população que nela reside, obter ganhos comparativos caso seja capacitada para conviver com seu habitat, passando a ter consciência das limitações e potencialidades do semi-árido. Esta consciência deve ser trabalhada, transmitida e convivida através da educação formal e informal.

No segundo segmento, propõe-se a realização de um mapeamento dos recursos naturais (solo, vegetação, recursos hídricos), e a caracterização das unidades de produção, a partir da forma de uso atual e do tipo de produtor existente.

Esta caracterização poderá ser feita usando-se a Extensão Rural, as ONGs, a Pesquisa Agropecuária, as Escolas Rurais, as Associações de Produtores, os Sindicatos e as estruturas oficiais dos municípios. A participação da escola da zona rural é de fundamental importância, não apenas por ter capilaridade na zona rural, mas, também, pela capacidade de discussão sobre a compreensão da realidade local e da cidadania.

O terceiro segmento será concernente à configuração de cenários alternativos de exploração das unidades de produção agropecuárias, à luz do estoque de tecnologias, da potencialidade do ambiente e da realidade do produtor. Estes cenários serão produzidos, complementando-se as informações das unidades de produção, com outras referentes às condições de posse e escala de exploração da terra, custo e prazo de pagamento do capital financeiro e de governança das cadeias produtivas.

O quarto, por sua vez, refere-se à operacionalização e administração do banco de dados, com vistas a subsidiar a tomada de decisão. Ressalta-se que, dada a dinâmica da oferta de tecnologia, bem como da evolução das condições ambientais e das unidades de produção, será imprescindível a formalização de “locus” de oferta de tecnologia de modo a alimentar o banco de dados. Além disso, será imprescindível, também, a alimentação do banco, com informações concernentes aos instrumentos das políticas públicas, e de mercado, de forma que, mudadas as condições reais de influência sobre as propriedades, alternativas de modelos de exploração sejam concebidas e difundidas.

Conclusões

O trópico semi-árido brasileiro se constitui de um aglomerado de unidades de produção com características diferenciadas quanto às potencialidades dos recursos naturais, tipos de produtores e sistemas de produção;

Não obstante todo o acervo tecnológico gerado pelos órgãos de pesquisa, tem-se verificado insignificante grau de transformação das unidades de produção localizadas nos semi-árido brasileiro;

Para ampliar a aplicação de tecnologia na produção dependente de chuva, há necessidade de informações com maior nível de detalhamento quanto ao solo, clima, vegetação, perfil do produtor, escala de exploração e políticas de crédito, objetivando a criação de cenários específicos para cada conjunto ou tipo de propriedade;

É imprescindível formalizar a participação da Escola Rural, não só como formadora da compreensão sobre o ambiente e a cidadania, mas também como um fórum permanente de discussão sobre a sustentabilidade das unidades de produção.

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Métodos de Captação de Água de Chuva "in situ"

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Resumo

Na região semi-árida brasileira, o regime pluviométrico anual é um fator preponderante para o sucesso da agricultura dependente de chuva, sendo a sua má distribuição, no tempo e no espaço, a principal responsável pela perda de safras agrícolas. O sistema tradicional de cultivo na região semi-árida é a semeadura em covas, no plano, com o auxílio de uma enxada, o que dá origem a uma pequena depressão, capaz de armazenar certa quantidade de água de chuva. Este sistema é aparentemente pouco agressivo ao meio ambiente, no entanto, como o solo não foi preparado (arado), a sua superfície apresenta-se ligeiramente compactada, dificultando a infiltração e facilitando o escoamento superficial, o que contribui para o processo erosivo. No entanto, técnicas simples de preparo do solo, visando a captação da água de chuva „in situ“ são mais apropriadas aos sistemas de produção adotados pelos agricultores, e podem ser implantadas usando-se tanto a tração mecânica quanto a tração animal. Os sistemas de captação de água de chuva „in situ“ mais utilizados na região semi-árida brasileira são: sulcamento pré e pós-plantio, sulcos barrados, camalhões inclinados ou sistema W, aração parcial e o sistema Guimarães Duque. Neste trabalho, são apresentadas as principais técnicas de captação de água de chuva „in situ“, adequadas aos produtores do semi-árido brasileiro.

1. INTRODUÇÃO

Na região semi-árida brasileira, a quantidade e a distribuição das chuvas, são fatores preponderantes para o sucesso ou fracasso da agricultura dependente de chuva, sendo a sua distribuição, no tempo e no espaço, a principal responsável pela perda de safras agrícolas.

Vários métodos de captação de água de chuva “in situ” foram desenvolvidos e/ou adaptados pela Embrapa - Semi-Árido, utilizando tanto força motriz como tração animal. Para se estabelecer um sistema de captação de água de chuva in situ, é necessário se dispor de informações sobre uma série de fatores, tais como o tamanho da área a ser cultivada, solo, topografia, quantidade e distribuição das chuvas, cultura (anual ou perene) e disponibilidade de equipamentos e de mão-de-obra. Estes requisitos devem estar associados a fatores socioeconômicos, a fim de viabilizar o investimento da tecnologia. Neste trabalho, são apresentadas as principais técnicas de captação de água de chuva “in situ”, adequadas aos produtores do semi-árido brasileiro.

2. FATORES DETERMINANTES NA IMPLANTAÇÃO DE SISTEMAS DE CAPTAÇÃO DE ÁGUA “IN SITU”

2.1. Época de Plantio

A época de plantio é um fator de extrema importância para o sucesso da agricultura dependente de chuva. Silva et al, (1982) mostram que, para a cultura de caupi, a melhor época de plantio no município de Petrolina, PE, é no mês de março; já para o milho, este período corresponde aos meses de janeiro e fevereiro, coincidindo com o período de maior concentração na distribuição das chuvas. Na região semi-árida do Nordeste brasileiro, os cultivos implantados em regime de sequeiro, são normalmente efetuados após o registro de no mínimo 30 mm de precipitação pluviométrica.

2.2. Solos

Os solos na região semi-árida brasileira são predominantemente de origem cristalina, rasos, silicosos e pedregosos, com baixa capacidade de retenção de água e, em geral pobres em nutrientes (Faria 1992).

O regime hídrico da região é caracterizado por chuvas de curta duração e alta intensidade, o que torna o solo mais vulnerável à erosão após as operações de preparo. Segundo Lopes e Brito (1993), o período crítico em relação à erosividade das chuvas no município de Petrolina, PE, é de fevereiro a abril, quando ocorrem, em média, 64,76% das chuvas erosivas. Esses fatores, agindo isoladamente ou em conjunto, promovem a degradação dos solos, o que conseqüentemente, diminui sua capacidade produtiva. Assim, torna-se necessário o emprego de técnicas simples e adequadas de preparo do solo, que além de favorecerem uma maior disponibilidade de água para a planta, promovem a conservação do solo e seus nutrientes.

2.3. Necessidade de água pelas culturas

Em regiões áridas e semi-áridas, à semelhança do trópico semi-árido do Nordeste brasileiro, onde a água é sempre um fator limitante, principalmente para a agricultura dependente de chuva, as pesquisas devem estar voltadas para técnicas de manejo racional desses fatores, visando aumentar a disponibilidade de água no solo para se obter a máxima produção por unidade de água precipitada.

Segundo Doorembos e Kassam (1994), a cultura do milho (*Zea mays* L.), dependendo das condições climáticas, e sem considerar outros fatores de produção, necessita, em seu ciclo, de 500 a 800 mm de água, bem distribuídos de acordo com suas fases fenológicas, principalmente as fases de floração e enchimento de grãos, para obter-se a máxima produção.

Associando as necessidades hídricas da cultura do milho, com os dados de precipitações médias para a maioria dos municípios da região do semi-árido do Nordeste brasileiro, Silva et al, (1993) observaram que, anualmente, ocorre déficit hídrico na cultura, principalmente devido à irregularidade na distribuição das chuvas no tempo e no espaço.

3. SISTEMAS DE CAPTAÇÃO DE ÁGUA DE CHUVA “IN SITU”

O sistema tradicional de cultivo na região semi-árida é a semeadura em covas, com o auxílio de uma enxada, o que dá origem a uma pequena depressão, capaz de armazenar certa quantidade de água de chuva. Este sistema é aparentemente pouco agressivo ao meio ambiente, no entanto, como o solo não foi preparado (arado), a sua superfície apresenta-se ligeiramente compactada, dificultando a infiltração e facilitando o escoamento superficial, o que contribui para o processo erosivo. No entanto, técnicas simples de preparo do solo, visando a captação da água de chuva “in situ” são mais apropriadas aos sistemas de produção adotados pelos agricultores, e

podem ser implantadas usando-se tanto a tração mecânica quanto a tração animal (Duret et al., 1986).

3.1. Sulcamento Pré e Pós-Plantio

A técnica de captação de água de chuva “in situ”, através do sulcamento em pré-plantio, consiste de uma aração da área seguida do sulcamento e semeadura sobre os camalhões. Após a aração da área, colocam-se três sulcadores na barra porta-implementos do chassi, distanciados entre si de 0,75 m, para confecção dos sulcos e camalhões. Abertos os três primeiros sulcos, retorna-se o chassi de maneira que um animal, um pneu e um sulcador passem dentro do sulco que fica do lado da área a ser sulcada, servindo como guia. A partir daí, efetivamente só dois sulcos serão abertos a cada passagem do chassi porta-implementos (Figura 1). Neste sistema, as capinas são realizadas utilizando-se sulcadores entre as linhas de plantio e complementadas com o auxílio de enxadas manuais, entre as plantas de uma mesma linha. Este sistema permite um maior aproveitamento da água da chuva, além de otimizar os tratos culturais e fitossanitários, possibilitando também a mecanização devido o camalhão definir a linha de plantio. A presença de tocos, pedras e pendentes superiores a 5% limitam a sua utilização

O sulcamento pós-plantio é uma técnica de captação de água de chuva que consiste de uma aração da área e semeadura no plano, seguidas do sulcamento entre linhas de cultivo, efetuado por ocasião da segunda ou terceira capina, a depender da cultura e de seu estágio de desenvolvimento, através de sulcadores à tração animal ou mecânica.

A época mais adequada para o sulcamento do solo é de 30 a 40 dias após o plantio do feijão e de 20 a 30 dias após o plantio do milho. A Figura 1 apresenta o esquema do sistema no campo.

Esta tecnologia apresenta como principal vantagem, a elevação do nível do terreno acima do colo das plantas, aumentando o volume de solo explorado pelo sistema radicular, propiciando, assim, um melhor desenvolvimento da cultura, além da eliminação de ervas daninhas que concorrem com a planta por água e nutrientes. Este sistema associa o abacelamento do cultivo com as capinas em uma só operação, reduzindo assim a mão-de-obra utilizada, tornando o sistema viável sob os pontos de vista técnico e econômico. Como desvantagem, não se adapta a declividades superiores a 5%.

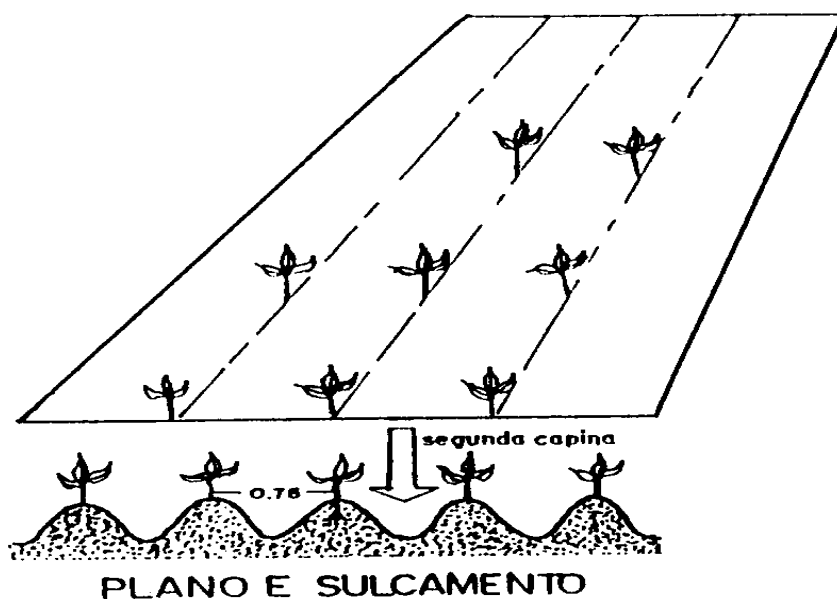


Figura 1. Representação do sistema de captação de água de chuva "in situ" com sulcamento pós-plantio

3.2. Sulcos Barrados

O sistema de captação de água de chuva "in situ" com sulcos barrados foi desenvolvido pela Embrapa Semi-Árido, e consiste de uma aração e sulcamento do solo com 0,75 m de distância entre sulcos, quando o trabalho é efetuado com chassi porta-implementos com rodas (pneus), seguidos da operação de barramento, que consiste na confecção pequenas barreiras dentro do sulco, com a finalidade de impedir o escoamento superficial da água de chuva (Figura 2). O barramento dos sulcos deve ser realizado antes da sementeira que é efetuada sobre os camalhões.

O sistema pode ser confeccionado com um chassi porta implementos tracionado por uma junta de bois ou por um barrador de sulcos tracionado por um só animal. A principal vantagem do sistema é que o uso de barrador de sulcos com um só animal, pode ser adaptado a diversos sistemas de cultivo, seja em regime de sequeiro ou sob irrigação, pois o porte da cultura não interfere na utilização e desempenho do equipamento, o que não é possível quando o barrador é usado em chassi porta-implementos com pneus.

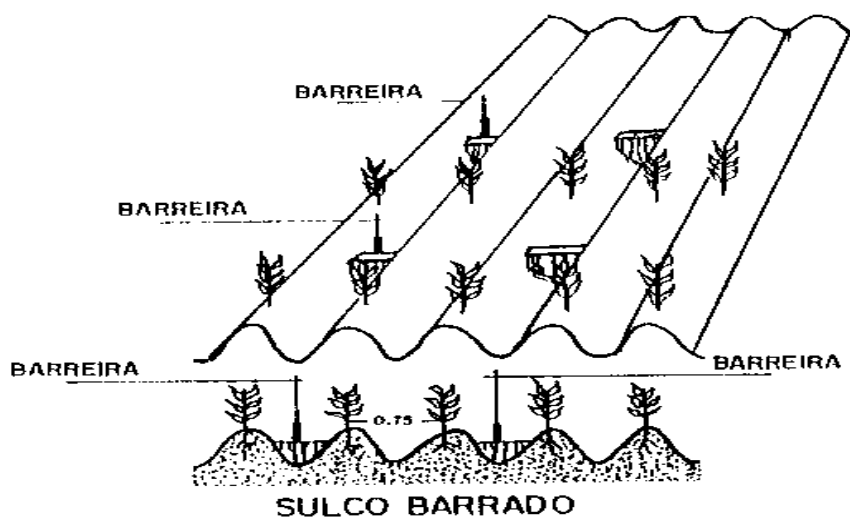


Figura 2. Representação do sistema de captação de água de chuva "in situ" com sulcos barrados.

3.3. Camalhões inclinados ou sistema W

O sistema de captação de água de chuva “in situ” com camalhões inclinados ou W, consiste de uma aração, seguida de sulcamento da área de captação de água e dos camalhões onde se faz o plantio, os quais são efetuados em uma só operação. É uma técnica pouco conhecida que apresenta um grande potencial para ser utilizada extensivamente no semi-árido brasileiro.

Para implantação desta técnica, adaptam-se dois sulcadores, tipo bico de pato, à barra porta-implementos, distanciados entre si de 0,75 m, por ser o espaçamento que mais se adapta ao trabalho efetuado com o chassi porta-implementos com rodas (pneus), determinando assim, o camalhão da área de plantio. A inclinação da área de captação de água é feita alongando-se as asas externas dos sulcadores. Várias passagens sucessivas do equipamento no terreno, dão origem ao sistema de captação de água de chuva “in situ” de forma em “W” (Figura 3).

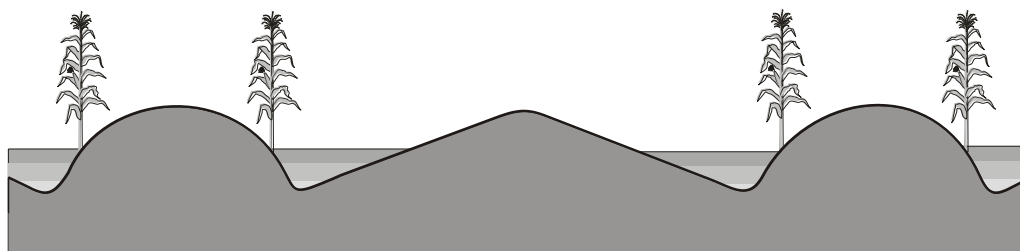


Figura 3. Representação do sistema de captação de água de chuva "in situ" com camalhões inclinados

As limitações deste método estão relacionadas à área com presença de tocos, pedras e pendentes superiores a 2%. Também, é inviável a capina mecânica na área de semeadura, só sendo possível na área de captação de água de chuva.

3.4. Aração Parcial

O sistema de captação de água de chuva “in situ” com aração parcial, consiste em duas passagens sucessivas na área com um arado de aiveca reversível a tração animal, deixando-se uma distância de 0,60 m a partir da muralha da segunda leiva do solo arado e assim sucessivamente. A parte do solo não arado entre duas faixas de aração é responsável pela captação e condução da água até a zona de plantio (Figura 4).

Nesse sistema, a semeadura é feita com plantadoras manuais sobre a segunda leiva deixada pelo arado em cada faixa, sendo a distância entre linhas de cultivo de 1,0 m. O sistema é refeito a cada ano, promovendo, assim, a rotação gradual da área de cultivo. As capinas podem ser efetuadas manualmente (com enxada) ou com o arado de aiveca reversível, arando-se a parte não trabalhada para eliminar as ervas e chegar terra à planta, fazendo-se o abacelamento (Figura 4).

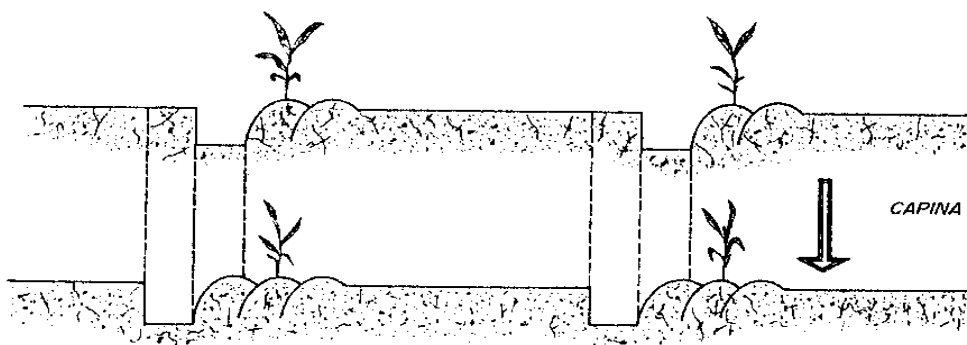


Figura 4. Representação do sistema de captação de água de chuva "in situ" com aração parcial.

3.5. Sistema Guimarães Duque

Segundo Silva et al (1982), a primeira técnica de captação de água de chuva “in situ”, adaptada às condições do semi-árido nordestino foi desenvolvida pelo INFAOL (Instituto Nordeste para o fomento do Algodão e Oleaginosas), denominada Método Guimarães Duque de Lavoura Seca. Este método foi adaptado pela Embrapa Semi-Árido para exploração de culturas anuais, principalmente milho e caupi.

O método Guimarães Duque consiste na formação de sulcos, seguidos por camalhões altos e largos, formados através de cortes efetuados em curva de nível, usando um arado reversível com três discos. Para fazer o sistema retira-se o disco que fica mais próximo dos pneus traseiros do trator, sendo o trabalho efetuado com os outros dois discos do arado.

O operador (tratorista) inicia a aração tomando por base as curvas de nível, direcionando a leiva de solo arado no sentido da pendente do terreno, devido a aração ser efetuada em faixas. Depois de efetuado o primeiro sulco, o trator retorna com os pneus passando sobre o solo que

ainda não foi arado, isto é, margeando o sulco anterior e, assim, sucessivamente. Este procedimento permite a formação da área de captação entre os camalhões, sendo o espaçamento entre linhas de cultivo de 1,50 m. A Figura 5 apresenta o esquema do sistema em campo. A presença de tocos, pedras e pendentes superiores a 5%, apresenta-se como principal restrição ao sistema.

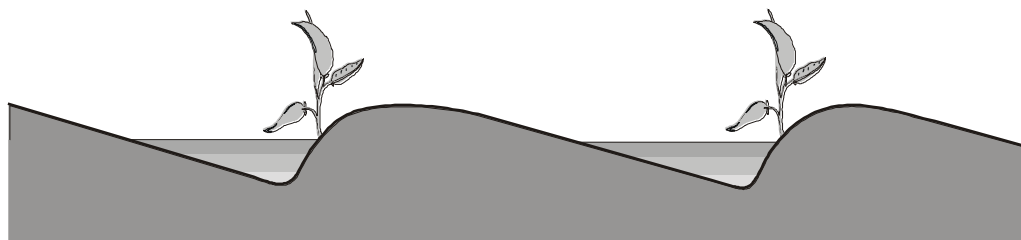


Figura 5. Representação do sistema de captação de água de chuva "in situ" Guimarães Duque.

UTILIZAÇÃO DOS SISTEMAS DE CAPTAÇÃO DE ÁGUA DE CHUVA “IN SITU”

Segundo Silva et al, (1993), em função da grande variação das chuvas registradas nas unidades geoambientais, identificadas na região semi-árida do Nordeste brasileiro é de fundamental importância o preparo do solo com técnicas de captação de água de chuva “in situ”, visando assegurar os cultivos implantados em regime de sequeiro, principalmente, para amenizar os efeitos do déficit hídrico ocorrido em anos de pouca precipitação pluviométrica

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Conservação da Capacidade Produtiva do Solo em Sistemas de Captação de Água de Chuva "in situ"

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Resumo

O efeito de fertilizantes orgânicos e químicos aplicados em fundação, associado a técnicas de captação de água de chuva „in situ“ foi avaliado na cultura do milho em condições de sequeiro. Foram utilizados dois sistemas de captação de água de chuva „in situ“, um conhecido como sistema W e o outro como Guimarães Duque. Os tratamentos avaliados foram: 1. Testemunha (sem fertilizantes químicos e orgânicos); 2. Sistema de captação mais esterco bovino; 3. Sistema de captação mais fósforo; 4. Sistema de captação mais composto orgânico, e 5. Sistema de captação mais esterco bovino mais fósforo. Observou-se a mesma tendência de produtividade em todos os tratamentos com os dois sistemas de captação de água. O tratamento 5 apresentou a maior produtividade de milho, seguido dos tratamentos 4, 3, 2 e 1 (testemunha), respectivamente. Todos os tratamentos no sistema W apresentaram maior produtividade que no sistema Guimarães Duque, indicando uma maior eficiência do primeiro sistema no armazenamento de água no solo.

INTRODUÇÃO

A agricultura de sequeiro é a principal atividade agrícola na região semi-árida brasileira, apesar do alto risco causado pela irregularidade na distribuição da chuva no espaço e no tempo, que faz reduzir a produtividade dos cultivos, chegando, muitas vezes, a causar perdas totais. As pesquisas têm demonstrado que para reter a água de chuva no solo sem que esta se perca por escoamento superficial, mediante as técnicas de captação de água de chuva “in situ” são muito importantes (Smith, 1978; Duret *et al.*, 1985; Silva *et al.*, 1989). Estas técnicas consistem basicamente na modificação da superfície do terreno de modo que formem um plano inclinado entre dois sulcos sucessivos, chamados camalhões, que funcionam como área de captação da água de chuva (Eingg e Hawer, 1959). Estes sulcos são construídos seguindo as curvas de nível e fechados ao final para induzir uma maior captação e permitir uma maior infiltração da água no solo. Em caso de excesso de chuvas, abrem-se os sulcos para não reter muita água dentro deles, o que poderia prejudicar os cultivos (Stern, 1979).

No semi-árido brasileiro é possível obter boas produções mediante a adubação orgânica e mineral, associadas às técnicas de captação de água de chuva “in situ”, o que permite aumentar, substancialmente, a capacidade de armazenamento de água no solo (Silva e Anaya, 1979).

A geração e adaptação de tecnologias de baixo custo que consigam melhorar a renda familiar dos pequenos produtores é um programa prioritário da Embrapa – Semi-Árido, já que estes

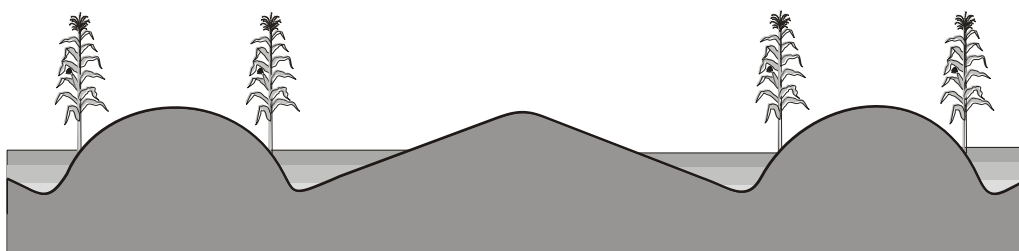
não dispõem de capital suficiente para a adoção de tecnologias de alto custo e também porque eles são os responsáveis por mais de 50% da produção de grãos da região.

O presente trabalho teve por objetivo avaliar dois sistemas de captação de água de chuva “in situ” associados à utilização de fertilizantes orgânicos e químicos, no aumento do rendimento do milho.

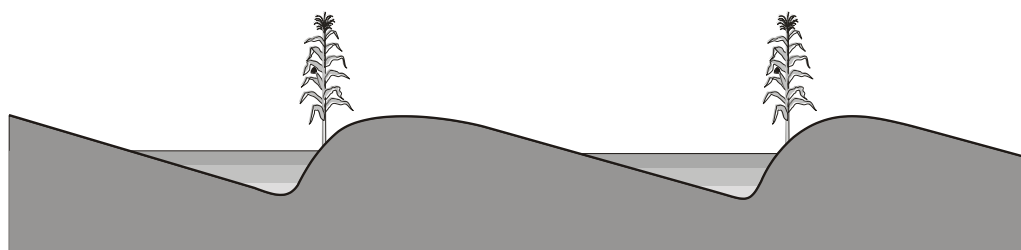
MATERIAL E MÉTODOS

A pesquisa foi realizada na Estação Experimental de Manejo da Caatinga da Embrapa – Semi-Árido, em Petrolina (PE), Brasil, em um solo classificado como Planossilic Eutric Paleargid, textura arenosa, com uma profundidade média de 1,20 m. A região apresenta um clima semi-árido, com uma precipitação média anual de 390 mm.

Foram selecionados dois sistemas de captação de água de chuva “in situ”, um conhecido como Sistema W e o outro por Sistema Guimarães Duque, cujos desenhos estão representados na Figura 1. Para a implantação do sistema W adaptou-se dois sulcadores tipo bico de pato à barra porta implementos de um policultor à tração animal, distanciados de 0,75 metro um do outro, o que delimita o camalhão da área de plantio. A área de captação de água foi preparada com uma placa metálica inclinada adaptada ao sulcador, que ao sulcar o terreno forma dois planos inclinados, um de cada lado. Com várias passadas paralelas do equipamento se origina um sistema de captação de água de chuva em forma de W. O sistema Guimarães Duque consiste na formação de sulcos seguidos por camalhões altos e largos, formados mediante cortes efetuados seguindo as curvas de nível com um arado de disco reversível de três discos tracionado por um trator. Para preparar o sistema retira-se o primeiro disco do arado fazendo-se o primeiro camalhão na primeira passada, retornando com os pneus do trator margeando o sulco, preparando o segundo camalhão, e assim sucessivamente.



Sistema W



Sistema Guimarães Duque

Figura 1. Representação dos sistemas de captação de água de chuva “in situ” avaliados.

O experimento foi instalado em parcelas de 20,0 x 5,0 m, utilizando-se o delineamento experimental de blocos ao acaso, com 5 tratamentos e 4 repetições. Os tratamentos avaliados nos dois sistemas de captação de água de chuva “in situ” foram: T1. Testemunha (sistema de captação sem fertilizantes químicos e orgânicos); T2. Sistema de captação mais esterco bovino; T3. Sistema de captação mais fósforo; T4. Sistema de captação mais composto orgânico e T5. Sistema de captação mais esterco bovino e fósforo.

O composto e o esterco foram aplicados nas linhas de plantio, com uma dose de $8,0 \text{ m}^3 \cdot \text{ha}^{-1}$. O composto orgânico utilizado foi preparado com palha de milho e esterco bovino. As doses de P_2O_5 utilizadas foram de $60 \text{ Kg} \cdot \text{ha}^{-1}$, aplicadas no momento do plantio com uma plantadeira-adubadeira manual. Foram colocadas 3 sementes por cova com espaçamento de 1,5 X 0,40 m, deixando-se depois de germinadas duas plantas por cova. Trinta dias após o plantio foi realizada uma adubação de cobertura com $50 \text{ Kg} \cdot \text{ha}^{-1}$ de uréia. Ao final do experimento mediu-se a produtividade de milho de cada parcela, analisando-se os resultados mediante a comparação de médias pelo Teste de Duncan para comparação dos tratamentos, e o Teste de t para a comparação dos dois sistemas de captação de água de chuva “in situ”, ao nível de 5% de probabilidades.

RESULTADOS E DISCUSSÃO

Na figura 2 pode-se observar que, apesar da quantidade de chuva caída entre os meses de novembro a março ter sido superior à média regional, a distribuição desta no espaço e no tempo foi bastante irregular, coincidindo com a falta de chuva no período mais crítico para a cultura, entre os 40 e 80 dias (floração). Analisando-se os dados de precipitação observou-se que a maioria das chuvas ocorreram no período de plantio e germinação, enquanto que durante o desenvolvimento vegetativo, floração e maturação do milho as chuvas foram escassas.

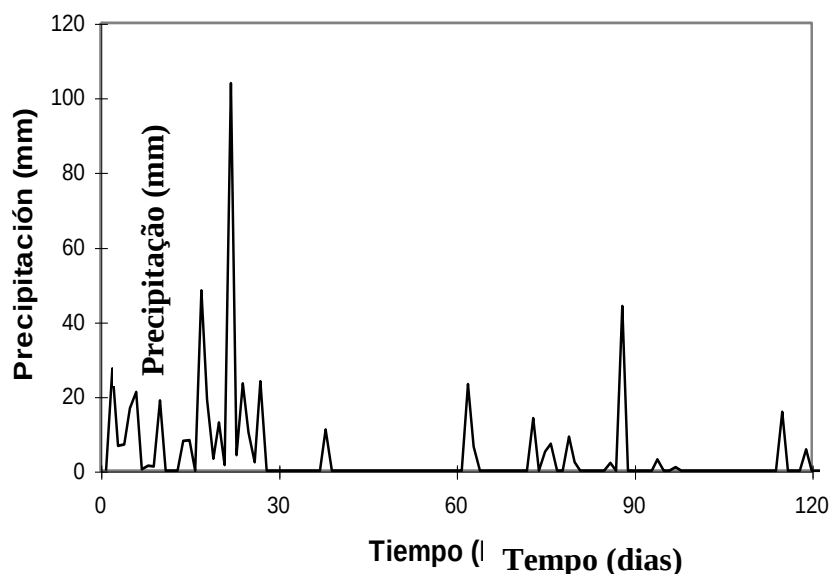


Figura 2. Distribuição das chuvas durante o ciclo de cultivo do milho.

A Tabela 1 apresenta as produtividades médias de milho para os diversos tratamentos com o sistema W de captação de água de chuva *in situ*. O tratamento T5 apresentou a maior produtividade, seguido dos tratamentos T4, T3, T2 e T1, respectivamente. A análise estatística dos dados permite comprovar que o tratamento T5 diferiu significativamente de todos os tratamentos, enquanto que os tratamentos T4, T3 e T2 não diferiram entre eles, entretanto os dois primeiros apresentaram diferenças significativas em relação à testemunha.

Tabela 1. Produtividade média de milho nos tratamentos com o sistema W.

Tratamentos	Produtividade (Kg.ha ⁻¹)	Incremento (%)
T1. Testemunha	1.654c ^{1/}	---
T2. Sistema de captação + esterco	1.936bc	17,5
T3. Sistema de captação + fósforo	2.116 b	27,9
T4. Sistema de captação + composto	2.235 b	35,1
T5. Sistema de captação + esterco + fósforo	2.614 a	58,0

1/ As médias seguidas da mesma letra não diferem estatisticamente pelo teste de Duncan a 5 % de probabilidade.

As produtividades médias de milho alcançadas nos diversos tratamentos com o sistema Guimarães Duque estão apresentadas na Tabela 3. O tratamento T5 apresentou a maior produtividade, reduzindo-se para os tratamentos T4, T3, T2 e T1, respectivamente. Ao comparar as produtividades médias dos tratamentos pode-se comprovar que o tratamento T5 apresentou o maior incremento de produção, reduzindo-se para os tratamentos T4, T3, T2 e T1, respectivamente. O tratamento T5 diferiu significativamente de todos os tratamentos avaliados, enquanto que os tratamentos T4, T3 e T2 apresentaram o mesmo efeito. Observou-se também que as produtividades dos tratamentos T4 e T3 foram estatisticamente superiores à testemunha, que apresentou o mesmo efeito de T2.

Tabela 2. Produtividade média de milho nos tratamentos com o sistema Guimarães Duque.

Tratamentos	Produtividade (Kg.ha ⁻¹)	Incremento (%)
T1. Testemunha	1.351d ^{1/}	---
T2. Sistema de captação + esterco	1.787c	32,3
T3. Sistema de captação + fósforo	1.972 cd	45,9
T4. Sistema de captação + composto	2.088 ab	54,6
T5. Sistema de captação + esterco + fósforo	2.200 a	62,8

1/ As médias seguidas da mesma letra não diferem estatisticamente pelo teste de Duncan a 5 % de probabilidade.

Observando-se os dados apresentados na Tabela 3, nota-se que nos dois sistemas de captação de água de chuva *“in situ”*, os tratamentos apresentaram as mesmas tendências de produtividade. O tratamento T5 apresentou a maior produtividade, reduzindo-se para os tratamentos T4, T3, T2 e T1, respectivamente. A comparação dos dois sistemas de captação de água de chuva *“in situ”* permite comprovar que o sistema W apresentou uma maior

produtividade de milho em todos os tratamentos testados que o sistema Guimarães Duque. Comparando-se as produtividades médias de cada tratamento nos dois sistemas, observa-se que todos diferiram estatisticamente entre si pelo teste de “t” ao nível de 5%, o que permite supor que o primeiro sistema foi mais eficiente no armazenamento de água no solo. A relação entre os dados de precipitação e produtividade de milho demonstraram a eficiência dos sistemas de captação de água de chuva “in situ” no armazenamento de água no solo, refletindo no aumento da produtividade da cultura.

Tabela 3. Comparação das produtividades medias de milho nos dois sistemas de captação de água avaliados.

Sistemas de captação de água de chuva “in situ”	Produtividade (kg.ha ⁻¹)				
	T1	T2	T3	T4	T5
W	1.654a	1.936a	2.116a	2.235a	2.614a
Guimarães Duque	1.351b	1.787b	1.972b	2.088b	2.200b

1/ Médias seguidas da mesma letra não diferem estatisticamente pelo teste t a 5 % de probabilidade.

CONCLUSÕES

A testemunha apresentou a menor produtividade de milho nos dois sistemas de captação de água de chuva “in situ”.

Para os dois sistemas de captação, a maior produtividade foi observada no tratamento em que se utilizou esterco e fósforo.

Os resultados obtidos demonstram que todos os tratamentos avaliados apresentaram as mesmas tendências, evidenciando o efeito do sistema de captação de água.

Em todos os tratamentos avaliados o sistema W apresentou maior produtividade de milho que o sistema Guimarães Duque.

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Water as a means of reconciliation in the Middle East

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Abstract

Fresh water, the key element for life, is a critical resource in the Middle East. There is a conflict among the region's countries because of scarcity and misuse of fresh-water. Scarcity is one element of the crisis, inefficiency is another factor. In fact, water used in the agricultural sector exceeds by ten times water used in the industrial and municipal sectors combined. There has been a rapid population growth in the Middle East in recent decades. This population boom has put an extreme pressure on the existing limited and vulnerable water resources.

An integrated management of water resources including technical, social and economic aspects is needed, since, unlike oil, water cannot be easily exported from a water-surplus country to a water-deficit country due to economic, political, environmental, psychological, ideological and emotional reasons.

One of the most important aspects of land and water resource development programs is to determine the inventory of the resources. The resources and opportunities should be known accurately, and current supplies and future supplies which will be available as a result of supply management policies in terms of foreseeable water demands should be considered. However, in the Middle East there is no scientific co-operation on the crucial importance of demand management aiming at water use efficiency, equity, and long-term water security. If nations of the region would share both water technology and boundary resources, fresh-water could not drive them to war, and it will not be a hindrance for peace.

In 1988, Turkey proposed a "peace pipeline" of water from two Turkish rivers- the Ceyhan and Seyhan- that flow south into the Mediterranean sea. The dual pipelines would deliver potable water to millions in Syria, Jordan, Saudi Arabia and other Arab gulf states.

Introduction

Arid and semiarid regions, inhabited by some 900 million people, comprise almost 40 percent of the world's land surface. Most of the inhabitants are farmers living in developing countries. In about 1970, the Middle East and other dry regions entered a period of progressively worsening water deficit as the result of their rising population (Aydin, 1995; Allan, 1998).

In the past three decades, this population increase has put a strain on the region's fresh-water resources. In spite of the scarcity of this resource in most countries of the Middle East Region, water supplies are still managed in a rather irrational way.

The water problem cannot be addressed by the present fragmented approach. This paper presents an alternative approach on water management that could be a bridge for peace among the Middle East States.

Population and fresh water use

A great pressure on the fresh water has been caused by the very rapid population growth in the twentieth century (Fig.1). Some Middle East countries have experienced a two-fold increase in population between 1972 and 1992. For a number of countries, available data show a three-fold increase in population in a period of only 20 years.

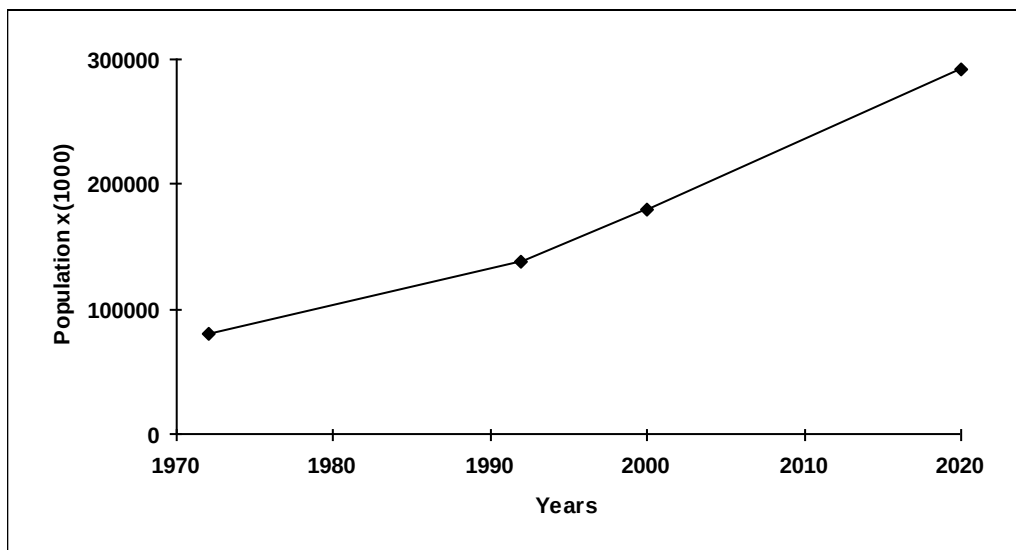


Fig.1. Population growth in the Middle East (Source: Akmandor et al., 1994)

Three countries of the region, Turkey-Iraq-Syria, will contain nearly two thirds of the total Middle East population in 2020, i.e. twice their current number (Fig.2).

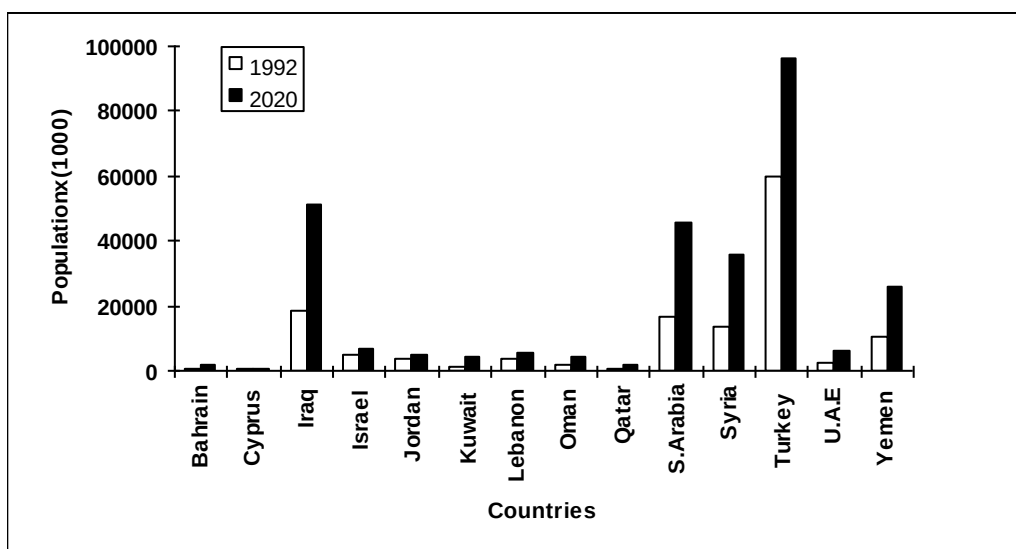


Fig.2. Population, 1992 and 2020, in the Middle East Countries (Source: Akmandor et al., 1994)

The water requirement of the people living in arid zones has been widely discussed. If calculated on a per capita basis, it is expected that by the year 2020, the available water/capita will be reduced by nearly 47% of the present availability (Table 1).

According to the water stress index, a level of 1200 cubic meter/person/year (CM/P/Yr) is considered adequate; when the value falls below 1000 CM/P/Yr, countries experience chronic water stress; and when countries fall below 500 CM/P/Yr, they experience absolute water stress.

The 1000 cubic meter bench-mark level reported by some authors from the countries with a more temperate climate assumes that major amounts of water will be used for agriculture (Hamdy, 1995).

Some countries in the region are already experiencing chronic and absolute water scarcity.

Table 1. Annual renewable fresh water available per person in 1992 and 2020 in the Middle East Countries.

	1992	2020
<u>Countries</u>	<u>CM/P/Yr</u>	<u>CM/P/Yr</u>
Bahrain	-	-
Cyprus	1200	1000
Iraq	3500	1250
Israel	460	320
Jordan	320	230
Kuwait	-	-
Lebanon	1800	1100
Oman	-	-
Qatar	-	-
Saudi Arabia	-	-
Syria	2100	800
Turkey	3600	2200
U.A.E	-	-
Yemen	-	-
<u>Selected Countries</u>		
Egypt	1100	640
United States	9900	7500
<u>Selected Region</u>		
Samaria West	160	60

Another important point is to determine the inventory of the land resources. The total area of the Region's Countries is shown in Table 2. Even more important, considering the limitation imposed with respect to water resources, irrigatable land potential of each country should be determined.

In irrigation sector, the proper management of the catchment, command and areas below the command are essential if sustainable development is to be achieved. The focus is thus on the entire watershed which can be defined as the catchment, reservoir, command and drainage areas (Mohtadullah, 1994). Long-term and careful planning of the water supply in order to cope with the growing shortage would bring solutions in other fields.

Table 2. Land resources in the Middle East Countries
(Source: Akmandor et al., 1994)

<u>Countries</u>	<u>Total Area (1000 ha)</u>	<u>Countries</u>	<u>Total Area (1000 ha)</u>
Bahrain	66	Oman	21246
Cyprus	925	Qatar	1087
Iraq	17592	Saudi Arabia	217559
Israel	2032	Syria	18518
Jordan	9774	Turkey	78058
Kuwait	1808	U.A.E	8192
Lebanon	1040	Yemen	49268

Scarcity is only one element of the crisis. Inefficiency is another, as is the reluctance of some water-poor countries to change priorities from agriculture to less water-intensive enterprises (Vesilind, 1993). In fact, water used in the agricultural sector exceeds by ten times the water used in the industrial and municipal sectors combined. The sectorial water demand in the countries of Middle East are presented in Table 3.

Table 3. Water use in three different sectors in the Middle East Countries (%)
(Source: Papadopoulos and Stylianou, 1998)

<u>Countries</u>	<u>Domestic</u>	<u>Industry</u>	<u>Agriculture</u>
Bahrain	1	0	99
Cyprus	20	2	78
Iraq	3	5	92
Israel	-	-	-
Jordan	29	6	65
Kuwait	64	32	4
Lebanon	11	14	75
Oman	-	-	-
Qatar	45	8	47
Saudi Arabia	45	8	47
Syria	7	10	83
Turkey	24	19	57
U.A.E	11	9	80
Yemen	4	2	94

Prospect for future

In the Middle East Countries, water demand for domestic purposes by the next decade will exceed 50% of the available water resources. Thus, the following measurements can be taken against the water scarcity which may be faced after about two decades (Tekinel, 1996).

- 1) Water should be used carefully and with high efficiency in all countries where water resources are very limited.
- 2) Ecological structures should be maintained
- 3) Water pollution must be prevented.
- 4) Excessive use of irrigation water must be avoided.
- 5) Research should concentrate on reusing the sewage and drainage water after some cleaning processes.

6) Sea water should be desalinated, and if feasible and economic, this salt-free water should be used in irrigation.

7) By improving the irrigation systems and the measurements, a priority should be given to the minimum water requiring systems (drip irrigation).

Even if all the measures mentioned above are taken, there will be no ultimate solution to the water shortage in the Middle East. In some countries the available conventional water resources will be inadequate to even meet the domestic demand. This circumstance resulted in starting the Peace Water Project in 1988 for providing the required drinking water in the Middle East. The aim of this project is to pump about 6 millions cubic meter of water per day out of a 16 millions cubic meter per day total capacity from two Turkish rivers, Seyhan and Ceyhan, to other countries in the Middle East. Two pipelines are to be constructed. The first pipeline will be 3900 km long and it will have a 2.5 millions CM/day capacity, providing drinking water to Syria, Jordan, Saudi Arabia, Kuwait, Bahrain, Qatar, United Arab Emirates and Oman. The second pipeline with 2700 km long and 3.5 millions CM/day capacity will deliver water to Syria, Jordan and Saudi Arabia. The total cost of the two pipelines project will be about US \$ 20 billion. The water costs per cubic meter will be US 70-80 cents.

Conclusions

In the Middle East, water scarcity is only one element of the crisis. Inefficiency is another factor. A rational management of water needs a broad approach based on adequate proficiencies and research programs, meeting the requirements of the country and aiming at a better valorization of water.

If nations of the region would share both water technology and resources, water will not be a hindrance for peace. Regional and international co-operation have an important role to play in strengthening national competencies and to promote the exchange of knowledge and experiences.

Unlike oil, water cannot be easily exported from a water-rich country to a water-poor country due to economic, political, environmental and psychological reasons. However, in 1988, Turkey proposed a “peace pipeline” of water from two Turkish rivers. It seems the most realistic project for solving drinking water problems in the Middle East.

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Targeting Sites For Rainwater Harvesting With Remote Sensing: A Case Study From Jaipur City And Its Hinterland, Western India

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Abstract

Water is a precious asset of humanity. A well managed society is one that knows how to treat its water with care, prudence and respect. Keeping in view this dictum, the present study has been carried out pertaining to Jaipur, the internationally famous pink city of India which falls in the semiarid region and is situated very close to the eastern fringe of the Thar desert. The present requirement of water for domestic agricultural and industrial needs are met mainly by the subsurface water resources which is increasingly under great stress due to exponential growth in population, urbanisation, industrialisation and modernisation in agriculture and irrigation practices. The water table of the region is showing a declining trend which is evident from the fact that the water level declined during the period 1987-91 on an average of 1.25 m per year as compared to 0.47 m per year during the period 1981-87. Pollution and fluoride contamination has further worsened the situation.

Integration of Remote Sensing Technology with meteorological data provides a reliable, accurate and updated data base on land and water resources which is also a prerequisite for an integrated approach in identifying runoff potential areas and to identify the suitable sites for rainwater harvesting.

The present study, which is based on remote sensing data and a very limited field check, is a small case study with a sole objective to identify more runoff potential zones for planning of rainwater harvesting in Jaipur in western India and its hinterland, mainly to increase the ground water resources. Jaipur lies in the north east part of Rajasthan at 26 degree 55 minute North latitude and 78 degree 48 minute East longitude. Arawalli hills, one of the oldest on the globe, surrounds the city on the north and east sides. The rock types of the area are Quartzites and Phyllite belonging to Delhi Supergroup which is overlain by the quaternary and recent sediments. The Dhund river, which is an ephemeral river system, passes through the city and its hinterland. The methodology adopted in the present study consists of the preparation of various thematic maps using the high resolution satellite data, including Spot and IRS data, coupled with ground truth data. Using the existing model, water balance was computed, runoff potential zones were identified, and sites for rainwater harvesting were proposed. The areas with different recharge possibilities, such as highly favourable, moderately favourable, less favourable and poor were categorised. The sites for the construction of dikes has also been precisely located, which if effected may significantly recharge the groundwater reservoir by tapping the rain runoff water. The outcome of this study may be replicated in a somewhat similar terrain condition.

Introduction

In tropical countries like India, the water availability and demand varies due to exponential growth in population. The water table around Jaipur has shown a declining trend which is evident from the fact that the water table declined in recent years on the average of 1.25 m. per year. Thus inequitable demand of water in time and space has further made the matter more complex both for planners and users (Mehta et al, 1994). The only alternative is to recharge groundwater with the help of rainwater harvesting. The success of such recharge structures and its location depends on correct evaluation of hydrological parameter and the delineation of the groundwater potential zones. The Remote Sensing based methodology has been adopted in the identification of suitable sites for rainwater harvesting structures (Rao et al, 1993). Looking to this, Jaipur and its hinterland, and its calls for immediate attention, was chosen for the present study using Remotely Sensed data.

Study Area

The Study area which comprises Jaipur and its hinterland, falls on the Survey of India Toposheet No. 45 M/16 and 45 N/13 having latitude 26 degree 50 minute and 27 degree 12 minute North and longitude 75 degree 45 minute and 75 degree 58 minute East, covering an area of 1035 sq. Km. (approx.). The area has a semiarid climate with an average annual rainfall of 588 mm and is predominantly occupied by quartzites and phyllites of Delhi Supergroup and the alluvium deposits. The meteorological parameter are shown in Table 1. The main drainage system of the area is the Dhund river basin which is ephemeral in character.

Methodology

The study is mainly based on visual interpretation of IRS LISS II and Spot data to derive information on geology, geomorphology, lineament and hydrogeomorphology of the area. By integrating this information along with drainage density, lineament intensity, and their intersections, feasible artificial recharge sites have been proposed for the rainwater harvesting structures.

Morphometric analysis of Dhund River Basins has been done separately. The water balance study of the Jaipur region has been made which is shown in Table 2.

Geology

The study area mainly comprises of two litho-units i.e. Quartzites of Delhi Supergroup and Alluvium deposits of Quaternary formation. A small patch of Granitic Gneiss of Bhilwara Supergroup has been also observed in the southern part of the basin. Lineaments of the area reveals that the rocks of different age groups of the area are structurally controlled. Such features control the occurrence and movement of groundwater.

Geomorphology

Geomorphology of any basin/area has a greater control on the occurrence and movement of groundwater. The study reveals that the framework of this area is being constituted by

buried channel, linear ridge, valley fill, buried pediplain, gullies and sand dunes complexes. Geomorphic unit and their hydrological characters of the area are shown in Table 3.

The morphometric analysis of the Dhund river basin have been done for both Linear and Areal aspect. The Bifurcation ratio of sub-basin ranging between 3 to 11. Maximum value of Bifurcation ratio reveals that the drainage pattern is affected by the geological structure. Drainage density has an immense control on runoff and infiltration. The higher value of the drainage density reveals that the runoff is greater and the infiltration is minimum. Infiltration Number also reveals that lower will be the infiltration and higher will be the runoff. Thus, the maximum rainwater will be drained out due to runoff.

Rainwater Harvesting Structure And Artificial Groundwater Recharge

In this area groundwater occurs in both under unconfined and confined to semi-confined conditions. In Jaipur there is a wide range in depth to the water table and it ranges from less than 5 m. bgl (around Jalmahal) to more than 33 m. bgl (around Jhotwara).

In the present study, rainwater harvesting structure for augmentation of groundwater resources has been proposed on the basis of the characterisation of drainage density, lineament intensity, lineament intersections, lineament drainage intersections, lithological, and geomorphic set-up, hydrogeomorphic units, lineament controlled drainage courses, soil thickness and channel confluence.

On the basis of the aforesaid studies, suitable sites have been identified for various rainwater harvesting structures such as check dams, plugged dams and tanks to augment the groundwater resources depending upon the morphological set-up. All structures are recommended on 2nd and 3rd order streams (Fig.1). The capacity of each structure will be less than 5-10 MCM. At a few places, constructions of sub-surface dikes have also been suggested in those areas where the water table is very near to the surface (Fig.2).

Conclusion

Remote sensing data is very much helpful in the identification of different geomorphic units and their lithology and hydrological characters. In the present study, highly elevated areas are beyond the approach, while low lying valley and plain areas are very much suitable for rainwater harvesting structures for sustainable development of Ground Water Resources with time and space.

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TABLE 1
CLIMATOLOGICAL PARAMETERS OF JAIPUR REGION

Annual Rainfall	588 mm
Maximum Temp. during summer	44 degree C
Minimum Temp. during winter	8.3 degree C
Relative Humidity (8.30 Hrs.)	53 %
Relative Humidity (17.30 Hrs.)	37%
Wind Speed	12.4 Km / hr.

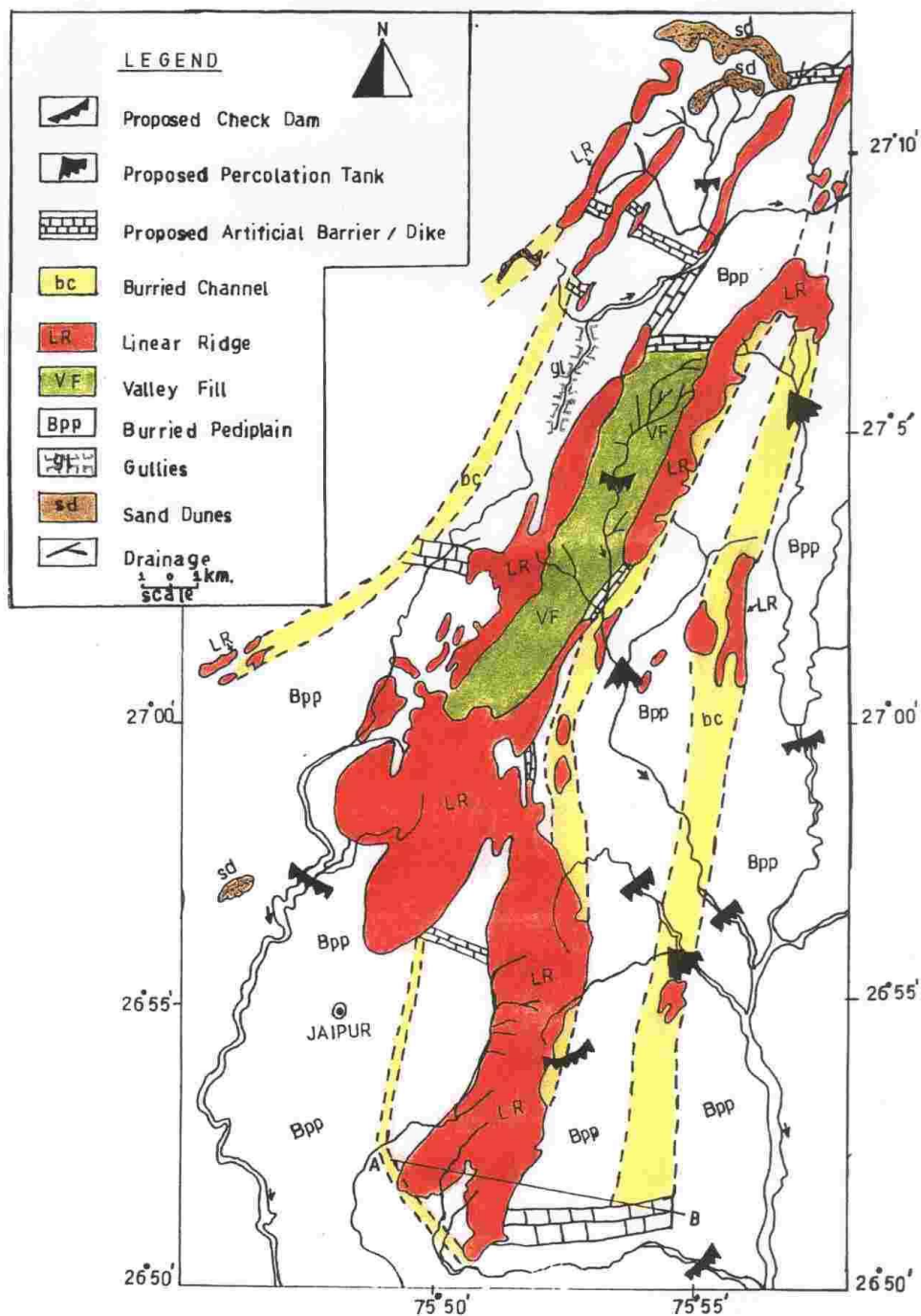
Data source: IMD, India and District Gazetteers.

TABLE 2
GROUND WATER POTENTIAL, EXTRACTION AND BALENCE OF JAIPUR REGION

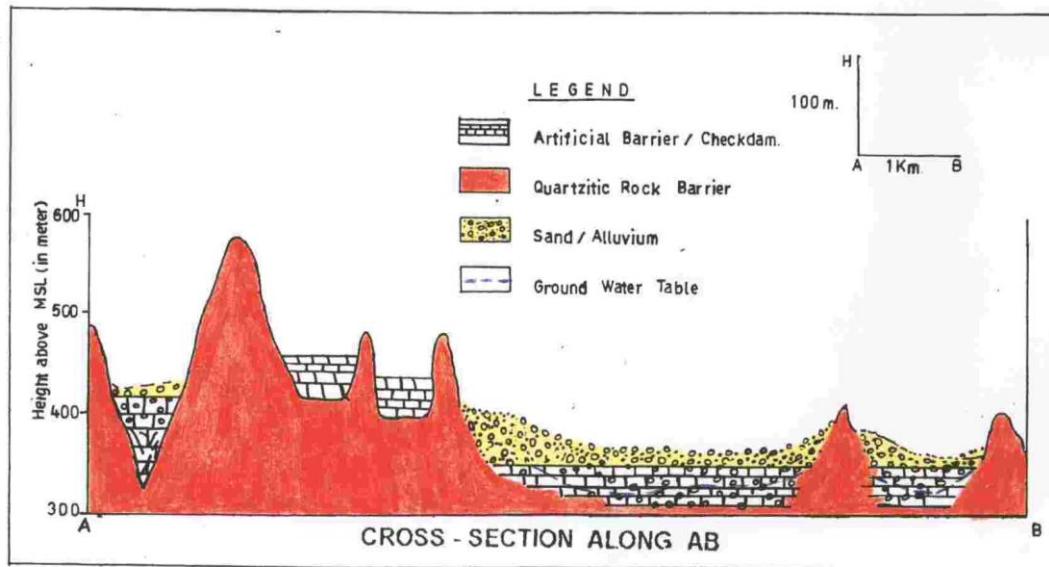
Area of District	11061.44 sq.Kms.
Total area of Potential Zones	9994.67 sq.Kms.
Annual Recharge from Rainfall	655.06 MCM
Annual Recharge from other source	154.03 MCM
Annual Natural Discharge	40.45 MCM
GW Draft for Irrigation	992.16 MCM
GW Draft for Domestic and Industrial use	133.58 MCM
Existing Gross GW Draft	1125.74 MCM
GW Allocation for Domestic & Industrial as on 2025 AD	341.45 MCM

TABLE 3
GEOMRPHIC UNITS , HYDROLOGICAL CHARACTERS AND RECHARGE STATUS

Sl.No.	Geomorphice Units	Lithology	Hydrological Characters	Recharge Status
1.	Burried Channel (bc)	Sands, Alluvium Silts, Clays	Low runoff / High infiltration	Moderately favorable
2.	Linear Ridge (LR)	Quartzite	High runoff / Low infiltration	Less favorable
3.	Valley Fill (VF)	Boulders, pebbles Clays, Stones	High runoff / High infiltration	Highly favourable
4.	Burried - Pediplain (Bpp)	Alluvium, clays, Silts, Sands	Low runoff / Moderate infiltration	Moderate to less favorable
5.	Gullies (gl)	Clays, Sands Alluvium	High runoff / Low infiltration	Less favorable
6.	Sand Dunes (sd)	Clay, Sands	High runoff / Low infiltration	Less favourable.



RAINWATER HARVESTING SITES FOR ARTIFICIAL RECHARGE
Fig.1



CROSS SECTION SHOWING THE PROPOSED SITE OF SUB-SURFACIAL ARTIFICIAL BARRIER OR CHECKDAM

Fig.2

Construção de Cisternas em Campo Alegre de Lourdes - BA, Convivendo com o Semi-Árido Nordestino

Maria Salete Pereira - CPT da Diocese de Juazeiro - Ba

Armínio de Deus Braga - STR de Campo Alegre de Lourdes - Ba

Resumo

No limiar do século XXI, a quase totalidade da população rural do município de Campo Alegre de Lourdes, assim como a maioria daquelas que também estão localizadas nas áreas de sequeiro do Semi-árido nordestino ainda continuam vivendo em situação de permanente penúria provocada pelos efeitos da seca, traduzidos na falta de água para o consumo humano e animal e na freqüente inviabilização da atividade agrícola.

Por conta disso, famílias inteiras são constantemente obrigadas a migrar para a sede do município ou para outras regiões. Aquelas que teimam em permanecer, além da extrema dificuldade para manterem suas roças e criatório, tem a vida ainda mais agravada pela escassez, e, às vezes, ausência total de água para beber e satisfazer outras necessidades básicas.

Diante dessa situação, as medidas adotadas pelo poder público, têm-se prestado, no máximo, para amenizá-las momentaneamente. Não que o problema seja insolúvel. As soluções existem. Sob o nome, já bastante difundido, de “formas alternativas de convivência com a seca”, são bastante conhecidas as experiências de captação e armazenamento de água desenvolvidas por órgãos públicos, por exemplo, EMBRAPA, ou organizações não governamentais como CAATINGA e IRPAA.

De igual modo são conhecidas as razões pelas quais o poder público, seja no plano municipal, estadual ou federal, tem-se mostrado incapaz de enfrentar de forma eficaz as conseqüências do fenômeno da seca.

Conscientes dessa “incapacidade” política dos governantes os trabalhadores rurais de Campo Alegre de Lourdes resolveram enfrentar o problema.

Queremos, neste breve relato, contar a história desses trabalhadores e de como enfrentaram o problema e as conseqüências advindas desse processo.

A História

O município de Campo Alegre de Lourdes situa-se ao norte do Estado da Bahia na divisa com o Estado do Piauí. Embora esteja dentro da área do Vale do São Francisco, fica a 120 km do mesmo. Não é cortado por nenhum curso de água permanente e situa-se no chamado POLÍGONO DA SECA. Possui uma população de 28.000 habitantes sendo que 21.000 na área rural. A base de sua economia é a agricultura de subsistência e a pecuária de pequeno e grande porte.

A população depende totalmente da água da chuva. A água do subsolo é salgada, devido ao tipo de formação dos solos, servindo tão somente para os rebanhos.

O município de Campo Alegre de Lourdes já existe a 37 anos e não havia, até o ano de 1998, uma só obra para armazenar água feita pelo poder público municipal. Em 1998, a Prefeitura construiu algumas cisternas (6 em prédios escolares do interior e 12 na cidade). Os barreiros existentes foram feitos pelos próprios moradores. As pequenas e médias barragens foram executadas nas frentes de serviços, durante os períodos agudos de seca, subsidiadas e administradas pela CODEVASF.

É neste contexto que surgiu a Luta pela Água em Campo Alegre de Lourdes.

Em 1991 a diretoria que assume o Sindicato dos Trabalhadores rurais tem metas bem definidas. Uma delas: LUTA PELA ÁGUA.

Ao STR soma-se a ação da CPT no município e da Paróquia que promove cursos de CONVIVÊNCIA COM O SEMI-ÁRIDO. Os cursos são ministrados pelo IRPAA.

Em 1992 o STR promove um primeiro levantamento sobre os recursos e a demanda de água necessárias nas comunidades. 47 comunidades participaram, num total de 641 famílias. Dessas, 180 famílias mostraram-se dispostas a entrar na luta por uma vida mais viável no sertão. A partir dos dados levantados foram elaborados documentos sobre as necessidades de obras para armazenar água, sobretudo cisternas, e enviados a diversos órgãos públicos - SUDENE, SECRETARIA DE AGRICULTURA DO ESTADO DA BAHIA, PREFEITURA MUNICIPAL, CODEVASF, ENTRE OUTROS. Não houve resposta.

Em 1993 o Sindicato dos Trabalhadores Rurais de Campo Alegre de Lourdes, elabora o Primeiro Projeto de Construção de cisternas familiares para a captação de água das chuvas para consumo humano.

O Projeto de Construção de Cisternas Familiares em Campo Alegre de Lourdes previa a construção de 100 cisternas e foi enviado à OXFAM. O Projeto é a fundo perdido; contudo, como a intenção não é simplesmente construir cisternas, mas fazer com que a experiência se torne um passo de um processo mais amplo, os trabalhadores beneficiados com as cisternas assumem o compromisso de devolver 50 % do valor da cisterna para que outros também sejam beneficiados. De *fundo perdido* passa para *fundo rotativo*.

O Projeto foi aprovado e as construções iniciadas. Já no período das chuvas em 93-94 muitas famílias conseguiram armazenar água suficiente para o ano todo.

Em meados de 1994 é apresentada à Câmara de Vereadores uma proposta de emenda ao orçamento para a construção de 400 cisternas familiares. Os vereadores nem sequer lêem a emenda.

Em 1995 quando o Deputado Alcides Modesto foi Presidente da Comissão de Agricultura, tentou-se que fossem alocados recursos no orçamento da união para a construção de cisternas em Campo Alegre de Lourdes. Também não se conseguiu nada.

Todas essas tentativas e recusas foram criando nos trabalhadores, uma espécie de “indignação” e uma “determinação” mais forte ainda de conseguirem o que queriam: “água”.

Desde o início do Projeto de construção de cisternas familiares começou-se a discutir também as outras necessidades de água para a população e para o criatório. Para se ter o quadro real, optou-se por fazer um levantamento sobre água em todo o município.

O levantamento foi feito em 132 comunidades.

Feita a tabulação dos dados, convocou-se um seminário com os trabalhadores de Campo Alegre de Lourdes. No seminário foram apresentados os dados e discutido como dar os próximos passos.

A decisão foi fazer um Plano de Água para o município. Para isso percebeu-se a necessidade de mais dados técnicos. Formaram-se, então, grupos de trabalho para buscar esses dados. As fontes foram a EMBRAPA, a CODEVASF e a CERB.

Os contatos com a EMBRAPA resultaram numa reunião do grupo de trabalho com os seus técnicos e com o então secretário da Agricultura do Município de Petrolina que expôs para os trabalhadores o Plano de Abastecimento do Município.

Os contatos com a CODEVASF, rendeu a ida de engenheiros ao município para fazer o levantamento dos locais possíveis de construção de barragens, orçamento e capacidade de armazenamento de água.. Além disso a CODEVASF forneceu os valores pagos pelo governo quando da construção de barreiros, cisternas e barragens, tanto manual como mecanizado.

Com os dados levantados nas comunidades e os dados técnicos obtidos junto à EMBRAPA, CODEVASF E CERB foi possível a elaboração do PLANO DE ÁGUA.

]

Elaborado o Plano de Água o passo seguinte foi discutir nas comunidades que caminho tomar para que o Plano se transformasse em Lei Municipal.

A decisão tomada foi apresentar ao Legislativo Municipal um PROJETO DE LEI DE INICIATIVA POPULAR QUE DISPÕE SOBRE O PROGRAMA MUNICIPAL DE APROVEITAMENTO DOS RECURSOS HÍDRICOS.

Redigidos o Projeto de Lei e o Programa, foram aprovados em assembléia pelo trabalhadores no dia 25 de julho de 1996, dia do trabalhador Rural. A partir daí foi feita a colheita das assinaturas - são necessárias 5 % das assinaturas dos eleitores. Em duas semanas de trabalho conseguiu-se que 8 % dos eleitores assinassem o Projeto de Lei.

O Projeto de Lei de Campo Alegre de Lourdes deu entrada na Câmara dos Vereadores no dia 08 de outubro de 1996. Nos meses de agosto e setembro a Câmara não teve quorum para reunir-se..

O Presidente da Câmara marcou a votação do Projeto de Lei para o dia 21 de outubro. Mais de 100 trabalhadores estiveram presentes no dia da votação. Novamente não deu quorum.

Nova votação foi marcada para o dia 28 de outubro de 1996. E o Projeto de Lei não foi aprovado pela Câmara de Vereadores, atendendo a indicação do Prefeito recém eleito.

Este é o resumo do processo vivido até agora pelos trabalhadores de Campo Alegre de Lourdes, na luta por viabilizar a vida no sertão tendo acesso à água em quantidade suficiente e em qualidade condizente com a condição de pessoas, homens e mulheres, cidadãos brasileiros.

O que está resultando desse processo

Sabemos que a água no sertão é um fator que mantém o povo subjugado aos “mais fortes” pela dependência, seja na época das secas seja nos períodos normais de estiagem.

Além de todo um universo simbólico cultural que pesa forte, há o fator econômico que impede a população rural de abastecer-se de água para o ano todo. Praticamente nenhum trabalhador rural de Campo Alegre de Lourdes teria condições de juntar R\$ 500,00 de uma vez só para construir uma cisterna.

Dessa forma, fornecendo ao trabalhador o que não se encontra na natureza, já foram construídas 1.240 cisternas, com recursos de ONGs e administrados pelo STR. A partir de 1998, com a abertura de linhas de crédito para os pequenos produtores, mais 400 cisternas foram financiadas pelo Banco do Brasil e Banco Nordeste.

As famílias que já foram beneficiadas sentem-se “livres” com relação à água, adquirem autonomia, não precisam mais implorar por carro-pipa.

Tornar-se autônomo no abastecimento de água, sentir que nem tudo depende dos “poderosos” é um passo significativo para a conquista da cidadania.

O individual e o comunitário

As cisternas são individuais (família-casa). E um dos pontos nevrálgicos de todo o Projeto é fazer com que as pessoas (da família-da casa) beneficiadas continuem interessadas pelo Projeto.

“A cisterna foi um começo, a luta da gente nunca pára. Se eu for parar porque tenho essa cisterna em casa e a maioria dos companheiros não tem, se cada um que adquire sua cisterna for parando, desse jeito a gente nunca, nós vamos adquirir nada..” (Armando - comunidade da Lagoa do Joãozinho)

Esse depoimento do Armando diz bem o significado da luta para que “todos” tenham água.

A cisterna é individual, mas prevalece, no uso da água, a generosa solidariedade do povo sertanejo. E a cisterna torna-se a fonte de água para muitas famílias. “O que se percebe é a união das famílias, porque a cisterna é familiar, só que no momento da seca, no momento mesmo que termina a água nos barreiros ela se torna uma cisterna comunitária, porque toda a comunidade faz uso dessa água”. (Armínio - Presidente do STR).

O “natural” e o Político

Por séculos o sertanejo afirmou aquilo que lhe foi ensinado: “Deus quer assim”. “A chuva vem de Deus”. “Se Deus quiser vós vamos ter água”. “A seca é castigo de Deus”. Esse tipo de discurso é que encobre a verdadeira razão do padecimento do sertanejo: a falta de vontade política de resolver o problema de abastecimento de água.

Parece-nos que está se rasgando o véu. A partir da construção das primeiras cisternas que, cheias na época da chuva, abasteceram as famílias o ano todo, a compreensão começou a ser outra.

“Um dos desafios é que o pessoal colocava que aqui no Nordeste, aqui em Campo Alegre de Lourdes não chovia. Que a seca era um fenômeno mesmo, era que Deus queria e não sei o que. Como nossos anseios não encontraram resposta nos políticos, começamos a fazer cisternas. E uma coisa interessante aconteceu: o crescimento que deu à gente como cidadão e cidadã para assumir essa luta. Mudou até a mentalidade do povo de que a chuva é Deus que manda, a seca é quando Deus quer e hoje o pessoal já descobriu que o que faz a seca mesmo é a administração política, a falta de vontade política de administrar essa questão da água”. (Armínio - Presidente do STR).

O exercício do poder/governo

O Projeto dos trabalhadores de Campo Alegre de Lourdes está colaborando para o desvelamento de uma outra herança: o exercício do poder, do governo e consequentemente para o resgate e exercício da cidadania. Entendendo por cidadania a participação no governo através da discussão, proposição e decisão do que diz respeito à vida pública e aos destinos dos cidadãos.

Somos herdeiros de uma história colonial onde o senhor manda e governa, o escravo trabalha e obedece. Temos pouco costume de pensar o exercício da cidadania como governo que não se reduz às iniciativas e propostas do Estado e nem se esgota no voto.

Em entrevista, Armínio afirma a necessidade de se fazer algo concreto e não só reivindicações. Esse algo concreto são as cisternas já que os “senhores/governantes” não tem a iniciativa, ou não querem fazê-las. É o trabalhador decidindo/propondo/executando independentemente do senhor/governante soluções para as suas vidas.

Mas não é obra substituta do estado. Com isso os trabalhadores querem interferir diretamente nas políticas públicas e democratizar o poder, os recursos para que as soluções atinjam a todos.

O governo, a administração interna do Projeto tenta ser democrática. Há a coordenação que é exercida pelo STR (presidente e outros membros da diretoria). Nas diversas regiões do município estão os delegados sindicais que formam equipes de trabalho para discutir e tomar decisões nos seus lugares, nas suas comunidades e irem a outras comunidades para difundir o Projeto, discutir, decidir.

Anualmente são feitas duas assembléias gerais onde se avalia o Projeto, discutem-se problemas e se tomam decisões. Nas regiões são feitas assembléias periódicas pelo menos

duas vezes ao ano com a mesma finalidade. Nas comunidades, 132, são constantes as reuniões.

Há um fluxo contínuo de informações entre os trabalhadores e os coordenadores do Projeto, o que nos parece, é garantia de participação/democracia.

A prestação de contas é pública, nas assembléias, através do rádio e em circulares. Mesmo assim há problemas. Ainda há delegação de poderes aos dirigentes e há dirigentes que tentam tirar proveito de sua situação.

Outro aspecto desta mesma questão são as possibilidades que os trabalhadores começam a perceber de estender o seu raio de governo para outras atividades da vida pública.

Parece-nos que os trabalhadores estão descobrindo formas novas de intervir na realidade sócio-político-econômica do município de forma organizada, eficiente, co-responsável, solidária. Será essa uma nova forma de exercer o governo/poder?

Democratização do saber

Enquanto no mundo néo-liberal cada um quer patentear seus produtos, resguardar seus inventos e tecnologias, ter exclusividade do seu saber e com isso auferir lucros, a experiência de Campo Alegre de Lourdes aponta um outro caminho, que chamo de democratização do saber.

Às técnicas já conhecidas dos trabalhadores somaram-se técnicas novas que hoje já estão incorporadas no dia a dia. Algumas delas já foram citadas neste trabalho.

E os conhecimentos que necessitavam e não puderam adquirir ali mesmo em Campo Alegre de Lourdes foram buscar com quem tinha condições de saber e fazer. Praticamente “arrancaram” as informações dos órgãos do governo.

Os trabalhadores são participantes do processo e não apenas beneficiários ou executores, isso graças à difusão dos conhecimentos e o senso de corresponsabilidade impresso fortemente desde o início do processo.

Novas relações

É por demais conhecida a sujeição da mulher nordestina. A típica imagem da mulher carregando os filhos pendurados nas saias e nos braços, andando a pé atrás do homem que vai à cavalo na frente, é uma realidade ainda nos dias de hoje.

O homem nunca se preocupou com a água de dentro de casa. Ele se preocupa com a água para o “criatório”. A água da casa é função da mulher encontrar e abastecer os potes.

Com a construção das cisternas, a água da casa passa a ser preocupação do homem também e com isso parece que o homem começa a ver a mulher de maneira diferente, mais como companheira.

Vi na comunidade - Lagoa de Dentro - uma casa com duas cisternas. O dono da casa explicou porque havia feito duas cisternas, uma com recursos do Projeto e a outra por conta própria. Segundo ele, depois que construiu a primeira cisterna, a do Projeto, ele começou a perceber como havia, por tantos anos, sujeitado a sua mulher a um trabalho pesado, estafante, do qual ele usufruía sem nunca agradecer a sua mulher por ter sempre água em casa, e que não era justo e que ele nunca mais queria ver a sua companheira com uma lata de água na cabeça andando todos os dias uma distância absurda, com todo aquele peso.

A relação cidade/zona rural em Campo Alegre de Lourdes, sempre foi muito tensa, desde a época em que os agricultores saquearam a cidade lá por volta de 1983.

O projeto de cisternas tem contribuído para refazer essa relação. E são dois os motivos: Primeiro - o Plano de Água prevê o abastecimento de água também para a cidade. Já foram construídas várias cisternas nas casas da cidade. Segundo: Com a construção das cisternas a economia de Campo Alegre de Lourdes foi dinamizada. De alguma forma o tecido social campo / cidade está sendo modificado.

Uma outra mudança, parece-nos, está acontecendo na relação dos trabalhadores com os políticos locais. Uma relação mais amadurecida, mais confiante, de igual para igual e não mais de senhor/servo.

Ainda no campo das relações não há dúvida de que o Projeto das cisternas, com todos os seus desdobramentos fez com que os trabalhadores revalorizassem/reinventassem suas organizações. O STR, tornou-se, novamente um órgão confiável e aglutinador das aspirações e proposições dos trabalhadores. Hoje é indiscutível a confiabilidade do STR até mesmo por parte daqueles que não concordam com sua política.

A essas formas de participação somaram-se novas formas de organização voltadas para interesses específicos: associações de Fundo de Pasto para a regularização fundiária, associações comunitárias, voltadas mais para a produção e, ultimamente grupos de trabalhadores que vinham explorando a criação de abelhas, estão fundando uma cooperativa de mel.

Mudanças culturais

No bojo da experiência dos trabalhadores de Campo Alegre de Lourdes estão se processando algumas mudanças culturais significativas e outros traços culturais permanecem ainda bastante inalterados para a maioria dos trabalhadores.

Entre as mudanças podemos citar: de uma visão fatalista da seca, passa-se a ter uma visão mais crítica - de vontade divina para vontade política; da resolução individual, imediata do problema, para uma busca coletiva e social de solução para a falta de água; do buscar o próprio benefício, para a busca do bem para todos; da submissão aos políticos/senhores/governantes, para o traçar o seu destino; da sujeição feminina, para o questionar, enfrentar, realizar da mulher; do reclamar, “pedir”, para o propor e realizar.

Entre os traços inalterados da cultura, está muito forte ainda, a delegação de poderes a outros, um certo corporativismo, a quase ausência total de jovens enfrentando o Projeto.

Mantém-se, também, muito forte e com novas nuances, a solidariedade entre a população, o apego à terra, a festa.

Reinventando a vida - Conclusão

Para lidar com a fragilidade da vida no sertão é necessário reinventar modos de viver continuamente. E nesse reinventar está a possibilidade de se continuar vivendo e de criar uma fortaleza que, aparentemente, nada significa diante das investidas dos que exploram a fragilidade.

Mas o processo vivido em Campo Alegre de Lourdes nos mostra que é possível fortalecer a fragilidade e que isso só é possível quando a vida é a motivação mais forte.

Para quem não tem problema de abastecimento de água, é difícil perceber o alcance que tem, o significado real e simbólico de ter uma cisterna no oitão da casa, de ter certeza que se vai ter água para beber, que não vai ser necessário “retirar-se” de sua casa, de sua terra, por falta de água.

Por séculos o sertanejo acreditou naturalmente que não tinha água devido a uma vontade superior à sua, uma vontade que se comprazia em mandar ou não mandar chuva segundo os seus caprichos e que essa vontade tinha uma extensão, ali, bem próximo dele que também agia segundo a vontade que tivesse no momento. Isso tornava o morador do sertão mais frágil ainda e a vida, nestas condições, nada mais era do que adequar-se a essas duas vontades.

Há, agora, um descortinar-se de outra possibilidade onde entra a vontade do homem, do trabalhador que percebe que o fizeram frágil mas que pode tornar-se forte o suficiente para mudar as condições de sua existência.

Esse desvelamento dos mecanismos de sujeição é lento, doloroso, sofrido, mas, também, desperta nos que o processam, uma gama imensa de possibilidades de estarem continuamente reinventando a vida, as relações, a compreensão do mundo e do espaço em que vivem.

Comparative Review of Drinking Water Quality from Different Rain Water Harvesting Systems in Sri Lanka

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Abstract

The main constraints on using rainwater for domestic use have been the water quality aspects. The quality of rainwater collected depends on the cleanliness of the atmosphere, materials used for the catchment surface, gutters and down pipe of the storage tank and the water extraction device. In the hill country and in the north central province acid rain has been recorded and in the western province rainwater has carried high nitrate levels. Compared to other industrialised countries in the region, however, acid rain is still not considered a serious problem in Sri Lanka.

This study reviews the quality of rain collected throughout Sri Lanka from different types of storage tanks and roofs. It will compare the traditional rainwater collecting methods with the present available technology of the Community Water Supply and Sanitation Project (CWSSP). It looks at the health aspects of drinking rainwater related to biological contamination and indirectly due to disease vectors like mosquito and other insects/pest breeding in the stored water. Recommendations will be given on the different water treatment methods along with some suggestions for improvement.

The result shows that the rainwater collected and stored with adequate care meets the microbiological standards set by the WHO for total coliform in drinking. The data obtained reveal that the quality of the rainwater collected depends on the storage and the management of the system.

Introduction

In Sri Lanka rain water harvesting for domestic use was practised for many centuries, such as for example the 5th Century Sigiriya fortress complex, the sophisticated rain water-cum-reservoir systems. In recent years many of these rain water collection skills have become obsolete due to introduction of pipe supplies, boreholes or protected wells or springs. However the pressures of increasing population and competition for resources in the second half of the 20th century have forced people to settle in areas that have less water resources. In certain part of the dry zone, the coastal belt, with salt water intrusion into the ground water, and some uphill localities in the wet zone, rainwater harvesting remains an important, and sometimes the sole, source of water.

More than 75% of the island's landmass receive minimum of 1250 mm annual average rainfall and rain water harvesting is feasible in all zones. Rainfall pattern in Sri Lanka exhibit a noteworthy regional and seasonal variation (Abeyratna, 1998). Rainfall pattern is influenced by two major monsoons. The North East Monsoon bringing rain to the dry

zone of the country from November through April while the South-West monsoon brings rain to the wet zone from May through October.

The main constraints on using rainwater for domestic use have been the water quality aspects. Quality of rainwater collected depends on the cleanliness of the atmosphere, material used for the catchment surface, gutters and down pipe, the storage tank and the water extraction device.

Atmosphere

Precipitation comes from the condensed vapour of meteoric water and its water quality relies to a greater extent on local environment conditions. The composition of the precipitation is highly influenced by the combustion of fossil fuels, large-scale industrial emissions and dust and debris derived from both natural and human influences. Acid precipitation occurs when SO_2 and NO_x , emitted by burning of coal, natural gas and petroleum products, oxidised in the atmosphere form sulphuric acid and nitric acid

Ileperuma (1988) reports of acid rain (rain water having $\text{pH} < 5.6$ from the hill country and the north central province. This was attributed to winds carrying exhaust fumes from western province (Colombo), fumes originating from power stations in Tamil Nadu and increased use of diesel fuel from rice mills which had run on rice hull before. However, acid rain is not thought to be a major problem in Sri Lanka compared to more industrial countries in the region such as Singapore, Thailand, Indonesia and Malaysia (Ileperuma, 1998).

Storage of Rain water

Storage of rainwater is one of the major factors influencing the quality of water. This study compares the water quality data collected from the traditional square brick tanks as well as CWSSP tanks.

Traditional Methods

Traditional domestic rainwater harvesting in Sri Lanka can be categorised in three methods: open air collection, collection from tree trunks and collecting from temporary gutters into square brick tank (Ariyabandu, 1998). Many of the traditional systems collect water during the wet-day or wet-season only and do not store water for more than few days. A study reveals (Hapugoda 1995) that rain water harvesting for domestic consumption was extensively practised especially in upland areas (Kundasale, Bandarwela). In these areas rainwater is collected from permanent roofs made of tiles, asbestos or tin sheet. Thatched roofs have also been used for rainwater collection in some remote villages; however, this water is not used for drinking. Some of the gutters used in traditional system are tin sheets, banana stems, Aricunut (Areca catechu) sheaths and Bamboo (Ariyabandu 1998).

Common storage tanks found in Kandy district (Ahaspokuna) and in some localities in the dry zone are rectangular square cement tanks with a capacity of 1500-3000 liters. These tanks are generally kept open, (sometimes covered with a mesh) and water supplies are sufficient for an average family for a few days. The average cost building such tank is Rs. 3,000-6,000

CWSSP Tanks

In the last few years there has been a revival of rainwater harvesting and research was conducted to improve the technology. In 1992, the government of Sri Lanka initiated the Community Water Supply and Sanitation Project (CWSSP) with assistance from the World Bank. The objective is to provide affordable safe drinking water and sanitation facilities to rural community in Badulla, Matara and Ratnapura district. During the implementation of CWSSP, it was noted that several villages in Badulla district could not be served with available conventional water supply technology. For these uphill settlements, rainwater harvesting would be a possible option to provide water with minimum cost.

In 1995, two types of 5m^3 storage tanks were designed for local use. One, called brick dome tank, (fig. 1) is constructed below ground and made of burnt brick and cement sand mortar. It is modelled after the Chinese biogas digester. The other, called ferrocement tank (fig 2.), is constructed above ground and made of chicken mesh reinforced cement sand mortar and built in the shape of sapherical jar. Both tanks collect roof runoff through a system of gutters and down pipes.

Figure 1: Underground Brick Dome tank

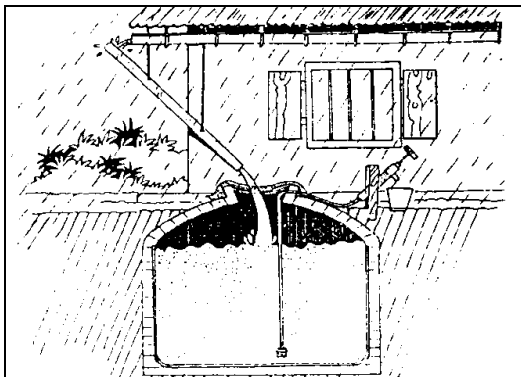
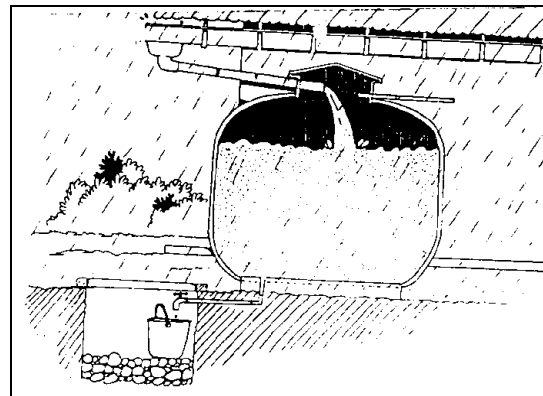


Figure 2: Above Ground Ferrocement Tank



The tank was designed taking into account the roof size, rain fall data, number of people and their daily requirements as well as the subsidy offered per household by CWSSP. On this basis a family of 5 with a minimal daily requirement of 20l for a period of 50 days the storage requirement will be 5000l ($5 \times 20\text{l} \times 50 = 5000\text{l}$ (5m^3)). Even with a small roof, it takes only few days to fill during the rainy season.

Table. 1 Cost estimates for Brick and Ferrocement Tanks

Description	Unit	Rate	Brick tank		Ferrocement Tank	
			Quantity	Total in Rs.	Quantity	Total in Rs.
Cement	Bags	310	8.5	2635	8.0	2480
Sand	Cubes	1700	0.4	680	0.6	1020
$\frac{3}{4}$ " Metal	Cubes	4000	0.1	400	0.06	240
Brick	Nos.	2/10	800	1680		
Padlo Cement	Kg.	100	0.5	50	0.5	50
Chicken wire	Sq.m.	40			40	2200
Binding Wire	Kg.	85			1	85
Skilled labour	Days	250	4	1000	8	2000
			Total Rs.	6445	Total Rs.	8075
Unskilled labour	Days	150	12	1800	14	2100
			Total Rs.	8245	Total Rs.	10175

Heijnen & Mansur (1998)

Initially only the storage tank was provided by CWSSP and beneficiaries had to include the lid of the tank, gutters, pipes, first flush device and a simple gravel filter in their system. People who included such devices in their system found improvement in the water quality. Subsequently, filters and lid of the tank were also provided by CWSSP and they were made compulsory for all types of tanks to prevent contamination. The tight cover ensures dark storage condition preventing growth of algae and breeding of mosquito larvae. A simple hand pump was also designed to extract water from the underground tank, which was later included in the subsidy.

Water Quality

Table 2 Water quality data from the two types of Rainwater harvesting tank systems

Location/types of tank	No. of samples	pH	Colour	Turbidity	Conductivity	Total Colioform per 100ml	E. Coli per 100 ml
Open rectangular tanks (Ahspokuna)☞	18	6.0-7.5	5-110	5-15	50-200	04-1000	00-180
CWSSP tanks (Badulla)☞☞	39	6.5-10	10-40, 100	0-16	45-229	0-170	0
Drinking water WHO standard		6.5-8.5	0-30	0-20	5-1500	10	00

☞ Padmasiri (1998) ☞☞ Mansur (1999)

pH

pH is within the required range for drinking water in the Ahapokuna open tanks, however in the CWSSP tanks 90% of the samples meet the WHO standard. High pH value were obtained from the newly build tanks due to the cement byproducts. (Table 2).

Color

High value in the Ahaspokuna tank was due to the presence of decaying leaves in these tanks. In the CWSSP tanks high value was obtained from an almost empty tank. However, 82% of the tanks meet the required WHO standards, even though none of the tanks were fitted with filters.

Turbidity

Suspended matter such as silt, dust, debris from the roof and the atmosphere are the main substance causing turbidity to increase in rainwater. Both tank types meet the required WHO standard.

Conductivity

Conductivity indicates the total dissolved solids. Water with high conductivity means high total dissolved solid content, changing taste, hardness, and other associated properties that effect portability. In both tanks the conductivity value is similar and meets the required standards.

Total Coliform at 35°C and Fecal coliform (E.Coli) at 37°C

Contamination by sewage or by human or animal excrement is the greatest danger associated with water for drinking. Sewage from human or animal sources may contain the causative organism of many communicable diseases. E. coli and Coliform are present in large number in faeces and sewage and can be detected in numbers as 1 in 100 ml of water. A sensitive indicator has been used to detect contamination of water by human excrements.

According to the total Coliform values (table 2) both tanks do not comply with the drinking water standards. However, E.coli has not been detected in the CWSSP tanks. This can indicate several things, one being that the contamination has been remote and E. coli had died out. Contamination can also stem from soil washing or from growth on decaying vegetation. Coliform, other than E. Coli, can also occur in water sources.

Mosquito and other insect pests have been reported in both tanks (Padmasiri, 1998, Ariyabandu, 1998²). At Ahaspokuna mosquito breeding is prevented by rearing fish in the tanks. Mosquito breeding was detected in the CWSSP tanks without a lid and unclean gutters with accumulated water. Other insects such as lizards, frogs and ants are also reported in underground brick tanks (Ariyabandu, 1998²). Most of these tanks either have no lid or the insects have gained access through overflow pipes.

Conclusion and Recommendations

Quality of collected rainwater in the CWSSP tank is better than in the traditional open rectangular tank. The main reason for this is that the CWSSP tank is covered with a lid and the absence of sunlight prevents formation of algae and spoiling of water. It also prevents mosquitoes and other insects from breeding in the tanks.

In terms of physical parameters both tanks systems satisfy the guidelines and are suitable for drinking. However, regarding bacteriological quality, the Ahaspokuna tank does not meet the required standards and the CWSSP tank indicates faecal contamination, though it may not be from humans.

None of the tanks tested used a first flush device and did not have a filter system. A simple screen made up of cloth or mosquito net and simple gravel and sand filter (later adopted by the CWSSP system) has been found to improve the water quality, preventing dust, decaying leaves and other impurities from entering the tank.

Quality of the collected water also depends on the operation and management system. Regular cleaning of the roof, tanks and gutters, as well as using an extraction device or pipe system to withdraw water and using the first flush device contribute to the collection and storage of good quality rainwater.

Good quality drinking water can be collected from rainwater, if it is collected with utmost care. Nevertheless contamination can occur through the various surface it has to pass through. Therefore, disinfecting through boiling or chlorinating or solar water disinfection is recommended to ensure the safety of water for drinking purpose.

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Uso da semente do gênero *moringa*

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Resumo

Tradicionalmente, em diferentes países do continente asiático, africano e sul-americano, varias plantas estão sendo utilizadas como coagulantes ou floculante natural. O objetivo deste processo é precipitar os colóides presente nas águas destinadas principalmente ao consumo humano. Devido principalmente à presença de partículas argilosas e de matéria orgânica, estas águas não apresentam os padrões qualitativos para o consumo tanto do ponto de vista físico (turbidez alta) como da contaminação microbiológico. O gênero *MORINGA*, e particularmente as espécies *M. olerifera* e *M. stenopetala*, destacam-se como um dos mais promissores coagulantes naturais. Além desta propriedade de coagulação contida nas sementes, estas arvores de médio porte apresentam outras funções (farmacêutico, alimentar, melífera) valorizadas nos numerosos países tropicais onde este gênero esta presente.

1. ALGUMAS INFORMAÇÕES SOBRE O GÊNERO “*MORINGA*”

1.1 ALGUNS DADOS BOTÂNICOS

A pequena família *Moringaceae*, da ordem *papaverales*, conta com apenas um gênero (*Moringa*). Das 14 espécies conhecidas, 9 são originarias da África, 2 de Madagascar, 1 da Arábia e 2 da Índia. O efeito coagulante foi demonstrado para 6 espécies, porem somente 2 foram objetos de pesquisa mais intensa: a *M. oleifera* Lam. Originaria da região noroeste da Índia que esta difundida em muitos países tropicais e a *M. stenopetala* originaria da Etiópia (Al azharia Jahn, 1998).

São plantas arbóreas de crescimento rápido, caducifólias, com casca de cor clara, atingindo até 10 metros de altura. O fruto seco, capsular, de seção triangular se abre em 3 valvas. As sementes possuem 3 asas.

1.2 HISTÓRICO DA DIFUSÃO

A difusão da *Moringa oleifera* está ligada aos impérios colonialistas do século XIX. Os funcionários ingleses levaram a semente da Índia para a África do leste, principalmente no Sudão. Inicialmente, o uso desta arvore era principalmente ornamental. A descoberta das propriedades do óleo contido nas sementes, deu um valor comercial a esta planta e, consequentemente uma difusão mais ativa por parte dos ingleses, mas também dos franceses e holandeses. No final do século XIX, foi introduzida na América Central (Guatemala) a parti do Haiti (Cárceres et al.). No Brasil, a introdução da arvore foi tímida e limitou-se a objetivos de ornamentação nos parques públicos (Brandão Joly, 1977).

1.3 CARACTERÍSTICAS AGRONÔMICAS

Segundo uma pesquisa de Mayer et al. No sul da Etiópia, *M. stenopetala* se adapta bem as condições climáticas tanto do clima semi-árido como sub-úmido com altitude inferior a 2000 metros. As exigências assimilam-se às da *M. stenopetala*: uma pluviometria mínima da ordem

de 600 a 700 mm, temperaturas ótimas entre 24 e 30 °C e solos bem drenados. Segundo um estudo edáfico dos mesmos autores, a planta não apresenta exigências específicas em termos de tipos de solo a não ser a impossibilidade de se desenvolver em solos encharcados.

A propagação da semente da *M. oleifera* não apresenta dificuldades qualquer que seja escolhido o método. Plantio direto, produção de mudas a partir de sementes ou de estacas.

Segundo vários autores, a melhor taxa de germinação da moringa obtém-se depois de deixar a semente 24 horas na água a temperatura ambiente. O plantio em viveiro (bolsa de polietileno) é realizado imediatamente depois. Os resultados mostraram uma taxa de germinação da ordem de 90% com sementes de até 9 meses (Cárceres et al).

1.4 CARACTERÍSTICAS FENOLÓGICAS:

1.4.1 Primeira frutificação:

A idade da árvore na primeira frutificação é variável; em geral, considera-se que a *Moringa oleifera* frutifica no primeiro ano nas condições ideais de manejo. Nas regiões semi-áridas da África, considera-se que a *M. oleifera* frutifica a partir do segundo ano (Wolf from Nigg, 1993).

1.4.2 Floração/Frutificação:

A floração acontece geralmente no final da estação úmida, a perda das folhas ocorre no início do período seco. As observações de vários autores mostraram que frequentemente existem vários estados fenológicos ao mesmo tempo numa árvore: folhas, flores e frutos mais ou menos maduros.

1.4.3 Produtividade em vagens

☐ Comprimento das vagens:

Segundo Al Azharia Jahn, o comprimento das vagens da *M. oleifera* é muito variável e pode ser classificado em três grupos:

- ☐ Vagens curtas com um comprimento variando entre 15 a 25 cm;
- ☐ Vagens médias com um comprimento variando entre 25 a 40cm
- ☐ Vagens longas com um comprimento variando entre 50 a 90 cm

☐ Número de vagens por árvore:

O número de 300 vagens por árvore foi apresentado como um máximo no Egito, Sudão e Quênia por B. Durand citado por Wolf from Nigg. porém, na Índia, Al Azharia Jahn, chegou a calcular produção de 1.000 até 1.600 vagens por árvore.

☐ Número de sementes por vagens:

Pode-se considerar que o número satisfatório de sementes oscila entre 10 e 20 por vagem.

☐ Estimação da produção anual de sementes

A mesma autora classificou o nível de produção anual das *M. oleifera* em três níveis:

- ☐ Baixo - 1,5 a 2.000 sementes/planta
- ☐ Médio - 6 a 8000 sementes/planta

Elevado – 20 a 24000 sementes/planta

Na bibliografia consultada, os números de produtividade apresentam grandes variações segundo os autores, os países, o clima (sobretudo, a disponibilidade de água) mas também o manejo da árvore.

2. UMA PLANTA DE USO POLIVALENTE

☐ COAGULANTE PRIMÁRIO:

Várias pesquisas no mundo mostraram que os cotilédones de 6 espécies do gênero *Moringa* contém propriedades de coagulação. Isso que permitem precipitar as partículas de barro contidas tudo nas águas de origem superficial como a dos açudes e barreiros. Posteriormente, retira-se o resíduo precipitado para obter uma água de boa qualidade.

Esta função é realizada no mundo inteiro, com um produto químico, sulfato de alumínio. No meio rural, os moradores geralmente consomem a água bruta, com contaminação microbiológica e turbidez muito acima dos “limites aceitáveis”. A possibilidade de utilizar um coagulante primário natural, produzido no local e com baixo custo representa um grande potencial na luta contra os problemas ligados ao consumo de água não potável.

2.1.1 - Princípio ativo:

A tentativa de isolar o produto coagulante presente nas sementes, foram identificados 6 polipeptídios na *M. oleifera* e 9 na *M. stenopetala*, de peso molecular entre 6 e 16.000 daltons. Os aminoácidos detectados foram maioritariamente o ácido glutâmico, a proline, a metionine, e a arginine (Al Azharia, 1988). Mas o mecanismo de coagulação pelos polipeptídios é ainda desconhecido.

2.1.2 Realização da coagulação

O tratamento físico das águas barrentas pela semente da *Moringa* efetua-se em duas etapas : Primeiro a preparação de suspensão ativa e depois a clarificação da água.

☐ Preparação da suspensão feita com pó da semente:

É aconselhável utilizar sementes colhidas recentemente porque as propriedades flocculantes das sementes podem diminuir com o tempo. A dose a ser utilizada depende da turbidez inicial da água: no caso de água de turbidez fraca (pouco barrenta), uma suspensão com uma semente é suficiente para um volume de água a tratar de 5 litros, mas esta dose pode subir até uma quinzena de sementes no caso de uma água de alta turbidez. Isso corresponde a uma necessidade variando entre 50 e 400 mg de sementes por litro de água a tratar.

Os diferentes passos da preparação da suspensão são os seguintes:

- ☐ Deve-se retirar as asas e casca da semente; somente deve-se utilizar sementes cujos cotilédones não apresentam óbvios sinais de descoloração e/ou extrema dessecação.
- ☐ Cortar as sementes em pequenos pedaços
- ☐ Num pilão, moer os pedaços
- ☐ Agrega-se água limpa na medida seguinte: 1 colher de sopa (10ml) para cada semente
- ☐ Mexer durante 2 a 5 minutos, o produto obtido é uma pasta oleosa chamada de suspensão
- ☐ Deixar descansar durante 5 minutos
- ☐ Filtrar para retirar as partículas (no meio rural pode-se utilizar um pano de algodão)

Depois da filtração, a suspensão esta pronta para ser utilizada para o tratamento da água. Em clima seco e quente, a suspensão não tem estabilidade e, portanto, deve ser preparada diariamente. A uma temperatura de 18-19°C, a suspensão tem uma validade de 3 dias. Refrigerada, a validade pode atingir até uma semana.

- ☐ Clarificação da água
- ☐ Despejar a suspensão na água a ser tratada
- ☐ Mexer rapidamente durante 30 segundos
- ☐ Mexer lentamente durante 5 minutos (18 a 20 rotações por minuto)

- ☐ Cobrir o recipiente
- ☐ Deixar descansar entre 1 ou 2 horas (isso depende da qualidade e da temperatura da água). No fundo do recipiente, são acumuladas todas as partículas grossas deixando a água limpa pronta a ser consumida.

2.1.3 Resultados de coagulação de água barrenta:

O uso das ementas da Moringa como coagulante apresenta uma dupla vantagem:

- ☐ Primeiro, um efeito de tratamento físico (diminuição da turbidez) da água pela coagulação do material em suspensão.
- ☐ Segundo, um efeito de tratamento biológico eliminando os microorganismos patogênicos; esta ação é devida a dois fatores: primeiro, uma grande parte dos microorganismos estão fisicamente ligados as partículas em suspensão na água. Quando estão retiradas depois da coagulação, elimina-se estes patogênicos. Além desta propriedade interessante, uma pesquisa de Al Azharia Jahn (1981;1986) sobre duas espécies de Moringa (*M. stenopetala* e *M. oleifera*) mostrou que os cotilédones contém uma substancia antimicrobiana aumentando o efeito do tratamento biológico da água. Segundo Al Azharia Jahn, com a dosagem de semente adequada, é possível reduzir de 98 a 100% o numero de coliformes fecais de águas brutas inicialmente fortemente túrbidas, após a coagulação, a uma turbidez inferior a 10 ntu³. A água tratada por este método foi objeto de pesquisa para verificar a potabilidade: resíduo nocivo, mudança de ph, de sabor, de cor... Os resultados mostraram que a água tratada pela semente da moringa não apresenta nenhum perigo para a saúde humana (Al Azharia Jahn, 1988).

2.2 OUTROS USOS:

A literatura faz referencia a múltiplos usos das plantas do gênero Moringa:

- ☐ As sementes contém, segundo os autores, entre 27 e 40% de óleo que apresenta a características de não secar. Esta propriedade permitiu o uso para mecanismo de precisão como dos relógios, a parti do século XIX. foi usado também no Haiti como óleo de cozinha e ingredientes na fabricação de sabão durante a primeira guerra mundial. Atualmente, teria um uso na industria de cosméticos para fixar substancias. Segundo Folkard et al., seria possível extrair o óleo da semente e depois utilizar o resíduo para coagulação. Isto não reduziria a eficiência do principio ativo.
- ☐ As folhas contém cerca de 27% de proteína, são ricas em vitamina A e c, cálcio, ferro e fósforo, os que as tornam interessante para a alimentação humana e/ou animal. Lembramos que em vários países da África do Oeste, a Moringa é uma planta comercial para a produção de folhas com destino ao consumo humano.
- ☐ Outras partes da arvore são consumidas pelos humanos como as vagens verdes e às vezes as flores
- ☐ Os usos farmacêuticos de várias partes da arvore foram trabalhados pelo CEMAT na Guatemala como anti-inflamatorio, anti-espasmódico... Foram identificadas também substâncias antibióticas como a ptérygospermine e a espirochine (Wolf from Nigg, 1993).
- ☐ A arvore apresenta propriedades melífera sendo portanto aproveitável na apicultura.

3. POTENCIAL DE DIFUSÃO NO BRASIL:

3.1 A PROPOSTA DE VALORIZAÇÃO DO GÊNERO MORINGA NO NORDESTE BRASILEIRO:

Dentro dos diferentes potenciais da Moringa, o mais promissor parece ser a função de coagulante primário. Podemos imaginar duas zonas de difusão que significam estratégias diferentes: meio rural ou seja as comunidades rurais sem sistema de abastecimento d'água e o meio urbano.

3.1.1 A difusão da Moringa para o tratamento das águas de consumo familiar nas comunidades rurais:

A proposta consiste em uma produção familiar de sementes visando suprir a demanda para o tratamento das águas destinadas a beber e cozinhar. O tratamento seria feito nos próprios potes onde a água é armazenada; a dona de casa colocaria a água e a suspensão a noite para o consumo do dia seguinte. Registros colocados na base do pote (chamado também de “moringa”) permitiriam de esvaziar o acúmulo coagulado e a água tratada.

□ Cálculo da demanda anual em sementes por família:

Considerando uma família de 8 pessoas consumindo 3 litros de água para beber e cozinhar por pessoa por dia, chegamos a um total anual de $3 \times 8 \times 360 = 8.640$ litros/família/ano. Para ter uma margem superior, vamos considerar 10.000 litros de água para beber e cozinhar por família anualmente. Vamos trabalhar com uma hipótese de uma dosagem média anualmente de 1 semente por cada litro. Isto nos leva a uma demanda de 10.000 sementes de Moringa/família/ano.

□ Cálculo da quantidade de árvores necessários para suprir a demanda familiar

Considerando os dados bibliográficos disponíveis, podemos supor que o nível de produção no Sertão seja baixo, devido à pouca disponibilidade de água, uma média de 2.000 sementes/árvore/ano e um nível superior no Agreste de 5.000 sementes/árvore/ano. Este cálculo muito aproximado nos levaria a uma necessidade de 5 árvores/família no Sertão e 2 árvores/família no Agreste.

3.1.2 A difusão da Moringa para o tratamento das águas no meio urbano:

Sem dúvida, não é uma proposta aplicável imediatamente porque necessita numerosas pesquisas e ajustes. Porém, não é uma proposta utópica já que algumas experiências no mundo estão revelando-se frutuosas como no Malawi (citado por Folkard et al). As vantagens do uso de coagulante natural como a Moringa em substituição ao sulfato de alumínio são bastante convincentes: economia de divisas já que o sulfato de alumínio é importado, criação de uma cadeia de comercialização completa de uma nova cultura de renda podendo ser produzida tanto no Agreste como no Sertão.

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*** Experiência de Cisternas de Placa de Pintadas**

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Pintadas, pequeno município, localizado no Sertão Baiano, (região semi-árida), território de 530 km², população aproximadamente 10.5000 habitantes, dos quais 78% vivem no meio rural. Água em Pintadas, sempre foi um bem muito escasso e de baixa potabilidade. Pela sua escassez, a água é uma fonte de poder e de dominação política, principalmente na zona rural. Essa preocupação levou o CCSP - Centro Comunitário e Social de Pintadas a desenvolver uma infra-estrutura para armazenamento de água.

A cisterna de placas foi inventada aproximadamente há 35 anos por um pedreiro de Simão Dias -SE chamado Nel, que em São Paulo na construção de piscinas aprendeu a utilizar placas de cimento pré-moldadas. Ele voltou ao Nordeste e se valeu de sua experiência para criar um novo modelo de cisterna rural de forma cilíndrica, com placas pré-moldadas curvadas, a chamada cisterna de placas.

A partir da invenção de Nel, o CCSP procurou treinar pedreiros pintadenses, os quais aprimoraram a técnica, diminuindo o custo e o tempo para a execução. Hoje gasta-se apenas 3 dias de trabalho e em média R\$ 430,00 para a construção de uma cisterna de 15.000 litros.

Assim temos mais de 650 cisternas de placas construídas, um benefício muito grande para as famílias, pois, agora bebem água de cisterna e não de cacimbas, diminuindo o risco de doenças. A família ganha tempo para outras atividades que antes usava para a busca d'água longe de casa.

Assim Pintadas ficou conhecida como pioneira nas cisternas de placa, pois se não a inventamos, fomos nós que aprimoramos e divulgamos esta técnica. Estamos recebendo muitas visitas e realizando treinamentos para pessoas e entidades do Nordeste todo.

Orçamento para a construção de uma cisterna de placas

Capacidade: 15 000 litros

Pintadas - Bahia

Rubrica	Quant.	Unidade	Valor Unitário	Valor Total
Cimento	13	saco	R\$ 6,50	R\$ 84,50
Ferro de 1/4	2	vara	R\$ 3,20	R\$ 6,40
Brita	10	lata	R\$ 1,00	R\$ 10,00
Arame nº 12	12	KG	R\$ 2,00	R\$ 24,00
Areia	120	lata	R\$ 0,40	R\$ 48,00
Impermeabilizante	1	lata	R\$ 6,00	R\$ 6,00
Escavação	5	dia	R\$ 10,00	R\$ 50,00
Zinco p/ calha	21	m	R\$ 2,30	R\$ 48,30
Cano PVC 75mm	2	vara	R\$ 13,20	R\$ 26,40
Joelho PVC 75mm	3	und	R\$ 1,30	R\$ 3,90
"T" 75mm	1	und.	R\$ 3,00	R\$ 3,00
Transpote de material	#	#	#	R\$ 25,00
Mão-de-obra / Pedreiro	#	#	#	R\$ 90,00
Mão-de-obra / Servente	#	#	#	R\$ 35,00
			TOTAL	R\$ 460,50

Construção de cisternas de tela-cimento na comunidade Xixiakhlá do povo indígena Fulni-ô, Águas Belas – Pernambuco

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Antes da chegada dos europeus nesse imenso território – que atualmente chamamos Brasil – habitavam aproximadamente 5 milhões de índios; com numerosas diferenças econômica, social, política, religiosa e cultural. Nos dias atuais, mesmo depois de tanto genocídio, ainda vivem no Brasil cerca de 240 mil índios com cerca de 170 línguas distintas.

Os índios Fulni-ô são sobreviventes dos povos indígenas de Pernambuco, localizados no município de Águas Belas, na região semi-árida a 310 km de Recife. Com a vinda dos europeus, os índios Fulni-ô doaram forçadamente, parte de suas terras ao patrimônio da igreja, as quais foram mais tarde arrendadas pelo pároco a não-índios e teve como conseqüências: o crescimento da população, a formação da cidade de Águas Belas; aumento dos conflitos entre ambos e o afastamento da população indígena para um quilômetro adiante do antigo aldeamento, onde permanece a maioria até hoje. A distribuição de 11.500 ha de terra aos índios, prometida em 1877 pelo governo provincial, até hoje não foi resolvida.

Atualmente a população Fulni-ô é de aproximadamente 4.000 índios distribuídos entre a aldeia grande, a pequena comunidade Xixiakhlá e os que arriscaram a sorte para sobreviver em outras cidades e estados. O povo Fulni-ô é único dentre os 23 povos indígenas do Nordeste que conserva sua língua nativa o Yathê.

Os índios viviam da caça, da pesca e da colheita. Mas como foram expulsos do litoral e das margens dos rios, não tinham mais como pescar, e com os inúmeros desmatamentos, a caça, os frutos e sementes que coletavam para sua subsistência, tornaram-se escassos. Como os Fulni-ô estão inclusos neste contexto histórico dos índios do Brasil, tiveram que se adaptar as novas exigências da sobrevivência, ou seja, aderir à economia dos não-índios – criar gado e desenvolver atividades agrícolas. Como desconheciam as técnicas agropecuárias, muitos índios preferiram arrendar seus lotes.

No decorrer da colonização, os índios foram vítimas das manipulações políticas, sendo que até hoje não conseguiram se libertar, um exemplo desta situação é como os políticos conseguem se eleger em troca de carro pipa de água, das cestas básicas, ou mesmo da troca de favores, aproveitando especialmente as grandes estiagens para que o povo não tenha outro meio de sobrevivência e autonomia.

Quem sofre mais dentro os Fulni-ô é a comunidade Xixiakhlá, que tem uma população estimada em 15 famílias. Esta comunidade é a mais atingida com a falta de água, pois é um pouco afastada da cidade e não existe um sistema de abastecimento. Já alguns anos atrás fizeram a instalação de um chafariz, mas a rede vem da cidade e só tem água no período de 03 meses. E os índios não tem reservatórios para armazenar água quando chove. Enquanto isso, consomem a água do riacho que em épocas chuvosas, leva o esgoto e toda sujeira da cidade.

Várias instituições tentaram desenvolver atividades de subsistência, como por exemplo uma horta comunitária e construção de um tanque com capacidade para 4.000 litros de água, mas infelizmente não obtiveram êxito.

Diante dessa situação o CIMI - Conselho Indigenista Missionário incentivou os índios desta mesma comunidade a participarem dos cursos do IRPAA - Instituto Regional da Pequena Agropecuária Apropriada sobre sobrevivência no semi-árido. E a partir deste encontro surgiu a idéia de fazer um projeto para construção de poços bate-estaca. A princípio a

pequena Xixiaklhá não foi incluída, mas com o agravamento desta realidade, foi feito um remanejamento, e para insatisfação da comunidade não foi encontrada água subterrânea, o que impossibilitava a construção do poço, mas depois de várias discussões do CIMI, IRPAA e o Pólo Sindical de Petrolândia, decidiu-se construir cisternas de tela-cimento, que segundo o IRPAA seria a solução mais viável para obtenção de água própria para o consumo humano.

Com a construção de 14 cisternas na comunidade Xixiaklhá, o CIMI tem consciência de que não resolverá todos os problemas daquele povo, e sim, é o ponto de partida para segurar-lhes os meios de convivência com o semi-árido e ajudará a amenizar a submissão dos povos indígenas às elites dominantes, ou seja, fortalecendo sua autonomia e consequentemente sua cultura.

Poços Bate-estaca

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Resumo

Os poços bate-estaca tem sido muito importantes para amenizar os problemas causados pela seca ao homem do sertão nordestino. Baseado em um método simples de perfuração de poços, em que um cano de ferro com lâmina (de aço) cortante é preso por uma corda e suspenso por uma roldana que servirá para balancear o peso do carro de ferro, que puxado por algumas pessoas num sistema de vai e vem, o cano de ferro, vai aos poucos conseguindo perfurar o poço. Lembramos ainda que paralelo a escavação utiliza-se água para facilitar a perfuração. Para retirar os resíduos da escavação, retira-se o cano de escavação e com outro cano de ferro semelhante ao primeiro, porém com uma válvula que retém o escoamento escavado, retira-se o que se cavou. É importante lembrar que os poços deverão ser revestidos, para evitar que os mesmos possam fechar em caso de terreno pouco consistente. Os poços bate-estaca podem ser cavados a uma profundidade de até mais de 90m e só podem ser cavados em terrenos de arenito, não sendo viável a sua utilização em terrenos de granito.

Depois de perfurado o poço, para retirar a água pode-se utilizar bombas submersas ou pôr um carro cano com válvula amarrada a uma corda com uma roldana que depois de cheio é puxada para a superfície. Esta tecnologia feita com a participação dos trabalhadores tem ajudado a muitas comunidades a encontrar soluções para a escassez da água e o desenvolvimento sustentável de maneira durável, melhorando a qualidade de vida combinando eficiência econômica (os poços são baratos) e justiça social, sem prejuízo para o meio ambiente. Durante o tempo que trabalhamos com poços bate-estaca podemos observar que um dos pontos negativos é a demora na escavação, porém, perfeitamente recompensado com o baixo custo e com uma tecnologia barata acessível a todos os trabalhadores.

Esses exemplos, e muitos outros espalhados em todo o semi-árido, mostram que ações permanentes possibilitam a convivência com a realidade do semi-árido. Depois dessas ações, viver um ano de seca torna-se perfeitamente viável.

Who drinks what: Potable Water Usage in South Australia

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Abstract

Recent studies which have implicated mains supply water as a source of gastroenteritis (Payment et al, 1991; 1997), have ramifications for water supplies in Australia. This is particularly so for those water supplies in rural or semi -rural communities where the source water is often of a lower quality and its treatment limited.

Rainwater collected and stored in tanks on domestic premises is an important source of potable water in South Australia. However knowledge about the risk to health from drinking tank rainwater is limited. Potential sources of contamination include faecal material from birds, rodents, possums and other animals; accumulated fallout from air pollutants; breakdown products from roofing material, and organic debris from overhanging trees. The focus of this study is the microbiological quality. A number studies of tank rainwater have indicated the water quality to be below guideline values for indicator organisms (Fuller et al. 1981; Thomas and Greene 1993; Edwards 1994). *Cryptosporidium* and *Giardia* cysts have been detected in tank rainwater in the Virgin Islands (Crabtree et al, 1996). Tank rainwater has also been implicated as a cause of an outbreak of gastroenteritis in Trinidad (Koplan et al 1978).

Introduction

The data presented here forms part of a larger study to assess the microbiological health risk associated with tank rainwater consumption. Before examining the health impacts of rainwater use it was first necessary to determine the extent of use of tank rainwater and to clarify regional differences in use across South Australia.

Aim:

To identify the main sources of water used for drinking and cooking, and to determine the extent of use of water from rainwater storage tanks.

Methods:

In 1996 a sample of 4500 telephone numbers was randomly selected from the Adelaide and country regions electronic white pages telephone listings. Within each household, the person who had their birthday last, and was eighteen years or over, was interviewed using a computer assisted telephone interview system. The questionnaire included questions on the main sources of water for both drinking and cooking used in the household and the amount consumed per day for cold and hot drinks and cooking.

Of the initial sample of 4500 households, 3014 interviews were completed. There were 532 ineligible for sampling: 359 had telephone numbers that were not connected, 135 were non-residential numbers and 38 were fax/modem numbers. With an eligible sample of 3968, a response rate of 76.1% was obtained.

Results:

Sources of water

Respondents were asked to nominate the main source of water used for both drinking and cooking within their household (Table 1). Tank rainwater was the main source of water for drinking, whereas public mains supply was the main source of water for cooking.

Table 1 Main Sources of Water for Drinking and Cooking in South Australian Households

Source of Water	Drinking		Cooking	
n %	n %			
	(95% confidence interval)		(95% confidence interval)	
Rainwater only	1271	42.2	901	29.9
	(40.4-44.0)		(28.3-31.5)	
Public mains supply	1215	40.3	1939	64.3
Only	(38.5-42.1)		(62.6-66.0)	
Bottled or spring water	421	14.0	60	2.0
	(12.8-15.2)		(1.5-2.5)	
Rainwater & mains supply	58	1.9	58	1.9
	(1.4-2.4)		(1.4-2.4)	
Ground or bore water	14	0.5	21	0.7
	(0.3-0.7)		(0.4-1.0)	
River or lake	13	0.4	19	0.6
	(0.2-0.6)		(0.3-0.9)	
Rainwater and river or lake	0	0	3	0.1
			(0.0-0.2)	
Other sources ¹	22	0.7	13	0.4
	(0.4-1.0)		(0.2-0.6)	

1. other sources includes a mixture of water sources such as bottled and mains, rainwater/spring water, and distilled water. For cooking it includes no cooking.

Water type for drinking by region, as categorised by the source of public mains water, is shown in Table 2. In rural areas the primary source of drinking water was rainwater; overall 81.5 per cent of households used rainwater as their main source of drinking water compared with 27.7 per cent of households in metropolitan Adelaide. For cooking, 70.1 per cent of rural South Australian households used rainwater as their main source of water compared with 15.0 per cent of households in metropolitan Adelaide.

For those households reporting use of rainwater (n=1348), the extent of use for cold drinks versus hot drinks/cooking was investigated. The average number of cups consumed per person per day was 3.9 for cold drinks (about 1.0 litre) and 4.5 for hot drinks or cooking (about 1.1 litres).

Main Findings:

More households in South Australia use tank rainwater as the major source of drinking water than use mains supply water.

Rainwater is clearly the primary source of drinking water for rural South Australia with an overall consumption of tank rainwater of 82 per cent outside the metropolitan area.

The level of use of bottled or spring water as a main source of drinking water was also higher than expected at 14 per cent.

Discussion:

This study indicates that tank rainwater is the major source of water for drinking and an important source for cooking in South Australia. Possible reasons for high levels of consumption of tank rainwater include:

an historical dissatisfaction with the aesthetic quality of public water supplies in South Australia
a concern regarding the use of chemical in water.

Regional differences in tank rainwater consumption for drinking and cooking across country South Australia may be a reflection of differences in the aesthetic quality of mains water. Unfiltered supplies in South Australia, particularly from the River Murray, tend to have problems associated with physical appearance, taste and odour.

Table 2 Sources of drinking water by region of South Australia (percentage of households)

Household Source of Water									
Region	Source of Mains Supply	Treatment ^a		N Spring	Mains	Rainwater Sources ^b	Bottled or	Other	
		%	%	%		%	%		
Metropolitan Adelaide:									
1.	Northern Metro area	Reservoir mainly		chl & fil	310	54.5	26.1	15.8	3.5
2.	Rest of Metropolitan area	Reservoir + river		chl & fil	1780	52.8	25.3	18.7	3.2
3.	Adelaide Hills	River	chl165	5.5	82.4	8.5	3.6		
Rural South Australia:									
4.	Lower North	Reservoir +river		chl	64	3.1	93.8	3.1	0.0
5.	Strathalbyn and Milang	Reservoir +river		chl	19	0.0	100.0	0.0	0.0
6.	Fleurieu Peninsula	Reservoir		chl & fil	97	14.4	73.2	11.3	1.0
7.	Mid- North plus York Peninsula	River by pipeline		chl	222	12.6	81.5	2.7	3.2
8.	Riverland	River	chl72	2.8	95.8	1.4	0.0		
9.	Murray Mallee	River by pipeline		chl	18	5.6	94.4	0.0	0.0
10.	South -East ex. Mt Gambier	Groundwater		-	74	8.1	82.4	1.4	8.1
11.	Mount Gambier	Lake	chl67	64.2	28.4	4.5	3.0		
12.	Port Lincoln	Groundwater		chl 31	32.3	67.7	0.0	0.0	
13.	Rest of Eyre Peninsula	Grd & Reservoir		chl	29	6.9	93.1	0.0	0.0
14.	Other Small Supplies	Groundwater		Some chl	37	5.4	83.8	2.7	8.1
15.	No public water supply	Local Source		-	29	0.0	93.1	0.0	6.9

a chl=chlorinated, chl=chloraminated, fil= filtered

b. Other sources includes groundwater or bore, and mixtures of sources such as rainwater/ mains, bottled/mains, rainwater/spring water. The categories *rainwater plus river* and *river or lake* were omitted because no respondents indicated using these water sources as main supply for drinking, apart from respondents in Mt Gambier where the main supply is lake water.

The policy implications of the findings presented here are significant. Substantial resources are committed to supplying water and maintaining the infrastructure for rural water supplies. Furthermore, these systems may require upgrading at considerable cost to comply with the 1996 Australian Drinking Water Guidelines (NHMRC/ARMCANZ 1996). Yet this study has indicated that 82 per cent of consumers in country regions do not use the public mains supply water as their drinking water supply. Thus, it is appropriate to review the use of rainwater storage as an alternative water supply particularly as rainwater has been shown to be a community preference for drinking water. However the safety of tank rainwater must be a prime consideration in promoting this source of water.

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Artificial Recharge System and the Fate of Dissolved and Suspended Particles in Floodwater: A Case Study in Damghan Playa, Iran.

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Abstract

Spreading floodwater on arid lands is a new widespread experimental technique that is in progress in several parts of Iran. Intensive short period rainfalls that is characteristic of arid regions, carry huge amount of soil particles of various sizes. Damghan playa, where an artificial recharge project is in progress, was selected in order to study the fate of carried suspended and dissolved particles of clay, calcium carbonate, and gypsum. This playa is located 30 km east of Damghan city. The main objective of this investigation was to determine the effects of artificial recharge system on transportation of soil particles and their subsequent redeposition in soils. Calcareous and gypsiferous parent materials of the region was found to be the source of clay, calcium carbonate, and gypsum particles that were carried by floodwater. Physico-chemical properties and micromorphological characteristics of soils were determined in order to study distribution and redeposition of these particles in soil profiles. Results of this investigation showed some physico-chemical and micromorphological changes in soils. Changes included were translocation and addition of calcium carbonate, gypsum, and clay particles; type and distribution of voids; reduction in soil permeability; formation of cutans and calcitans; calcite hypocoatings; and calcite infillings of voids. Deposited particles caused plugging of large voids.

Introduction

More than 90% of Iran has arid and semiarid climatic conditions with mean annual precipitation of 115 and 365 mm, respectively. Low amounts and uneven distribution of precipitations caused surface runoff which annually drains into the seas, inland lakes and swamps. Nevertheless, water shortage is one of the main limiting factors in the economic development of Iran, particularly in the agricultural sector. However, spreading floodwater has been practised as an irrigation method in order to apply the wasted surface flows of water to the soils for various purposes (Kowsar, 1991). Addition of the suspended particles carried by floodwater to the coarse-textured soils was among the purposes (Kowsar, 1991).

McFadden et al. (1991) proposed that preferred movement of water in noncapillary pores may perhaps act to favour open chemical system behaviour in medium and coarse-textured soils. As shown in part by the studies of Arkley (1963), soil water balance, combined with available water-holding capacity, plays a critical role not only in determining the mass of carbonate that can be dissolved and redistributed in the soils, but also determines the pattern of carbonate redistribution with depth over the duration of soil development. Monger et al. (1991) stated that pedogenic

calcite is most transient in surface layer, because this layer is subjected to most frequent wetting. They concluded that dissolved and suspended calcite was carried into the soil by percolating water. As the soil water was absorbed by roots or evaporated, calcite precipitated on root surfaces and on sand and silt particles as calcitans. Calcite was channelled into macropores during its downward movement, which resulted in hypocoatings and eventually nodules.

Although deposition of such particles may have improved some soil properties of the spreading area, long-term problems (if any) of such depositions should not be ignored. Therefore, research for determining the fate of suspended and dissolved particles and their effects on properties of soils under artificial recharge system was established in the arid region of Damghan.

Materials and methods

Damghan, the study area, is a vast (30000 ha) playa in Semnan province, Iran (Fig. 1). It extends between the latitudes 35° 23'N and 35° 45'N and longitudes 54° 22'E and 54° 29'E. Mean annual precipitation, temperature, and potential evapotranspiration for the study region is 130 mm, 17°C and 2638 mm, respectively. Geology of the area consisted of the Quaternary rocks of Plio-Pleistocene conglomerate, Eocene dacitic braccia, diorite, clastic rocks and phyllite.

Based on topographic maps (1:250000) and aerial photos (1:50000), seven representative pedons were dug in two physiographic units, namely foothills and flood plains, where floodwater spread every year. Soil profiles were dug, macromorphologically described, and then classified according to Soil Taxonomy (Soil Survey Staff, 1998). Soil samples were taken from horizons in each pedon. The air-dried samples were crushed and passed through a 2 mm sieve. Physico-chemical analyses were carried out on the < 2 mm soil samples. Particle size analysis (Days, 1965), cation exchange capacity (Chapman, 1965), calcium sulphate and calcium carbonate (Richards, 1954) were determined. Clay particles of < 2 μ m were fractionated from the < 2 mm soil samples (Kittrick & Hope, 1963; Mehra & Jackson, 1960) prior to X-ray diffraction analysis for clay mineralogy.

Micromorphological characteristics of the soils were described through examining soil thin sections (Bullock et al., 1985) prepared from undisturbed samples taken from horizons.

Results and discussion

Based on the laboratory analyses and macromorphological descriptions, soils were classified into two main orders, namely Entisols and Aridisols (Table 1). Thin (15 cm) AC horizon with 60% of sand particles was found in profiles of the Entisol of foothills (Pedon 1), whereas deep soils (150 cm) with horizon differentiation were recognised in the Aridisols of the level flood plains (Pedon 7). Young soils with no evidence of carbonate accumulation were found on mountainous and alluvial-colluvial fans (Pedon 1, Table 1). Redeposition of particles of calcium carbonate,

gypsum, and sodium chloride in forms of suspensions and solutions caused formation of calcic, gypsic, and sialic horizons, respectively, in soils which were formed on alluvial plains (Pedons 5, 6 and 7, Table 1). Because of low solubility, particles of calcium carbonate carried by floodwater were deposited on the top of gypsum and sodium chloride in soil profiles. Likewise, the calcite particles were carried to a shorter distance from foothills than the other soluble salts. Thus, CaCO_3 particles were accumulated in profiles of piedmont alluvial plains (Pedons 2 & 3, Table 1). A calcic horizon with many secondary carbonates in the form of nodules and soft powdery pockets was found in Pedon 5 on the flat flood plains (Table 1).

Micromorphology of soil thin sections showed sequential accumulations of carbonates. The calcitans were observed especially in horizons of the lowland pedons, i.e. Pedon 7 (Gile et al., 1966). Large voids were the main sites for calcite precipitation (Chadwick et al., 1987), because such voids dry more rapidly than smaller ones. Large voids are usually in direct contact with lower atmospheric concentration of CO_2 . Moreover, calcite has a preference for self-nucleation, therefore plugs progressively large voids by preferential precipitation on previously deposited calcite crystals. Well developed crystals of gypsum and NaCl were also observed in conductive voids. Such crystals were particularly formed in horizons of the lowlands.

Mineralogy of soils showed that different proportions of similar clay minerals are present in various pedons on physiographic units. Mica (illite), chlorite, smectite (montmorillonite), and vermiculite were recognised. The higher physiographic units contained more illite and chlorite, whereas the lower ones had a higher montmorillonite and vermiculite.

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Table 1. Classification and physico-chemical properties of soils of Damghan playa

Pedon No. ^a	Horizon	Depth cm	Sand	Silt ----- %	Clay ----- %	Texture ^b	EC dSm ⁻¹	CCE %	Gypsum %	CEC cmolk ⁻¹	pH %	Sp	
Sandy-skeletal, mixed, (calcareous), thermic, Lithic Torriorthents													
1	AC	0-15			60	32 8	sl		1.0	23.8	0.0	12	7.7 27.0
Sandy-skeletal, mixed, (calcareous), thermic, Typic Torriorthents													
2	A	0-5			66	22 12	sl		1.2	21.2	0.0	12	7.8 28.2
	C ₁	5-50			76	14 10	sl		1.7	18.8	3.5	12	7.7 26.1
	C ₂	50-150	74		8	18	sl	3.1	19.2	1.3	14	7.5	29.8
Sandy-skeletal, mixed,(calcareous), thermic, Typic Calcigypsid													
3	A	0-15			58	20 22	sl		3.8	22.6	0.0	13	7.9 51.1
	B _k	15-45	76		4	20	sl	12.0	21.9	0.0	13	7.7	40.6
	C _y	45-150	68		8	24	sl	2.8	11.5	67.6	14	7.5	48.5
Sandy-skeletal, mixed, (calcareous), thermic, Typic Haplocalcids													
4	A	0-15			58	20 22	scl		3.8	18.9	0.0	12	7.6 51.1
	B _k	15-130	76		4	20	sl	12.0	23.0	0.0	12	7.3	40.6
	C _y	130-150			68	8 24	scl		28.0	16.0	40.0	14	7.6 48.5
Sandy-skeletal, carbonatic, thermic, Calcic Petrocalcids													

5	A	0-15		80	10	10	sl		28.0	19.2	0.0	12	7.5	22.9
	B _{k1}	15-25	58	12	30	sl		16.0	27.3	4.2	12	7.7	40.2	
	B _{k2}	25-110	61	11	28	sl		14.0	40.4	31.2	10	7.5	35.5	
	C _y	110-150		68	8	24	scl		28.0	16.0	40.0	10	7.6	48.5

Table 1. Continued...

Pedon No. ^a	Horizon	Depth cm	Sand	Silt ----- %	Clay ----- %	Texture ^b	EC dSm ⁻¹	CCE %	Gypsum %	CEC cmolkg ⁻¹	pH %	Sp			
Sandy, mixed, (calcareous), thermic, Typic Calcigypsid															
6	A	0-10			85	10	5	ls		21.0	21.2	0.0	12	7.5	21.8
	B _{k1}	10-30	79		15	6	ls		16.0	21.6	0.0	12	7.8	28.1	
	B _{k2}	30-70	78		18	4	ls		25.0	19.5	6.2	13	7.7	42.1	
	C _y	70-120	74		21	5	ls		48.0	17.8	15.2	14	7.6	51.3	
Sandy, mixed, (calcareous), thermic, Gypsic Aquisalids															
7	A	0-25			36	58	6	sil		235.0	21.4	6.2	13	7.0	34.3
	C _{z1}	25-50	60		36	4	sl		114.0	18.3	12.2	12	7.0	31.8	
	C _{z2}	50-75	80		14	6	ls		56.0	17.1	12.0	11	7.0	26.4	
	C _y	75-150	52		42	6	sl		74.0	19.0	18.4	13	7.5	41.9	

a: 1= Foothill physiographic unit; 2-7= Flood plains physiographic units.

b: sl= sandy loam; scl= sandy clay loam; ls= loamy sand; sil= silty loam.

On the Result of Underground Temperature Survey for Detecting the Groundwater Vein-stream at the Barikan Landslide Area in I. R. Iran

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Abstract

It is recognised that rainwater infiltrating into soil tends to move in a vertical direction, and reduce its velocity and decreases horizontally when it reaches an impermeable layer. It is necessary to determine exactly the location and depth of the groundwater vein-stream flowing above the impermeable layer for effective use of the groundwater in arid climate area.

In order to accomplish this purpose, an electric resistance survey and electric logging were carried out primarily for obtaining this information. Using these methods it is very difficult to obtain information on the location and depth of the groundwater vein-stream.

An underground temperature survey method has been developed to detect accurate information on the groundwater vein-stream in Japan. This method utilises the different temperatures of the groundwater vein-stream, as well as ground temperature of the shallow layer. It is composed of the ground temperature survey at a depth of one meter, multiple points temperature logging, usual temperature logging, and measurement of direction and the velocity of groundwater vein-stream.

The groundwater investigation method, using temperature is extensively used in Japan as a useful method for research carried out on groundwater vein-stream, underground flow, groundwater disaster, groundwater obstruction and groundwater resources.

However the principle of the method is generally based on the following assumption. Since more frequently a green rich oasis in barren deserts in arid climate area or areas having very poor vegetal cover are formed around springs, which are the outcrop of the groundwater vein-stream, it forms sites with different temperatures in comparison to others. In these areas, walking with bare feet during the summer and fall seasons, particularly during the day, is impossible. At the same time it is possible to walk barefoot around spring outlets and neighbouring sites. The most basic principle of the investigation method of the groundwater vein-stream by measuring underground temperature is the same as these phenomena.

Based on this fact, it is suggested that one detects the location of the groundwater vein-stream by measuring the ground temperature at shallow layers of the soil. Therefore, using this method it is possible to measure temperature distribution of the soil surface, in areas with harsh and abnormal conditions such as the deserts or the Sahara. This is mostly because if there is groundwater vein-stream, the ground temperature around it will be lower because of the effect of the existence of the vein, particularly in the summer and autumn. This is due to the lower temperature of the ground around the vein-stream in comparison to the ground temperature where there is no vein-stream. On the other hand, the ground temperature of the vein-stream is obviously higher than other sites in winter and spring.

On the Result of Underground Temperature Survey for Detecting the Groundwater Vein-stream at the Barikan Landslide Area in I. R. Iran

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Key words: Groundwater survey, Groundwater vein-stream, Landslide, I. R. Iran

1. Introduction

It is recognized in many cases that underground water does not form groundwater surface but form groundwater vein-stream at the head scarp after occurrence of landslide. Generally, landslides are caused by the influence of underground water (pore pressure on the sliding surface) in the mass. Therefore, it is necessary for countermeasure of landslide to drain the groundwater.

When groundwater temperature is measured at spring-water points and bore holes in landslide area, it is found that the annual variation of temperature is comparatively stable. On the other hand, it is found that the annual variation of this is not stable near/on ground surface. Based on these phenomena, Takeuchi (1980, 1981) have developed the method of investigating groundwater vein-streams by measuring one-meter depth temperature. This method is employed the basic information of countermeasure for drainage underground water at landslide area in Japan (e.g., Takeuchi, 1981). The purpose of this paper is to detect the plane distribution of groundwater vein-stream at the Barikan landslide in I. R. Iran by means of the underground temperature survey and to examine this vein-stream is to use of the water resource or not.

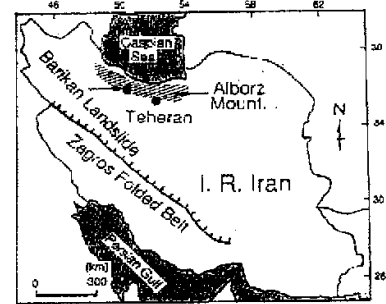


Fig. 1 Location map of the Barikan landslide.



Photo 1 The Barikan landslide.

2. Brief view of Barikan landslide

The plate of I. R. Iran is a part of Alpine-Himalayan system. Many landslides distribute at Alborz Mountains and Zagros Folded Belt (Shoacli *et al.*, 1997). The Barikan landslide is located in Alborz Mountains, west part of 150km from Tehran (Fig. 1). Photo. 1 and Fig. 2 show the area of Barikan landslide. There are accumulation terraces, many springs, irrigation canal, Kanat (underground waterway) in this landslide. Furthermore there are many houses and fruit farms, too. Slope is 10-20 degree; the length of the landslide is approximately 700m; and width is about 300m. It seems that bedrock is composed alternating beds of sandstone and mudstone, landslide mass is composed gravel (colluvium). Sliding blocks (Block1, 2, 3-1, 3-2) are shown in Fig.2. From the result of site investigation enforced on 1998, Block 1 and 2 are active movement blocks. Especially, many houses are destroyed at west part of the Block 2. The Block3-1 and 3-2 are possibility re-active movement by river erosion. It is presumed that the Barikan landslide is caused by 1) river erosion, 2) effect of groundwater, from the result of site investigation.)

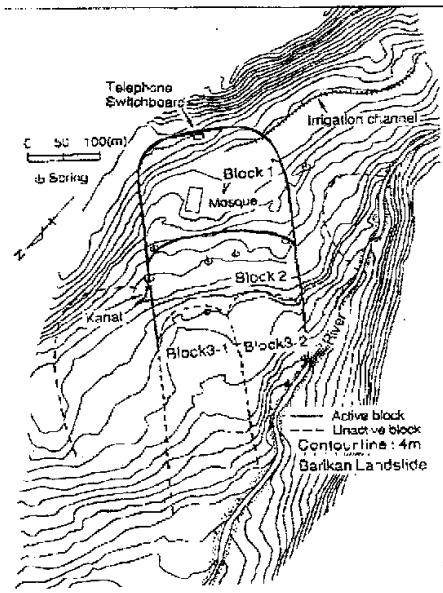


Fig. 2 Plan of the Barikan landslide.

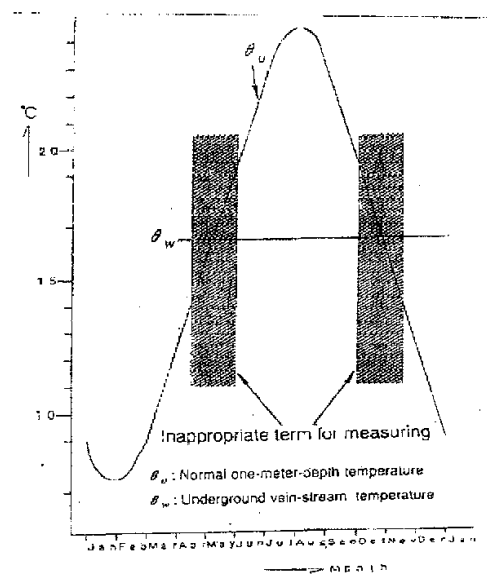


Fig. 3 Example of annual time series change between normal one-meter depth temperature (θ_u) and underground vein-stream temperature (θ_w) in Japan.

3. Investigation of groundwater vein-stream by measuring one-meter depth temperature

Fig. 3 shows the example of annual time series change between normal one-meter depth temperature (θ_u) and underground vein-stream temperature (θ_w) in Japan. In the area of temperate climate such as Japan, one-meter depth temperature around the groundwater vein-stream tends to be low in summer and autumn. On the other hand, the temperature around the vein stream tends to be high in winter and spring. The method of detecting the groundwater vein-stream utilizes this phenomenon (Takeuchi, 1980, 1981). From the statistical result of one-meter depth temperature at several landslides in Japan, this method can employ under condition of $|\theta_u - \theta_w|$ is more than 2.5°C . Therefore, when late spring to early summer and late autumn to early winter, this method can not employ.

Unemployment term in I. R. Iran is not known, because it has not been carried out that measuring one-meter depth temperature. Then, the authors carried out measurement of $|\theta_u - \theta_w|$ at Barikan landslide on 22 June 1998. This day is early summer that is unemployment term in Japan. However, the result of θ_w was 11.1°C and θ_u was 20.0°C .

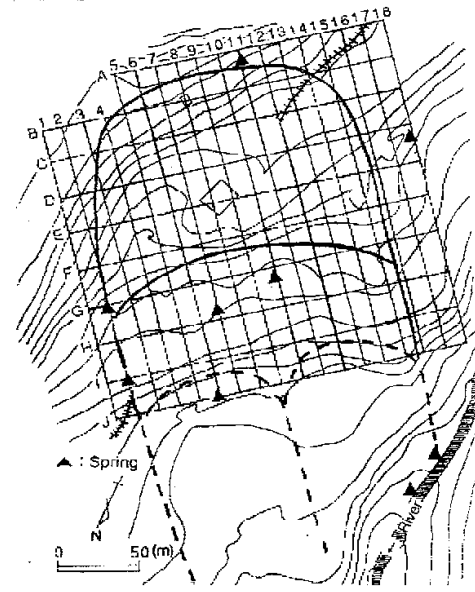


Fig. 4 Measurement points of one-meter depth temperature in the Barikan landslide.

Hence, $|\theta_u - \theta_w|$ was 8.9 °C, which suggested to be able to carry out the investigation of groundwater vein-streams.

The Measurement of one-meter depth temperature was enforced at Block1 and 2 on 22 to 24 June 1998. The method of this measurement is as follows:

- 1) 15 m × 30 m mesh of measurement points are set up in measurement area (Fig.4). Total points are 157 at Block1 and 2 in the Barikan landslide.
- 2) One-meter depth hole at these points are dug by steel pick ($\phi = 2.5$ cm, $l=150$ cm) and hammer (weight is 3-5 kg).
- 3) The thermometer (precision is ± 0.1 °C) is putted in these holes.
- 4) One-meter depth temperature is measured after 10 minutes insertion of the thermometer.

Measurement value is effected by various factors. It is need to calibrate measurement value for obtaining the accurate information on groundwater vein-stream. Then, Calibrated measurement values at each measurement points are obtained by means of the coefficient of factors about ground condition. The coefficient of factors is shown Table. 1. It seems that difference of geological condition affect one-meter depth temperature. However, effect of the difference of geological condition is not considered because the landslide mass of Barikan is composed approximately homogeneous layer. It is found that seepage water in the one-meter hole at four measurement points. These measurement points are not found surface flow. Thus, the value is not revised about factor of surface flow.

4. Detection of groundwater vein-streams

These calibrated values are plotted on the map of measurement site. The constant-temperature lines are drawn on this map. The variation of one-meter depth temperature are from 11.9 to 20.0 °C. To easily detect underground vein-stream, the authors pick up the part under 16 °C. Fig. 5 shows constant-temperature lines and distribution of lower than 16 °C, which indicate gray zones. From this figure, it is presumed that there are five groundwater vein-streams ("a" to "e") in upper slope of Barikan landslide. Details of these underground vein-streams are as follows:

Table. 1 Statistical management of measurement value and coefficient of factors

G. C.	N. P.	θ max.	θ min.	θ rang.	S. D.	θ av.	$\Delta \gamma$	%
Foot path	11	19.5	15.1	4.4	1.29	17.1	-0.7	7.0
Farm land	10	20.8	15.1	5.7	1.68	16.9	-0.5	6.4
Grass land	28	23.0	17.3	5.7	1.42	19.7	-3.3	17.8
Reed land	69	19.0	11.7	7.3	1.54	15.8	+0.6	44.0
Fruit farms	39	19.4	11.7	7.7	1.53	14.9	+1.5	24.8
Total	157	23.0	11.7	11.3		16.4		100.0

G. C. : Ground condition, N. P.: Number of measurement points,

S. D. : Standard deviation, θ : measured one-meter depth temperature (°C),

$\Delta \gamma$: coefficient of factors

Vein-stream a): This vein-stream forms along the northeast lateral boundary of the Block 1, 2, 3-1. There are two springs and kanat in the Block2.

Vein-stream b): This vein-stream exists from center of the Block 1 to west part of the Block 3-1 through center of the Block2. There are two springs in the Block 2 and Block3-1.

Vein-stream c): This vein-stream exists from head of the Block 1 to east part of the Block 3-2 through west part of the Block2. There are two springs head of the Block 1 and the Block 2. End of the irrigation channel locates upper part of this vein-stream.

Vein-stream d): This vein-stream forms along southwest lateral boundary of the Block 1

through west part of the Block2 and the Block 3-2. The irrigation channel is through upper part of this vein-stream.
 Vein-stream e): This vein-stream exists out side of landslide blocks. A part of vein-stream outlet the spring where locate D 18 point.

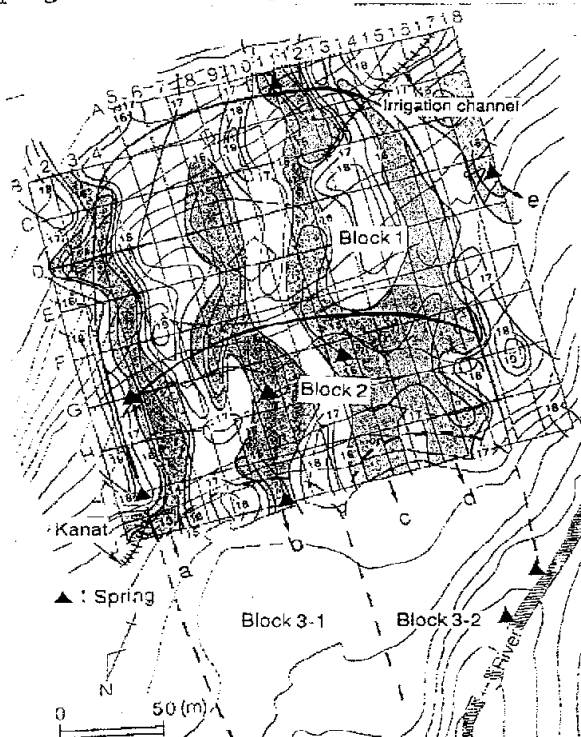


Fig. 5 Result of measuring one-meter depth temperature.

From this figure, directions of these vein-streams are approximately coincided with the direction of surface inclination. Low temperature zone is widely distributed at the G line to I line in the Block 2. This area coincides with the area of many houses destroyed.

The authors attempt to calculate the depth of vein-stream top at H line. Generally, magnitude of two-dimensional vein-stream under condition of Fig. 6 is presumed by Equation (1) (Takeuchi, 1983).

$$\theta'_{z=1} = \frac{\theta_d}{\log \frac{b+a}{b-a}} \times \log \frac{(1+a)^2 + y^2}{(1-a)^2 + y^2} \quad (1)$$

where $\theta'_{z=1}$: distance between normal one-meter depth temperature and measured one-meter depth temperature at the point of

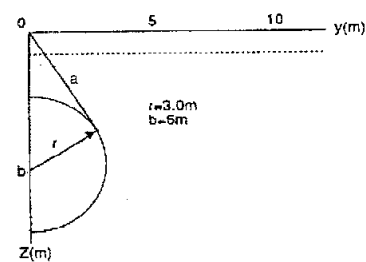


Fig. 6 Model of two-dimensional vein-stream.

- underground vein-stream top.
- θ_d : distance between normal one-meter depth temperature and temperature of underground vein-stream ($|\theta_u - \theta_w|$).
- a : $(b^2 - r^2)^{1/2}$ (m)
- b : depth of ground surface to center of vein-stream (m)
- r : radius of vein-stream (m)

Takeuchi and Kasai (1994) explain about Equation (1) that is as follows:

- 1) One-meter depth temperature is not effected by the difference of magnitude of vein-stream, but strong effected by the depth of vein-stream top.
- 2) θ_d is the larger, curve inclination of Equation (1) is the bigger, consequently capable of investigation depth is the deeper.
- 3) The difference of θ_d is more effect than the variation of vein-stream magnitude for the limit of presuming depth.

Then, the authors calculate theoretical temperature curve of θ_{zx} under conditions of $\theta_d = 8.9^\circ\text{C}$ and $r = 6\text{m}$ by means of Equation (1), which is shown Fig. 7. In this figure, when $b-r$ is deeper than about 10 m, the vein-stream top can not be presumed because inclination of temperature is smaller than 0.1°C/m .

Fig. 8 shows distribution of detected vein-stream top from G to I line. From this figure, high level of vein-stream top are presumed at No. 3 to 4 and No. 11 to 12 each lines. The levels of these vein-stream tops are about 2m from ground surface.

5. A role of groundwater for disaster prevention and water resource

From Fig. 5 and Fig. 8, presumed underground vein-streams distribute wide and shallow at west part of the Block 2. It suggests that the vein-streams c and d cause landslide activity at the Block 1 and 2. The reason of this suggestion is wide distributions and shallow of vein-streams cause high pore water pressure, subsequently, decrease of effective normal stress on slip surface. However, there is no investigation borehole in the Barikan landslide. Hence, It is necessary that investigation borehole is dug to make clear the detail of profile and to obtain the detail information of the vertical distribution of groundwater. The authors propose the countermeasure for controlling of the Barikan landslide activity, which is as follows:

- 1) Emergency counter measure by means of drainage well is needed nearby measurement point number 12 to 13 on the H line after investigation borehole set.
- 2) Another drainage well is needed to construct at nearby measurement points number 7 to 8 on the same line.
- 3) The irrigation channel is improved for the groundwater does not infiltrate into the landslide mass.
- 4) The river control is needed to prevent erosion of foot part of the Block3-1 and 3-2.

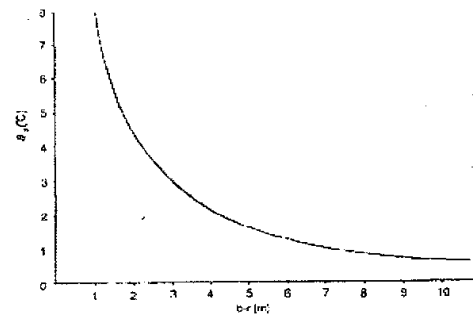


Fig. 7 Relationship between θ_d and $b-r$. θ_d , Distance between normal one-meter depth temperature and temperature of underground vein-stream ($^\circ\text{C}$); b , Depth of ground surface to center of vein-stream (m); r , radius of vein-stream (m).

It is very important for residents and agriculture to use groundwater. The level of underground vein-stream top is shallow in the Barikan landslide from Fig. 8. It suggests that not so hard problem to obtain the groundwater for drinking and agriculture. Then, the authors proposed that the groundwater in drainage well utilize for drinking and agriculture at the downstream area of the river. As the way of realizing this proposal, the groundwater in drainage well is flowed out by means of impermeable type kanat which dug from drainage well to out side of landslide area. The reason of this proposal is 1) many kanats have been constructing for long time, 2) constructing cost of kanat is very cheap, in I. R. Iran.

6. Conclusion

The measurement of one-meter depth temperature is carried out in the Barikan landslide, I. R. Iran. From the result of this measurement, the Barikan landslide is detected five groundwater vein-streams. In these vein-streams, two vein-streams are presumed the cause of landslide activity. For the viewpoint of disaster prevention, Construction of drainage well, improvements of irrigation channel, and river control are proposed to control the landslide activity. Furthermore, for the viewpoint of water resource, underground water in the Barikan landslide is seemed to use for drinking and agriculture at the down stream area of the river by combination of drainage well and kanat.

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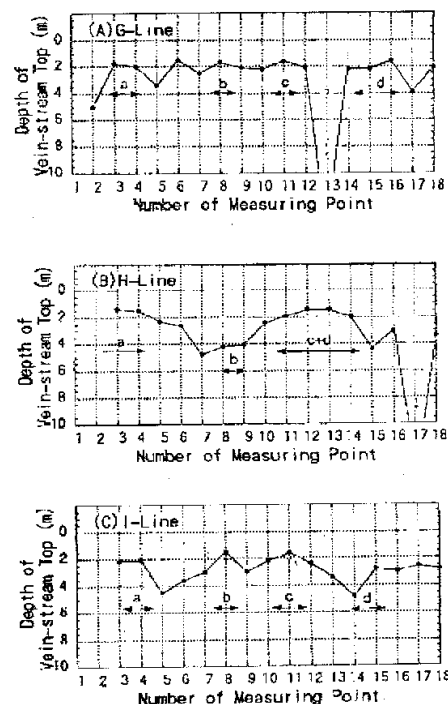


Fig. 8: Distribution of detected vein-stream top from G to I line.

Underground Temperature Survey for Detection of Groundwater Vein-Stream and Flowing Layer in Dry Area

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Abstract

It is known that rainwater infiltrating into soil tends to drop infiltrating velocity to the vertical direction and tends to flow horizontally when it reaches an impermeable layer. Therefore it is necessary to determine exactly the location and depth of the groundwater vein stream flowing above the impermeable layer for effectively using groundwater.

In order to accomplish this, an electric resistivity survey and an electric logging have been carried out. The information on the location of the groundwater is obtained by these methods. It is very difficult though to obtain information on the location and depth of flowing groundwater in vein streams.

The authors developed an underground temperature survey method to detect the accurate information on groundwater vein stream. This method uses the difference between temperature of flowing groundwater and ground temperature of a shallow layer. It is composed of a one-meter-depth temperature survey, a multiple point's temperature logging and/or usual temperature logging, and a flowing direction and a velocity measurement.

The groundwater investigation method utilizing temperature is extensively used for research of groundwater vein-streams in landslide areas, underflows, groundwater disasters, groundwater obstructions and groundwater resources.

Introduction

It is recognized that rainwater infiltrating into the soil tends to reduce infiltrating velocity in the vertical direction and tends to flow horizontally when it reaches an impermeable layer. It is necessary to determine exactly the location and depth of the groundwater vein stream flowing above the impermeable layer to make effective use of the groundwater.

In order to accomplish this objective, electric resistance survey and electric logging are carried out mainly for obtaining this information. The information on the distribution location of groundwater is obtained by these methods, but it is very difficult to obtain the information on the location and the depth of flowing groundwater vein streams. The authors developed an underground temperature survey method to detect accurate information on the groundwater vein stream. This method utilizes the difference between temperature of flowing groundwater and ground temperature of shallow layer.

It is composed by one-meter-depth temperature survey, multiple points temperature logging and/or usual temperature logging, and flowing direction and velocity measurements. An example applying the above method in a sand-gravel area was presented for water resource. Very useful information on the location and depth of flowing groundwater vein streams were obtained. Initially, an outline on one-meter-depth temperature investigation method and multiple point temperature logging method are described in this paper, and next, the effectiveness of this method was explained on the basis of in situ investigation. The groundwater investigation method utilizing temperature is extensively utilized as a method on the research of groundwater vein-stream in landslide areas, underflow, groundwater disaster, groundwater obstruction, groundwater resource, etc. in Japan and in dry areas.

1 The investigation method on groundwater vein stream by one-meter-depth temperature:

1-1 Principle of the method

A green rich oasis in the arid desert region is formed around a spring which is an outcrop of groundwater vein stream. It forms a cooler region than the rest of the area. Even in the case of very hot ground surface where one cannot walk barefoot, one can walk near the spring point barefoot. The basic principle of the investigation method of groundwater vein stream by measuring underground temperature is similar to this phenomena. Based on this fact, it is suggested that we can detect the location of a groundwater vein stream by measuring ground temperature at shallow layer in soil.

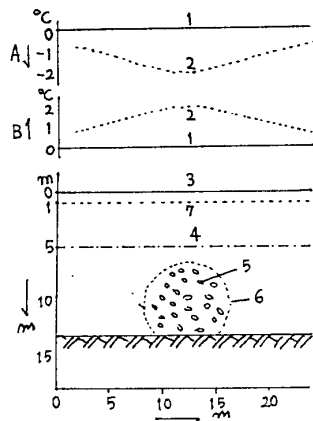


Fig. 1 Effect of existence of a vein stream to shallow ground temperature

A: in summer and autumn seasons,

B: in winter and spring seasons

1: normal 1-m-depth temperature,

2: temperature change by effect of existence of the vein stream,

3: ground surface,

4: groundwater level,

5: existence place of flowing groundwater,

6: unify temperature sphere by influence of existence of flowing groundwater,

7: one-meter depth of ground

The principle of this method is very simple. In short, it identifies the normal distribution of temperature. A groundwater vein-stream exists in the normal distribution area (Fig. 1). The temperature around the vein stream tends to be lower by the effect of the existence of the vein in summer and autumn seasons, because the temperature of the vein stream is lower than that of ground temperature without the vein stream (Fig. 1-A). On the other hand, the temperature of the vein stream is higher than that of ground temperature in winter and spring seasons, so that the temperature around the vein stream tends to be higher by the effect of the existence of the vein stream (Fig. 1-B).

1-2 Executing time for carrying out the investigation

This investigating method utilizes the difference of temperature between shallow part in the earth and flowing groundwater. Accordingly it is difficult to carry out this method when temperature is equal in the two areas. One-meter-depth temperature and that of a spring was measured for a long period of time at several investigating areas. This investigating method utilizes the difference of temperature between shallow part in the earth and flowing groundwater in situ to estimate the scale and the depth of a vein stream from the result of measurements of one-meter-depth temperature using the method of YUHARA (1955).

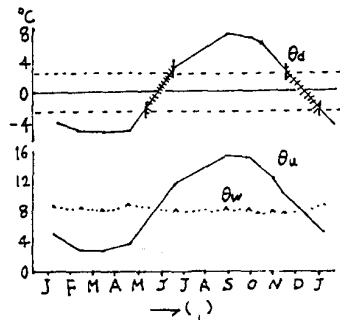


Fig. 2 Annual variation of one-meter-depth temperature (θ_u), temperature of flowing groundwater (θ_w), and difference temperature between them (θ_d)

On the basis of this examination, the preferable season for carrying out the investigating method in Japan was in the coldest season with February as the central month, and in the hottest season with August as the central month. As the result of the investigation in foreign countries, it was shown that the preferable season in the temperate region such as Taiwan, China, and France was nearly equal to Japan and the season in the tropical region such as Indonesia was year round.

1-3 Arrangement of measuring line

In order to estimate accurately the flowing channel of the vein stream, suitable measuring line and/or mesh must be arranged. They are usually arranged on a topographical map having 1/1000 or 1/500 scale. The interval of measuring point is usually 10 m crossing the vein stream and 20 m parallel to that. In the case of investigating a very small vein stream, measuring points are arranged at smaller intervals than is usual, for example 5 m $\times$ 5m or 2m $\times$ 3m, etc. On the other hand, in the case of investigating a very large underflow channels, measuring points are set at larger intervals than is usual, for example 50 m $\times$ 100 m or 50 m $\times$ 50 m, etc.

1-4 Measuring method of one-meter-depth temperature

The results are recorded as follows:

1. The temperature is measured at a one-meter depth hole at a selected point.
2. Insert a thermometer carefully into the hole;
3. After 10 minutes, measure the temperature of the inserted thermometer;
4. Record the measured data in the field notes noting the measuring point number, temperature recorded by the thermometer, inserted and reading times, ground conditions around the measuring point, and memorandum for the point.

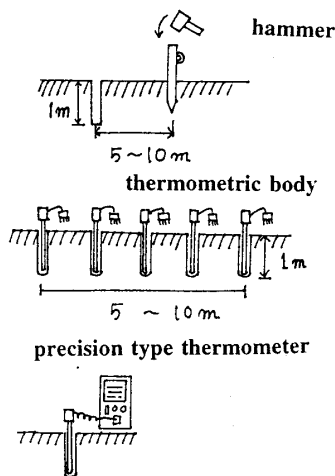


Fig. 3 Measuring process of one-meter-depth temperature survey

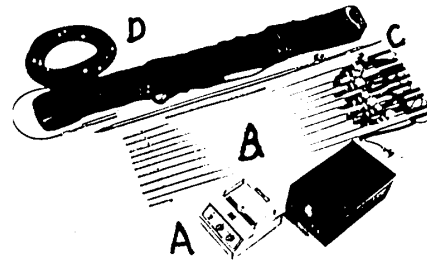


Photo. 1 Measuring apparatus for one-meter-depth temperature
A: Precision type thermometer,
B: thermometric bodies,
C: iron bar,
D: sender for temperature logging

1-5 Method of analysis

Measured data is effected by various factors. So it is necessary to nullify the various factors to obtain accurate information on groundwater vein streams.

Some factors that influence the measured data is as follows:

A: Factors influencing measuring time:

- 1 Peculiar error of thermometers;
- 2 Temperature variation with various measured depths;
- 3 Annual variation of ground temperature during the measurement period.

B: Factors influencing the location:

- 1 Ground conditions around the measured point;
- 2 Topographical conditions at the measured point;
- 3 Geological conditions at the measured point.

The removal of and correction method of various influencing factors in measured values are described in the paper of TAKEUCHI(1980) in detail.

1-6 Methods of results interpretation and analysis

The interpretation method of the analyzing result is very simple. The result of analysis is interpreted after grasping the relationship between normal one-meter depth temperature and temperature of flowing groundwater in situ. In the case that the temperature of flowing groundwater is lower than normal one-meter depth temperature in the survey area, the location of vein streams is detected by lower temperature than in other sites (Fig.1-A). On the other hand, if the relationship is opposite, the temperature of existing place of vein streams is detected by higher temperatures than in other sites (Fig.1-B).

2 Multiple points temperature logging for detection of flowing groundwater

2-1 Principle of this method

When hot water is poured into a borehole, the temperature will decrease rapidly at the groundwater flowing layer, while it will decrease very slowly at other layers. Accordingly, we can obtain the information on the existing depth and thickness of groundwater flowing layer by utilizing this phenomena (Fig. 4).

2-2 Outline of this apparatus

The apparatus of multiple points temperature logging is composed of a sensor furnished with precision thermometers at intervals of 50 cm, measuring instruments, notebook type personal computer, batteries and temperature rising instrument in a borehole (Photo. 2).

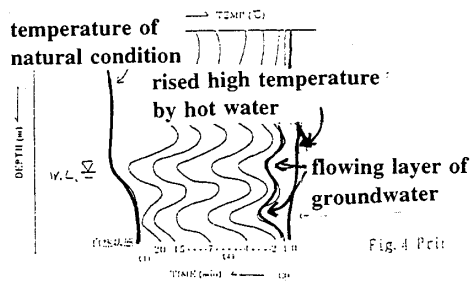


Fig. 4 Principle of this logging

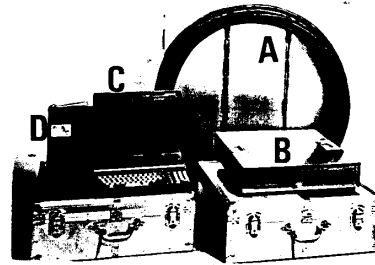
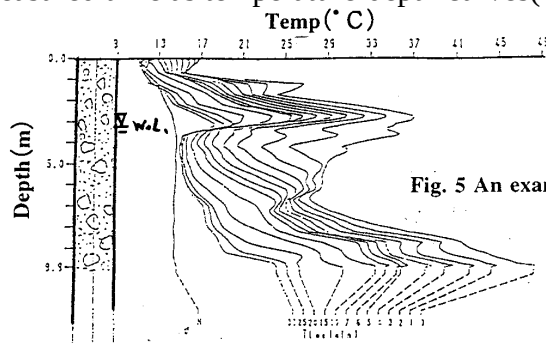


Photo. 2 Apparatus of multiple points temperature logging
A:sencer, B:interface, C:computer, D:battery

2-3 Measuring method

Temperature of air and water in a borehole rises as uniformly and as high as possible by pouring in hot water. After that, the temperature in a borehole is measured at intervals of one minute from one to seven minutes, at interval of 5 minutes from 10 to 30 minutes. The results of measurement are shown on the computer display at every measured time as temperature-depth curves (Fig. 5).



The investigation area is located in a fan-shape field near a river. It consists of thick sand and gravel layers. In February 1997, a groundwater investigation with one-meter depth temperature measurement method was carried out here to choose a suitable position for a well that will supply water to the city.

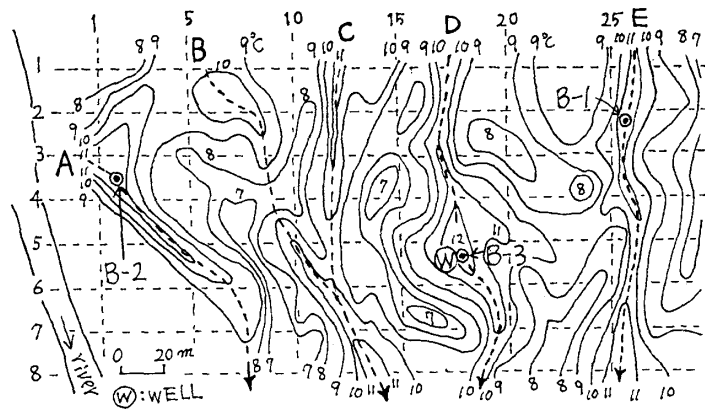


**Fig. 6 Distribution map of
one-meter-depth
temperature
A~E:estimated ground-
water vein streams
W :water resource well**

3-2 Investigation results of the ground temperature measurement method at one-meter depth

Fig. 6 shows the measurement net of the ground temperature measurement at one-meter depth. The mesh is 10 m× 20 m. The correction of temperature vector, day deterioration and ground condition have been carried out on the in situ data. From the above, it could be estimated that some groundwater veins exist in the investigating area (dotted line: A~E).

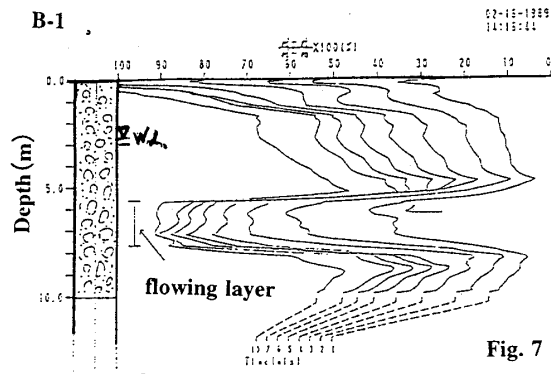


Fig. 7 Temperature restore rate-depth curve for B-1

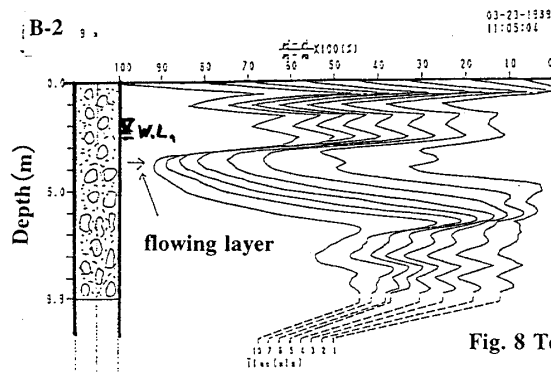


Fig. 8 Temperature restore rate-depth curve for B-2

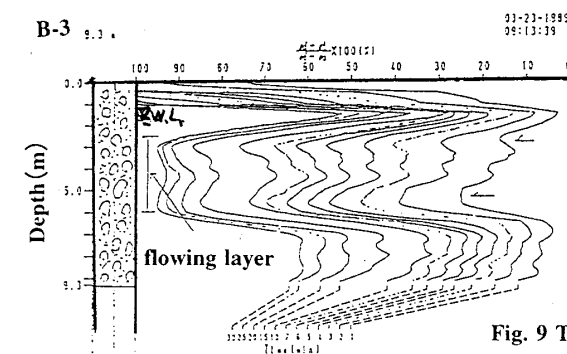


Fig. 9 Temperature restore rate-depth curve for B-3

3-3 Multiple-points temperature logging

To confirm the above results, some boreholes were dug at the location shown in Fig. 6, and the multiple-points temperature logging were carried out. Measurement results were shown in Fig. 7-9. It could be seen very clearly that a few groundwater flowing layers exist.

4 Conclusion

The investigation results show that the survey method of ground temperature is very effective to choose a location for the water well at a sandy and gravel area, and it is believed to be also effective for the water resource exploration in dry areas. We expect the investigation method will be applied in dry areas as well.

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The effect of storage location on collected rainwater quality

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Abstract

Water quality in stored rainwater changes during storage for various reasons and it is necessary to investigate these variations in order to use it safely. In this paper, an attempt is made to examine the effect of the location of storage reservoirs on rainwater quality. The experiment was, however, carried out using groundwater instead of rainwater due to a lack of rainfall during the period of the experiment. Water that was stored in the containers located both indoors and outdoors was analyzed for ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, turbidity, color, coliform bacteria and bacteria periodically for about three months from the beginning of August to the end of October. The results obtained show that variations in water quality were little different between the water stored indoors and outdoors, but the appearance of water was quite different.

Introduction

Rainwater is a valuable water resource. In Japan, however, although direct utilization of rainwater such as rainwater storage in the home and the office has been gradually popularized, it is not yet widespread in Japan (SHASEJ 1997). It is expected that its installation will bring a huge benefit, for example, a reducing urban water demand and the provision of drinking water in emergencies such as earthquake disaster, etc.

Generally speaking, rainwater quality is acceptable except for the initial rainfall (Yasutake et. al. 1992). However, it was reported that stored rainwater changes in water quality during the storage due to various reasons (Nagado et al. 1992). In order to utilize the stored rainwater safely from health side, it is necessary for the stored rainwater to satisfy a certain water quality standard.

This paper aims to clarify the effect of storage location on variations in the water quality of stored rainwater. However, due to lack of rainwater for storage this year, the experiment was carried out using groundwater that was pumped up and sprinkled onto the roof of a greenhouse instead of using natural rainwater. The experiment was carried out during about three months from the beginning of August to the end of October and the quality of the water stored in the containers was measured periodically.

The results obtained from the experiment show little variation in water quality between the water stored indoors and outdoors, although the appearance of water was quite different.

Methodology

Water Collecting and Storage

In this experiment, an attempt was made to examine the effect of the location of the storage containers on variations in water quality. A condition was that no water be added to the stored water during storage. Therefore, it was necessary that the container be filled up with rainwater in the single event of rainfall. However, we did not have a sufficient amount of rainfall for the experiment, so the experiment was carried out using groundwater that was pumped up from a well and sprinkled instead of using rainwater. Groundwater was collected from a greenhouse, which had a roof with an area of 80 m^2 and equipped with a gutter. The runoff was stored in polyethylene containers with the volume of 0.3 m^3 . Figure 1 shows the greenhouse and the gutter.



Photo 1 Greenhouse and gutter

Sprinkled water was collected in a bucket with the volume of 0.02 m^3 and transferred to the containers. Its intensity was about 5 mm/h estimated as a typical rainfall intensity. The collected water was stored in two containers. One container was placed indoors out of the direct sunlight. It was rather dim without artificial lighting and it had sunlight through a dark glass window. The other was placed outdoors and exposed to the direct sunlight from sunrise until about 3pm. when the place became shaded by the building. Figures 2 and 3 show two containers, respectively.

It did not rain for about one month after the gutter was fitted. During this period airborne debris (e.g., soil particles, bird droppings and insect carcasses) accumulated in the gutter and on the greenhouse roof. Water was not stored for half an hour after the beginning of sprinkling so that the debris could be flushed away and not be contained in stored water. However, not all airborne debris was flushed away from the appearance of water

collected in the bucket.

Water Quality Parameters and Methods for Analysis

Water was analyzed for ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, turbidity, color, Coliform bacteria and bacteria. Ammonia nitrogen, nitrite nitrogen and nitrate nitrogen were measured in mg/L using the HACH model DR/700 colorimeter and HACH method (Salicylate method, Diazotization method and Cadmium reduction method, respectively). The limits of detection of ammonia nitrogen, nitrite nitrogen and nitrate nitrogen were 0.024 mg/L, 0.0038 mg/L and 0.024 mg/L, respectively. Turbidity and color were measured in JIS unit(°) using KYORITSU model WA-PT-4 turbidity/color comparator set, where JIS is the Japanese Industrial Standard. Turbidity was measured in increments of 0.5°, 1°, 2° and 3°. Color was measured in increments of 1°, 2° and 3°. Coliform bacteria and bacteria were tested using test paper that could indicate only their presence.



Photo 2 Container indoors



Photo 3 Container outdoors

All water quality parameters were measured from August 2 to August 8 daily and from August 15 to October 30 weekly. All sets of water quality were carried out at about 1 P.M. Water pumped from the well was analyzed for the same parameters to compare with water for storage before the experiment. Rainwater, enough for a water test, was collected and analyzed.

Results and discussion

The results obtained from these measurements are shown in Table 1. Water without sprinkling did not contain airborne debris. Ammonia nitrogen in it was below the limit of detection. It was also below the limit of detection on the first day of storing. Ammonia nitrogen indoors increased from 0.03 mg/L to 0.10 mg/L. Ammonia nitrogen outdoors increased to 0.08 mg/L on day 1 and decreased to 0.04 mg/L next day. After that, it increased to 0.07 mg/L on day 6. The presumed source of ammonia nitrogen was from bacteria associated with bird droppings and insect carcasses collected together with the water.

Nitrite nitrogen in water stored indoors was all below the limit for detection both initially and during storage. Nitrite nitrogen stored outdoors was below the limit of detection to day 6. It increased from 0.042 mg/L on day 13 to 0.55 mg/L on day 27 and after that decreased to below the limit of detection on day 83.

Nitrate nitrogen in water indoors varied between 1.8 mg/L and 2.7 mg/L repeating an increase and a decrease until day 20. After that, it decreased. Nitrate nitrogen levels in the outdoor storage was almost constant during the first week and then, decreased. Table 1 Results of Measurements of Water Quality

Color in both indoor and outdoor storage containers were all below 2° during storage. Turbidity in both indoors and outdoors was all below 0.5 ° except the first day of storing.

Coliform bacteria and bacteria were detected in all cases. The cause was due to the bird droppings in the gutter and on the roof of the greenhouse that was not flushed away and was collected together with water, since these were not initially detected in the pumped water.

Stored water after storage was shown in Figs. 4 and 5. There was quite a difference between them. Particles accumulated on the bottom of both containers. A membrane on the water surface and the particles attached inside were only detected in the container kept outdoors. The water itself was very clear in both containers.



Photo 4 Appearance of water stored indoors



Photo 5 Appearance of water stored outdoors

The measurement results obtained from the experiment show that there was little difference in the water quality whether stored indoors or outdoors. Therefore water quality was little affected but the appearance was affected by the location of the storage container.

Japanese water quality standard for each constitution is as follows:

1. Nitrite nitrogen and nitrate nitrogen are less than 10 mg/L in total.
2. Turbidity was less than 5°.
3. Color is less than 2°.
4. The number of colonies formed from sample water of 1 ml by bacteria is less than 100.
5. Coliform bacteria are never detected.

The experiment was carried out using water that was pumped up from the well instead of rainwater. The measurement results of water test for rainwater were obtained. The results are as follows:

1. Rainwater ammonia nitrogen was 0.42 mg/L.
2. Rainwater nitrate nitrogen was below the limit of detection.
3. The other was no difference between them.

From the above results, the stored water could satisfy the standard for nitrite nitrogen, nitrate nitrogen, turbidity, and color in both indoors and outdoors. Since ammonia nitrogen is indicator of faecal contamination, there seems to be a problem in utilization of stored water for drinking. Coliform bacteria were also detected during storage and the stored water could not satisfy the standard.

Conclusion

The results obtained from the experiment are as follows:

1. There was little difference in the variations of water quality between water stored indoors or outdoors. The water quality was hardly affected by the location of the storage container.
2. There was quite a difference between water stored indoors and outdoors. The appearance was affected by the location of the storage container.

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Storage duration	NH ₄ ⁺ -N (mg/L)		NO ₂ ⁻ -N (mg/L)		NO ₃ ⁻ -N (mg/L)		Color (°)		Turbidity (°)		Bacteria		Coliform	
before	>0.024		>0.038		1.1		2		>0.5		n		n	
	in	out	in	out	in	out	in	out	in	out	in	out	in	out
0	>0.024	>0.024	>0.038	>0.038	2.4	2.3	2	2	1	1	p	p	p	p
1	0.03	0.08	>0.038	>0.038	1.7	1.8	2	2	>0.5	>0.5	p	p	p	p
2	0.03	0.04	>0.038	>0.038	2.3	2.2	2	2	>0.5	>0.5	p	p	p	p
3	0.04	0.06	>0.038	>0.038	2.1	2.2	2	2	>0.5	>0.5	p	p	p	p
4	0.05	0.06	>0.038	>0.038	2.1	2.2	2	2	>0.5	>0.5	p	p	p	p
5	0.05	0.07	>0.038	>0.038	1.9	2.2	2	2	>0.5	>0.5	p	p	p	p
6	0.07	0.07	>0.038	>0.038	2.0	2.2	2	2	>0.5	>0.5	p	p	p	p
13	0.10	>0.024	>0.038	0.042	2.1	2.0	2	2	>0.5	>0.5	p	p	p	p
20	>0.024	>0.024	>0.038	0.050	2.7	1.9	2	2	>0.5	>0.5	p	p	p	p
27	>0.024	>0.024	>0.038	0.055	2.5	1.8	2	2	>0.5	>0.5	p	p	p	p
34	0.03	>0.024	>0.038	0.054	2.3	1.3	2	2	>0.5	>0.5	p	p	p	p
41	>0.024	>0.024	>0.038	0.050	2.3	1.3	2	2	>0.5	>0.5	p	p	p	p
48	>0.024	>0.024	>0.038	0.046	1.8	1.2	2	2	>0.5	>0.5	p	p	p	p
55	>0.024	>0.024	>0.038	0.042	1.6	1.1	2	2	>0.5	>0.5	p	p	p	p
62	>0.024	>0.024	>0.038	0.049	1.6	0.9	2	2	>0.5	>0.5	p	p	p	p
69	>0.024	>0.024	>0.038	0.042	1.8	0.7	2	2	>0.5	>0.5	p	p	p	p
76	>0.024	>0.024	>0.038	0.039	1.8	>0.66	2	2	>0.5	>0.5	p	p	p	p
83	>0.024	>0.024	>0.038	>0.038	1.9	>0.66	2	2	>0.5	>0.5	p	p	p	p
90	>0.024	>0.024	>0.038	>0.038	1.8	>0.66	2	2	>0.5	>0.5	p	p	p	p
97	>0.024	>0.024	>0.038	>0.038	1.8	0.7	2	2	>0.5	>0.5	p	p	p	p

in: Storage container located indoors, out: Storage container outdoors,
p: Positive, n: Negative

Cultivo Mínimo em Sistemas de Captação de Água de Chuva “in situ”

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Resumo

O efeito do manejo de restos culturais, aliado à técnica de captação de água de chuva “in situ” foram avaliados na cultura do milho (*Zea mays* L.) em condições de sequeiro. O sistema decaptação de água de chuva “in situ” utilizado foi o Guimarães Duque, com as seguintes combinações, que constituíram os tratamentos: T1. Testemunha (sistema de captação sem refazerlo a cada ano, retirando os restos culturais da superfície do solo depois da colheita); T2. Refazer o sistema de captação a cada ano e retirar os restos culturais da superfície do solo; T3. Refazer o sistema de captação a cada ano e incorporar os restos culturais na linha de plantio; T4. Refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e incorporar na linha de plantio junto com os restos culturais; e T5. Não refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e deixar os restos culturais sobre a superfície do solo. Os tratamentos onde os restos culturais foram mantidos como cobertura morta ou incorporados na linha de plantio (T5, T4 e T3) apresentaram as maiores produtividades, porém não diferiram estatisticamente entre si. No entanto estes diferiram significativamente daqueles nos quais os restos culturais foram retirados da superfície do solo após a colheita (T1 e T2).

INTRODUÇÃO

O trópico semi-árido brasileiro, com uma área de 1.150.000 km², correspondente a 70% da área da região Nordeste e 13% do país, apresenta uma grande diversidade de quadros naturais, compreendidos em 120 unidades geoambientais, com grandes diferenciações de ordens física, biológica e socioeconômica (Silva et al. 1993). A escassez e a má distribuição das chuvas, as limitações de solos, as práticas agrícolas adotadas, entre outros fatores, constituem aspectos limitantes para o desenvolvimento agrícola da região.

As pesquisas tem demonstrado que a menor mobilização do solo, rotação de cultivos, manejo de restos culturais e os fertilizantes orgânicos e minerais contribuem para o aumento e/ou manutenção da capacidade produtiva dos solos (Vine, 1953). Na região semi-árida brasileira a utilização destas técnicas não é suficiente para garantir uma boa produção, devido a má distribuição das chuvas e que os cultivos se desenvolvem quase na sua totalidade em condições de sequeiro. As pesquisas tem demonstrado que para reter a água de chuva no solo sem que esta se perda por escoamento superficial mediante técnicas de captação de água de chuva “in situ” são muito importantes (Smith, 1978; Duret et al., 1985; Silva et al., 1989). Estas técnicas consistem basicamente na modificação da superfície do terreno de modo que formem um plano inclinado entre dois sulcos sucessivos, chamados camalhões, que funcionam como área de captação da água de chuva (Eingg e Hawer, 1959). Estes sulcos são construídos seguindo as curvas de nível e fechados ao final para induzir uma maior captação e permitir uma maior infiltração da água no solo. Em caso de excesso de chuvas abrem-se os sulcos para não reter muita água dentro deles, o que poderia prejudicar os cultivos (Stern, 1979).

A capacidade de retenção de umidade no solo é um fator extremamente importante no emprego dessa tecnologia. A textura, estrutura, porosidade e profundidade do solo são características indiscutíveis no planejamento do sistema, já que as mesmas são responsáveis pela maior ou menor retenção de água no solo (Porto e Silva, 1982).

O presente trabalho teve por objetivo avaliar o efeito da utilização de restos culturais aliado a técnicas de captação de água de chuva “in situ”, no aumento da produtividade do milho.

MATERIAL E MÉTODOS

O trabalho foi realizado na Estação Experimental de Manejo da Caatinga da Embrapa – Semi-Árido, em Petrolina, PE, Brasil, com coordenadas geográficas Latitude 09° 05' S, Longitude 40° 24' S e Altitude de 379m. O solo da área é classificado como Planossilic Eutric Paleargid, textura arenosa, com uma profundidade média de 1,20 m, cujas características físicas e químicas são apresentadas na Tabela 1. A região apresenta um clima semi-árido, com uma precipitação média anual de 390 mm.

Tabela 1. Características físicas e químicas do solo da área experimental.

Profundidade ---- cm ----	Textura			T	V	P	M. Orgânica
	Areia -----	Silte %	Argila -----	Meq/10	-- % --	- ppm -	----- % -----
0-10	80	13	07	4,16	50	5,47	0,76
10-20	84	08	08	4,36	39	2,88	0,59
20-30	75	13	12	4,55	40	2,88	0,36
30-40	60	13	27	5,74	40	0,48	0,33
40-50	51	16	33	7,69	58	0,29	0,12
50-60	47	15	38	8,33	68	0,38	0,00
>60	46	14	40	8,53	74	0,48	0,00

O experimento foi instalado em parcelas com dimensões de 20,0 x 5,0m, utilizando-se o sistema de captação de água de chuva “in situ” Guimarães Duque, que consiste na formação de sulcos seguidos por camalhões altos e largos, formados mediante cortes efetuados seguindo as curvas de nível com um arado de disco reversível de três discos tracionado por um trator (Figura 1). Para preparar o sistema retira-se o primeiro disco do arado fazendo-se o primeiro camalhão na primeira passada, retornando com os pneus do trator margeando o sulco, preparando o segundo camalhão, e assim sucessivamente.

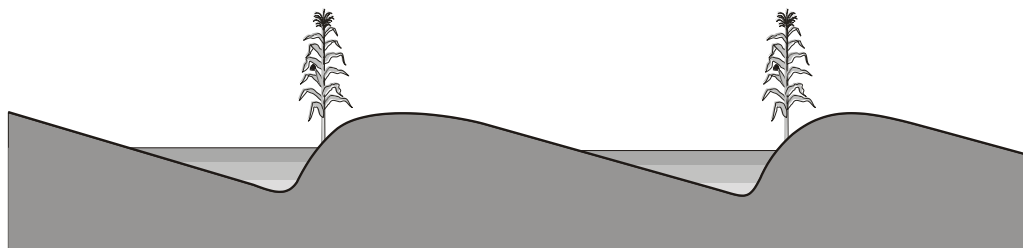


Figura 1. Representação do sistema de captação de água de chuva "in situ" Guimarães Duque.

O delineamento experimental utilizado foi blocos ao acaso com cinco tratamentos e quatro repetições. Os tratamentos avaliados foram: T1. Testemunha (sistema de captação sem refazê-lo a cada ano, retirando os restos culturais da superfície depois da colheita); T2. Refazer o sistema de captação a cada ano e retirar os restos culturais da superfície; T3. Refazer o sistema de captação a cada ano e incorporar os restos culturais na linha de plantio; T4. Refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e incorporar na linha de plantio junto com os restos culturais; e T5. Não refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e deixando os restos culturais sobre a superfície do solo.

No primeiro ano plantou-se milho para uniformizar a fertilidade do solo e para obter-se restos culturais para instalação dos tratamentos propostos no experimento. O plantio foi realizado com uma plantadeira-adubadeira manual, colocado-se três sementes por cova, com espaçamento de 1,5 X 0,40 m, deixando-se depois de germinadas duas plantas por cova. A adubação de fundação foi realizada no momento do plantio, com uma dose de 60 Kg.ha⁻¹ de P₂O₅. Trinta dias após o plantio foi feita uma adubação de cobertura com 50 Kg.ha⁻¹ de uréia. Ao final do experimento mediu-se a produtividade de milho de cada parcela, analisando-se os resultados mediante a comparação de médias pelo Teste de Duncan, ao nível de 5% de probabilidades.

RESULTADOS E DISCUSSÃO

As produtividades médias de milho alcançadas em cada tratamento avaliado, estão apresentadas na Tabela 2. O tratamento T5 apresentou a maior produtividade, seguido dos tratamentos T4 e T3, que no entanto não diferiram estatisticamente entre eles. Os tratamentos T1 e T2 apresentaram o mesmo efeito, sendo que no primeiro observou-se uma menor produtividade. Todos os tratamentos em que os restos culturais foram incorporados na linha de plantio (T3, T4 e T5) foram estatisticamente superiores aos outros dois em que os restos culturais foram retirados da área após a primeira colheita de milho (T1 e T2). Isto leva a crer que os restos culturais incorporados e/ou mantidos na superfície da linha de plantio, proporcionou ao solo uma maior capacidade de armazenamento de água, refletindo na produtividade da cultura.

Tabela 2. Produtividade média de milho nos tratamentos com o sistema Guimarães Duque.

Tratamentos	Produtividade -- Kg.ha ⁻¹ --	Incremento --- % ---
T1. Testemunha (sistema de captação sem refazê-lo a cada ano, retirando os restos culturais depois da colheita)	1.497a	---
T2. Refazer o sistema de captação a cada ano e retirar os restos culturais	1.686a	12,6
T3. Refazer o sistema de captação a cada ano e incorporar os restos culturais	2.051b	37,2
T4. Refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e incorporar ao solo	2.082b	39,0
T5. Não refazer o sistema de captação a cada ano, plantar mucuna preta para adubação verde e deixar os restos culturais sobre a superfície.	2.262b	51,1

Segundo Vine (1953) que a menor mobilização do solo, rotação de cultivos, manejo de restos culturais e os fertilizantes orgânicos e minerais contribuem para o aumento e/ou manutenção da capacidade produtiva dos solos. Na região semi-árida brasileira a utilização destas técnicas de captação de água de chuva “in situ” não é suficiente para garantir uma boa produção, devido a má distribuição das chuvas no espaço e no tempo.

Devido às condições de cultivo serem iguais em todos os tratamentos, exceto ao sistema de preparo do solo e manejo dos restos culturais, observa-se que os tratamentos em que os restos culturais foram incorporados e/ou mantidos na superfície do terreno, as produtividades foram maiores, o que leva a crer que estes sistemas foram mais eficientes no armazenamento e retenção da água no solo.

Na figura 2 pode-se observar que apesar da quantidade de chuva caída entre os meses de novembro a março ter sido superior à média regional, a distribuição desta no espaço e no tempo foi bastante irregular, coincidindo com a falta de chuva no período mais crítico para a cultura, entre os 40 e 80 dias (floração). Analisando-se os dados de precipitação observou-se que a maioria das chuvas ocorreram no período de plantio e germinação, enquanto que durante o desenvolvimento vegetativo, floração e maturação do milho as chuvas foram escassas.

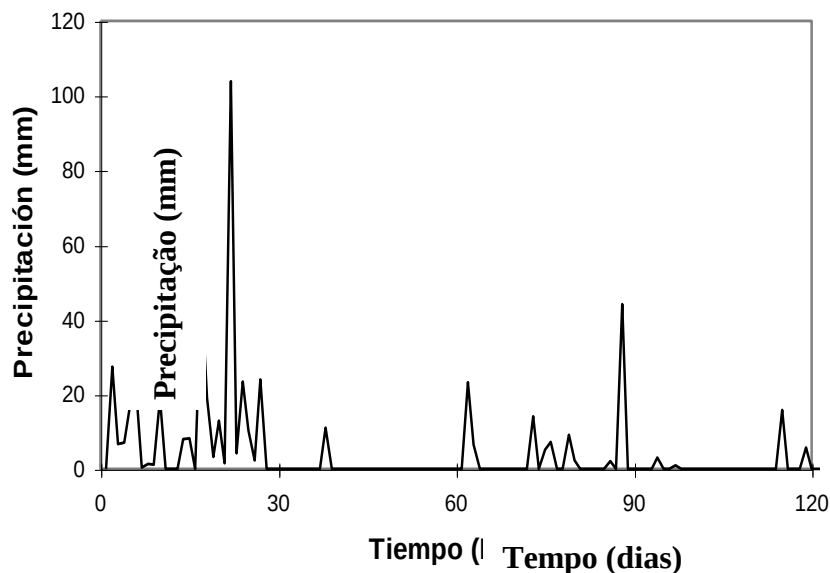


Figura 2. Distribuição das chuvas durante o ciclo de cultivo do milho.

A relação entre os dados de precipitação e produtividade de milho demonstraram a eficiência dos sistemas de captação de água de chuva “in situ” no armazenamento de água no solo, refletindo no aumento da produtividade da cultura. Devido às características edafo-climáticas da região, recomenda-se o uso do sistema de captação de água de chuva “in situ” sempre aliada a outra técnica complementar, capaz de otimizar o aumento da capacidade de retenção e conservação da água no solo.

CONCLUSÕES

Os tratamentos onde os restos culturais foram retirados das superfícies apresentaram as menores produtividades de milho;

Os tratamentos onde os restos culturais foram incorporados nas linhas de plantio apresentaram o mesmo efeito que aqueles em que os restos culturais foram mantidos na superfície como cobertura morta, contudo apresentaram-se superiores à testemunha, com maiores produtividades; A maior produtividade foi observada no tratamento em que os restos culturais foram mantidos na superfície do solo, porém não diferiu estatisticamente daqueles em que os restos culturais foram incorporados;

4. A manutenção da cobertura morta na superfície do solo ou a sua incorporação são técnicas capazes de conservar a unidade no solo.

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Rainwater Catchment System of Mizoram State, India

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Abstract

The state of Mizoram, located in the extreme northeast corner of India, is a small hilly state having an area of about 21,000 sq. km and thinly populated. The state is entirely mountainous covered with green vegetation. Villages are mostly located on hilltops. Mizoram State enjoys abundant monsoon rainfall of about 2500 millimetres annually. Run-off is rapid and people face acute water problems in the dry season. Villagers must descend long distances to fetch water from perennial springs and rivers. When English-speaking people came to establish their first administrative set-up in 1894, they obtained domestic water from a 12-lakh gallon capacity underground rainwater tank. From then on, the people started harvesting rainwater from roofs. Water tanks are constructed mainly using galvanised iron sheets.

Rainfall which penetrates in the soil emerge as springs on the lower reaches at the out-crop of sedimentary rock layers. Spring water collection tanks were constructed from where the people used to draw their water supply.

Rooftop rainwater harvesting and spring water collection are the main sources of domestic water supply in Mizoram. With the pace of development of gravity piping, the government took control of water supply and pumping water supply schemes. Yield of gravity water sources were reduced considerably in the dry season and unreliable. Piped water supply is supplemented by rainwater harvesting in most of the towns and villages. Many families prefer rainwater for direct consumption to that of piped water supply.

Aizawl, the capital town of Mizoram State, has a piped water supply as the result of pumping water 1040 meters height from a perennial river 8 kilometres away. The schemes commissioned in December 1988 are not sufficient to feed the increasing population. Even in the localities where piped water supply is available, rainwater collection still plays a very important role.

The government of India and the state government have taken up rainwater harvesting from rooftop collection and spring water improvement as one of the important development schemes. During the International Water Decade, a substantial amount of funding was sanctioned in the state and central plans for rainwater harvesting.

Mizoram

Mizoram is one of the smallest states in India having an area of only 21,000 sq. kms. It is located in the extreme North East of India bordering Myanmar and Bangladesh. The state is entirely mountainous covered with lush green vegetation. The mountains range in a North - South direction and the rivers flow in either a North or South direction. The highest peak namely Blue Mountain is only 7100 feet high and the climate of Mizoram is moderate. Towns

and villages in Mizoram are mostly located on hilltops or on the upper reaches of the hills. Since perennial streams and rivers are located much below the habitations, scarcity of water in the dry season is very common. The whole state enjoys abundant monsoon rainfall during the rainy season extending five or six months in a year. The state is thinly populated. Nearly one fourth of the seven (7) lakh population lives in Aizawl, the state capital, and the rest are scattered in about 800 small towns and villages.

Traditional Water Supply System

The state of Mizoram is backward and development started only about a century ago. The first water supply system in Aizawl consisted of a 12 gallon Rainwater Catchment ground reservoir constructed on a hilltop in 1900. A sloped roof of galvanised corrugated iron sheets on a timber frame was constructed around the reservoir for rainwater catchment. From then on people took to the practice of rooftop water harvesting to meet their domestic water demand.

Springs on the hill slope and valleys are the main water supply sources in the villages. In the dry period the yield from springs gets reduced drastically. During the worst dry periods one has to wait long hours to obtain just a bucketful of water from the spring sources. Spring water supplemented by rainwater harvesting still remains today, the main means of water supply in many villages and outskirts of towns.

Rain Water

Mizoram has an average rainfall of about 250 centimetres per annum. The rainy season of six months a year is between May and October. The pattern of annual rainfall recorded at Aizawl is shown in the following tables:

Year	1988	1990	1991	1992	1993	1994	1995	1996	
Rainfall (cm)	265.6	282.7	261.4	194.5	322.8	207.0	250.1	236.3	

Rainwater is free from undesirable chemical impurities. A study conducted by the Industrial Toxicology Research Centre, in Lucknow, India, on the water quality revealed that rainwater stored in rainwater tanks for a long period of time can develop bacterial growth but is free from chemical contamination; such bacteria can be removed by simple chlorination. An occasional dose of chlorine or bleaching powder once a month is considered sufficient.

Design Parameters

Rainwater harvesting depends on two things:-

- (1). Quantity of rainfall.
- (2). Area of catchment.

The catchment may be classified into three categories:-

- (i) Hard surfaces like roofs and rocks which give a total run-off of 100%.
- (ii) Semi-hard surfaces such as the rock compound of a house with 50% run-off.
- (iii) Loose soil which gives 25% runoff.

The following simple formula may be applied to arrive at the quantity of rainwater collected:

Quantity of water = Catchment area x Run-off x Rainfall

For example :-

(a) If a roof area is 10 m long and 5 m wide and rainfall is equal to 250 cm per annum.

Quantity of Rainfall = $\frac{10 \times 5 \times 250 \times 1000}{100}$

= 125,000 litres per annum

For a family of 8 persons, this is

$$\frac{125000}{8 \times 365} = 45 \text{ litres per capita per day.}$$

In Mizoram majority of the houses have sloped roofs of galvanised corrugated iron sheets which are very convenient for rainwater harvesting. Semi circular rain gutters of galvanised iron sheets fitted on the lower roof edges collect and convey the rainwater into cylindrical storage tanks made of galvanised iron. The first shower is let off without letting it enter the reservoir to flush out dirt accumulated in the roof during the dry period. The environment in Mizoram is unpolluted; rainwater thus harvested remains in good condition for a long period and is normally kept throughout the dry season.

Spring water Catchment

Rain water percolating inside the soil on hill slopes emerge as springs at the outcrops of rock layers. Catchment tanks of stone masonry or concrete are built to store water. Roof covers of suitable materials are constructed to prevent entry of leaves and other unwanted materials. Springs are a good sources of water during the rainy season and some months after the rains. The quantity of water diminishes after the rains stop and sometimes dries up during the driest months. Only a few spring sources are perennial. Water from spring sources normally has chemical and bacterial contamination rendering them unfit for direct consumption. Spring water is used mainly for washing and other uses.

Check dams

In a hilly terrain like Mizoram rainwater run-off is rapid. Earthen check dams of different sizes are constructed in valleys, streams, and rivers to collect the monsoon rainwater. These are mostly done by the people themselves without the help of the government. Water bodies created by this system serve a very useful purpose for fish cultivation, agriculture and animal husbandry.

Government Programmes

During the International Drinking Water Decade Programme (1981-90) a massive programme for providing drinking water to all Census Villages was launched in India. In a hilly state like Mizoram gravity pipe water supply schemes and groundwater exploration is not able to supply sufficient water. As most of the towns and villages are located on the high hill slopes or hilltops, gravity water sources and ground water yields are very scanty. Rainwater harvesting and spring development were taken up as a Government Programme. The Rajiv Gandhi National Drinking Water Mission, aiming at providing drinking water to every person, sanctioned a substantial fund for rooftop rainwater harvesting tanks. As many as 198 villages in Mizoram have benefited from the scheme.

Aizawl, the state capital has a Pumping Water Supply Scheme from a perennial river. The town is rapidly increasing, with the population doubling every decade. The Water Supply System is over stressed and outlying localities do not have pipe connections. Rainwater harvesting plays a very important role in the water supply in these localities. Similarly, many towns and villages supplement their water supply with Rainwater harvesting. In urban areas, people construct rainwater tanks of different capacities at their own expenditure. In Aizawl alone there are more than 10,000 rainwater tanks in private houses.

Conclusion

Fresh water resources, both surface and ground water are finite. With demand for fresh water rapidly increasing, the fresh water resources are decreasing day by day due to pollution. A rapid development process is damaging water resources; at the same time, the population is increasing at an alarming rate. Surface water resources of rivers and lakes are over stressed and threatened by development. Over extraction of ground water in many places results in chemical contamination and seawater ingress in coastal areas. Rainwater resources can supplement the short fall in fresh water supply. The technology is simple and can be practised even by laymen. Maintenance is easy and economical. In our effort for a sustainable water resource management, rainwater catchment seems to be the best option.

Utilização Das Tecnologias De Captação De Água De Chuva Na Região Semi-Árida Do Nordeste Brasileiro

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Resumo

A escassez de recursos hídricos que assola a região semi-árida do Nordeste brasileiro, torna praticamente impossível a prática de uma agricultura voltada para produção de excedentes alimentares e para sobrevivência dos rebanhos bovinos, caprinos e ovinos, que são a principal fonte de renda e reserva de poupança dos pequenos agricultores. Todavia, viver nesta região requer dos agricultores, principalmente aqueles das áreas de sequeiro, a utilização de algumas alternativas tecnológicas voltadas para a captação e armazenamento de água das chuvas. Entretanto, quando se analisam os níveis de adoção dessas tecnologias, percebe-se que poucos agricultores utilizam alguma tecnologia de captação de água da chuva. Este trabalho teve como o objetivo fazer um levantamento junto aos pequenos agricultores de 5 municípios da região semi-árida quanto à utilização das tecnologias voltadas para captação e armazenamento de água de chuva. O trabalho foi realizado nos municípios de Simplício Mendes (PI), Morada Nova (CE), Angicos (RN), Jeremoabo (BA) e Inajá (PE) no período de 1996 a 1998. Em cada município foi aplicado um questionário junto aos agricultores selecionados por meio de uma amostra aleatória simples, num total de 179 agricultores, com as seguintes variáveis: 1) agricultores que utilizam a cisterna rural, 2) agricultores que utilizam o barreiro para irrigação suplementar, 3) agricultores que utilizam a barragem subterrânea, 4) agricultores que utilizam o sistema de captação de água de chuva “in situ” e 5) Motivos da não utilização das tecnologias. Os resultados obtidos, mostraram que apenas 9,5% agricultores utilizam a cisterna rural. E que 51,96% dos agricultores não utilizam esta tecnologia por falta de recursos financeiros. As demais tecnologias não foram adotadas por nenhum agricultor. Com esses resultados pode-se concluir que há necessidade de maior difusão e demonstração destas tecnologias para os pequenos agricultores.

INTRODUÇÃO

A escassez de recursos hídricos que assola a região semi-árida do Nordeste brasileiro, torna praticamente impossível a prática de uma agricultura voltada para produção de excedentes alimentares e para sobrevivência dos rebanhos bovinos, caprinos e ovinos, que são a principal fonte de renda e reserva de poupança dos pequenos agricultores. Todavia, viver nesta região requer dos agricultores, principalmente aqueles das áreas de sequeiro, a utilização de algumas alternativas tecnológicas voltadas para a captação e armazenamento de água das chuvas. Entretanto, quando se analisam os níveis de adoção dessas tecnologias, percebe-se que poucos agricultores utilizam alguma tecnologia de captação de água da chuva.

Por outro lado, a região semi-árida do Nordeste brasileiro vem sendo alvo, nos últimos anos, principalmente a partir do final da década de 80, de grandes investimentos na pesquisa agropecuária, em busca de soluções para os problemas que afligem os pequenos agricultores.

Os resultados dessas pesquisas, segundo a EMBRAPA (1993), compõem um acervo tecnológico à disposição dos pequenos agricultores, o qual já possibilita a convivência do homem e de seus animais com as secas periódicas que assolam a região e dela tirar proveito suficiente para sua sobrevivência.

No entanto, esse progresso tecnológico não foi capaz ainda de realizar a grande transformação dos pequenos agricultores da região semi-árida, que seria à adequação de uma agricultura de subsistência às condições de adversidades climáticas, isto é, a uma convivência melhor com a seca.

Contudo, o baixo índice de adoção das tecnologias desenvolvidas, leva-nos a concordar com a afirmação de Campos (1998) de que “...a pesquisa básica com resultados tecnológicos sem perspectiva de relevância econômica ou social para o país, ainda que excelente do ponto de vista, acadêmico, é insatisfatório...”.

Diante dos resultados alcançados pela pesquisa e sua utilização pelos pequenos agricultores, principalmente os da região semi-árida do Nordeste “...a pesquisa, em relação ao pequeno agricultor, necessita ser repensada, pois até o momento, esta mostrou-se ineficaz, ou pouco eficaz, devido; a) ter se inspirado no modelo de alta produtividade e consumo energético, próprios dos países desenvolvidos, difícil de incorporar a realidade do pequeno agricultor familiar e tendente a homogeneizar ecossistemas diferenciados, provocando problemas de desequilíbrio ecológico e degradação dos recursos naturais; e b) não ter dado suficiente importância às tecnologias poupadoras de recursos de capital e de insumos, de baixo custo e de mais fácil adoção (FAO, 1988).

Por outro lado, segundo Schaun (1984), a pesquisa sobre difusão de inovações tecnológicas na agricultura raramente se preocupa em determinar os critérios que orientam a experimentação. Essa vulnerabilidade teórica é contornada pela pressuposição inerente à problemática da difusão de tecnologia, ou seja, nos estudos de difusão presume-se que a tecnologia foi gerada e/ou adaptada para o público para o qual se transfere a tecnologia. Há a pressuposição de homogeneidade entre o público previsto na geração e/ou adaptação e o público explícito da difusão. Na realidade, nota-se que há uma distância teórica entre a geração e a difusão de tecnologias, apesar das pressuposições de que essas duas dimensões atuem conjuntamente.

O objetivo deste estudo foi realizar um levantamento junto aos pequenos agricultores de 5 municípios da região semi-árida quanto à utilização das tecnologias voltadas para captação e armazenamento de água de chuva.

MATERIAL E MÉTODOS

O trabalho foi realizado nos municípios de Simplício Mendes (PI), Morada Nova (CE), Angicos (RN), Jeremoabo (BA) e Inajá (PE) no período de 1996 a 1998. Estes municípios caracterizam-se principalmente, por terem suas áreas inseridas 100% no Polígono das secas e segundo Hargreaves (1974) apresentam uma variação climática de muito árido a semi-árido, com alto risco de ocorrência de secas.

Em cada município foi aplicado um questionário junto aos agricultores selecionados por meio de uma amostra aleatória simples, num total de 179 agricultores, levando-se em consideração o tamanho do estabelecimento agrícola, tendo em vista a grande quantidade de estabelecimentos com área menor que 10 ha e entre 10 e 100 hectares, onde predomina a pequena produção, representada pelo cultivo de lavouras de subsistência e pelo uso de tecnologias tradicionais. Para o dimensionamento da amostra, foi utilizado o procedimento estatístico recomendado por Cochran (1965) e Richardson (1985), considerando-se o nível de significância de 5% de probabilidade e o desvio-padrão de 10% (Tabela 1).

O período de aplicação dos questionários foi o seguinte: 1) no município de Morada Nova (CE), de março a abril de 1996; 2) Simplício Mendes (PI), Angicos (RN) e Jeremoabo (BA) de agosto a setembro de 1997; e 3) no município de Inajá (PE), de março a abril de 1998.

A variáveis analisadas foram as seguintes: 1) agricultores que utilizam a cisterna rural; 2) agricultores que utilizam o barreiro para irrigação suplementar; 3) agricultores que utilizam a barragem subterrânea; 4) agricultores que utilizam o sistema de captação de água de chuva “in situ”; e 5) Motivos da não utilização das tecnologias.

Para análise estatística dos dados foi utilizado o procedimento PROC TABULATE que compõem o SAS (SAS, 1990) com o objetivo de criar tabelas de frequências simples e cruzadas, para classificar, hierarquizar e confrontar as informações.

Tabela 1 - Tamanho da amostra, segundo os estratos, em classe de área e número de estabelecimentos por município selecionados.

Municípios	Tamanho da amostra por classe de áreas (ha)		Total da amostra por município
	Menos de 10	10<100	
Simplício Mendes	23	25	48
Morada Nova	13	12	25
Angicos	23	22	45
Jeremoabo	18	22	40
Inajá	11	10	21

Fonte: Dados da pesquisa.

RESULTADOS E DISCUSSÃO

Na Tabela 2 pode-se observar que no município de Simplício Mendes, os pequenos agricultores fazem pouco uso das tecnologias de captação de água de chuva. Neste município a única tecnologia utilizada pelos agricultores é a cisterna rural, a qual é utilizada por apenas 4,17% dos agricultores.

Quanto aos motivos da não utilização das tecnologias, o destaque é para barragem subterrânea e a captação de água de chuva “in situ” que não são conhecidas por nenhum dos agricultores entrevistados. Já o barreiro para irrigação suplementar, também não é

conhecido por 95,83% dos agricultores. Outro motivo é a falta de recursos financeiros, os quais são responsáveis pela não utilização da cisterna rural por 58,34% dos agricultores.

Esse índice de utilização das tecnologias de captação de água de chuva é preocupante, visto que, muitos recursos já foram gastos em pesquisas e programas voltadas para geração e/ou adaptação dessas tecnologias às condições da região semi-árida, como o Programa “Semi-árido: proposta de implantação de sistemas de exploração de propriedades agrícolas para assegurar a convivência do homem com a seca” coordenado pela Embrapa e Embrater (EMBRAPA, 1982), entre outros como: Projeto Sertanejo; Prohidro; Projeto Padre Cícero e Projeto Áridas.

Todavia, como mostra Oliveira (1996), a maioria das recomendações tecnológicas para os pequenos agricultores da região semi-árida, não são adotadas.

Tabela 2 - Distribuição percentual dos pequenos agricultores do município de Simplício Mendes, que utilizam tecnologias e as causas da não utilização.

Tecnologias	Causas da não utilização das tecnologias									
	Agricultores que utilizam tecnologia		Falta de assistência técnica		Falta de informações sobre a tecnologia		Falta de recursos financeiros		Não conhecem a tecnologia	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Cisterna	2	4,17	4	8,33	7	14,58	28	58,34	7	14,58
Barreiro	0	0	0	0	0	0	2	4,17	46	95,83
Barragem	0	0	0	0	0	0	0	0	48	100
Captação “in situ”	0	0	0	0	0	0	0	0	48	100

Fonte: Dados da pesquisa.

No município de Morada Nova, a utilização das tecnologias analisadas, apresenta índices semelhantes aos encontrados no município de Simplício Mendes, onde pode-se observar na Tabela 3 que a cisterna rural é a única tecnologia utilizadas pelos agricultores deste município.

Quanto as causas da não utilização das tecnologias, a falta de assistência técnica, de informações sobre a tecnologia, de recursos financeiros e principalmente o desconhecimento das tecnologias pelos agricultores, são os principais motivos da não utilização. O barreiro para irrigação suplementar e a barragem subterrânea são desconhecidas por 100% dos agricultores entrevistados.

Tabela 3 - Distribuição percentual dos pequenos agricultores do município de Morada Nova, que utilizam tecnologias e as causas da não utilização.

Tecnologias	Causas da não utilização das tecnologias									
	Agricultores que utilizam tecnologia		Falta de assistência técnica		Falta de informações sobre a tecnologia		Falta de recursos financeiros		Não conhecem a tecnologia	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)

	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Cisterna	3	12,0	4	16,0	3	12,0	13	52,0	2	8,0
Barreiro	0	0	0	0	0	0	0	0	25	100
Barragem	0	0	0	0	0	0	0	0	25	100
Captação “in situ”	0	0	0	0	2	8,0	0	0	23	92,0

Fonte: Dados da pesquisa.

Essa pouca utilização das tecnologias, não ocorre apenas com as alternativas voltadas para captação de água de chuva, más também, com as tecnologias tradicionalmente utilizadas pelos agricultores, como: a utilização de sementes melhoradas; de adubos orgânicos e químicos; de defensivos agrícolas; e da vacinação de animais, como mostra Oliveira et al (1997) num estudo de topologia dos sistemas de produção praticados pelos pequenos produtores rurais do Estado do Rio Grande do Norte.

No município de Angicos, a utilização das tecnologias de captação de água de chuva “in situ”, segue a mesma tendência dos municípios de Simplício Mendes e Morada Nova. Neste município apenas a cisterna rural é utilizada por 4,44% dos agricultores entrevistados, como pode-se observar na Tabela 4.

Entre os motivos da não utilização das tecnologias, destaca-se o desconhecimento das mesmas. Embora conhecida pela grande maioria dos agricultores, a cisterna rural não é utilizada por 62,23% dos agricultores por falta de recursos financeiros.

Esses resultados encontrados no município de Angicos, são semelhantes aos encontrados por Oliveira (1997) onde apenas a cisterna rural foi adotada pelos pequenos agricultores como uma fonte de armazenamento e captação de água de chuva.

Tabela 4 - Distribuição percentual dos pequenos agricultores do município de Angicos, que utilizam tecnologias e as causas da não utilização.

Tecnologias	Causas da não adoção das tecnologias									
	Agricultores que utilizam tecnologia		Falta de assistência técnica		Falta de informações sobre a tecnologia		Falta de recursos financeiros		Não conhecem a tecnologia	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Cisterna	2	4,44	10	22,22	2	4,44	28	62,23	3	6,67
Barreiro	0	0	0	0	0	0	0	0	45	100
Barragem	0	0	0	0	0	0	0	0	45	100
Captação “in situ”	0	0	0	0	4	8,89	0	0	41	91,11

Fonte: Dados da pesquisa.

Nos municípios de Jeremoabo e Inajá, apenas a cisterna rural é utilizada pelos pequenos agricultores, como pode-se observar nas Tabelas 5 e 6. Nestes municípios, o desconhecimento das tecnologias é o principal motivo da não utilização da maioria das tecnologias analisadas.

Esses resultados reforçam a afirmação de Campos (1998) de que “... a pesquisa básica com resultados tecnológicos sem perspectiva de relevância econômica ou social para o país, ainda que excelente do ponto de vista, acadêmico, é insatisfatório...”. Daí a

necessidade de se repensar o desenvolvimento tecnológico da região semi-árida, principalmente das pesquisas voltadas para os pequenos agricultores, como afirma a FAO (1988).

Tabela 5 - Distribuição percentual dos pequenos agricultores do município de Jeremoabo, que utilizam tecnologias e as causas da não utilização.

Tecnologias	Causas da não utilização das tecnologias									
	Agricultores que utilizam tecnologia		Falta de assistência técnica		Falta de informações sobre a tecnologia		Falta de recursos financeiros		Não conhecem a tecnologia	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Cisterna	2	5,0	12	30,0	3	7,50	20	50,0	3	7,5
Barreiro	0	0	0	0	0	0	0	0	40	100
Barragem	0	0	0	0	0	0	0	0	40	100
Captação “in situ”	0	0	0	0	0	0	0	0	40	100

Fonte: Dados da pesquisa.

Tabela 6 - Distribuição percentual dos pequenos agricultores do município de Inajá, que utilizam tecnologias e as causas da não utilização.

Tecnologias	Causas da não utilização das tecnologias									
	Agricultores que utilizam tecnologia		Falta de assistência técnica		Falta de informações sobre a tecnologia		Falta de recursos financeiros		Não conhecem a tecnologia	
	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)	(n)	(%)
Cisterna	6	28,57	6	28,57	3	14,29	4	19,05	2	9,52
Barreiro	0	0	0	0	0	0	0	0	21	100
Barragem	0	0	0	0	0	0	0	0	21	100
Captação “in situ”	0	0	0	0	4	8,89	0	0	21	100

Fonte: Dados da pesquisa.

CONCLUSÕES

- Apesar de reconhecidas e comprovadas as vantagens de algumas tecnologias geradas e/ou adaptadas pela pesquisa agrícola para a convivência dos pequenos agricultores da região semi-árida com as secas periódicas que assolam a região, a maioria dos agricultores não as adotam, talvez porque não as conhecem, não dispõem de recursos necessários para sua implantação, não sabem usá-las corretamente ou porque não lhes tem sido demonstrada sua possibilidade de aplicação e eficiência. Daí a necessidade de maior difusão das mesmas e demonstração de que os pequenos agricultores desta região são capazes de adotá-las com os recursos que dispõem em suas propriedades e aproveitarem de forma racional os recursos disponíveis na região semi-árida do Nordeste brasileiro.

- É necessário não só avaliar o acervo tecnológico a disposição dos pequenos agricultores para convivência com a seca, buscando encontrar os pontos críticos, aos quais os pequenos agricultores são vulneráveis, como também, todo o processo de difusão dessas alternativas tecnológicas.

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Indução De Escoamento Superficial Em Microbacias No Semi-Árido Brasileiro

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Resumo

São apresentados resultados de dez anos de hidrologia superficial, referente a oito microbacias hidrográficas com diferentes sistemas de manejo da vegetação natural (caatinga) da região semi-árida brasileira, visando a indução do escoamento superficial, captação e armazenamento de água de chuva para a pequena irrigação. Em uma área uniforme foram construídas oito microbacias experimentais, com o objetivo de fazer-se a avaliação hidrológica de diversas combinações de manejo de solo e vegetação, visando a indução de escoamento superficial de água e conservação da vegetação natural. O experimento foi instalado nas microbacias (parcelas) com áreas variando de 1,1 a 2,7 ha e declividades de 0,7 a 1,4%. Na parte mais baixa de cada parcela (local de saída da água proveniente do escoamento superficial), foi instalada uma calha Parchal e um linígrafo para medição da água escoada. Em cada parcela foi também instalado um pluviômetro com o objetivo de monitorar-se a quantidade exata de chuvas ocorridas na área. Em todos os anos de observação a parcela onde foi feito o desmatamento total da vegetação aproveitando-se a drenagem natural da área e construídos terraços tipo canal, a maior eficiência de escoamento superficial de água e perdas de solo foram maiores, seguida da parcela desmatada em faixas alternadas (50 % da vegetação retirada) com drenagem intensa e aplicação de cloreto de sódio nas faixas desmatadas (300g m⁻²), e da parcela desmatada em faixas alternadas de vegetação natural com terraços de base estreita tipo canal, construídos na área desmatada. A parcela na qual a vegetação natural foi mantida inalterada, não houve escoamento superficial de água.

Artificial recharge methods of Kariz

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Abstract

Kariz is one of the Iranian traditional water harvesting systems. Unfortunately some experts believe that water loss during winter and out of the crop season is the main disadvantage of this method. One of the methods to increase the discharge of kariz, is to recharge the aquifer artificially, where the karez tunnels are dug in them. This can be done by different methods, which are divided by "surface recharge" method and "underground recharge" method. Some case studies of Iran will be considered in the paper.

Description of work

One of the methods to increase the discharge of kariz, is to recharge the aquifer artificially, where the kariz tunnels are dug in them. This can be done by different methods, which are divided by "surface recharge" method and "underground recharge" method.

1. Surface recharge methods:

Building the water-stopping facility on the ground in the aim of holding rainfall or surface water is called surface artificial recharge. In the surface recharging methods, water was spread and held on the ground, gradually infiltrating the underground and reaching the water table. Surface artificial recharges are classified as follow:

- a. Constructing artificial ponds: In the places with good infiltration, large ponds are to be built. These ponds are built by taking soil from different spots or by constructing walls on the ground. The walls will keep the water inside. Problems such as ruining the walls of a decrease of infiltration can be solved by taking off the silt from the surface of the ponds. Some of these ponds cover an area of 3 hectares and reach a depth of 2 meters. Some ponds are for depositing silts, while others are for infiltration. After a certain time, the small particles are accumulated in the infiltrated ponds and reduce their infiltration. They should be cleaned out, at least once a year.
- b. Storage of water at the upper reach of the kariz's mother well: in the ground that has a small slope and suitable topography water can be diverted from its main route and spread on the ground. We should try to minimize the intersection of the ground water table with that of the ground surface (slope), for stranging of soil structure water should e spread on the ground surface in the shape of thin layers with low velocity. Therefore before the pond was constructed it is absolutely necessary to make the ground surface smooth in order to be able to build an adequate cycling dam. Lastly, while collecting the surplus water, a certain measure should be managed in order to deduce the exhaustion of water.
- c. Construct water-storing pond, flood diverting facilities and earth dams on the flood-canal neighboring kariz: These facilities make the flooding-water recharge the spare water to accumulate near to the kariz, then infiltrate into the ground, result the aquifer be changed. In Yazed City, Iran, this kind of measure is called a „water-chatedau’’ method. The water has a very slow speed in downward infiltration, thus, in arid seasons; this method will be quite adaptable in augmenting the water quantity of kariz.
In Yazd, certain dried (or abandonned) wells were frequently reformed for reuse. Its method is damming the mouth (outlet) of the kariz, fill the wells with floodwater, thus it may increase the water yield of kariz.

- d. Extending the ground surface vegetation: re-construct the pasture, forest, especially on the slope of hills (or on even ground surface), extending the area of vegetation on the soil, preventing evaporation and enforce the surface water infiltrate into the ground totally.
- e. Cataloging the ground surface into several groups along tarekar of the kariz. The groups that formed in such a fashion will make the surplus water of the first group inject into the second group, in turn, then, descend into the third and fourth group, etc.

2. Underground recharging (feeding) method:

- a. Sometimes the recharging from the ground surface to the aquifer is impossible due to various different reasons; then, the method of underground feeding should be adopted. The reasons that make the surface recharging impossible are the following:

- suitable ground surface are not available;
- the price of the ground (earth) is high;
- the suitable land for recharging are residential areas;
- low permeability on the upper part of the aquifer;
- infiltration of the surface soil layers are low.

- b. The method of underground artificial recharging is as follows:

- Using wells for artificial recharging:

If there are vacant aquifers, which can be used, then the aquifer of the kariz can be fed with wells. The structure of this kind of wells looks like a drainage tunnel. From the bottom part of these shafts certain horizontal wells can be dug out. The depth of the recharging wells and the length of the horizontal tunnel will be decided according to the types and permeability of the soil. If the soil has low permeability, then several shallow wells filled with mud and sand can be build. L-Tarekar is a variety of this kind of kariz, whose water table is above the tunnel.

- Most of these artificial recharges are undertaken in deep wells. These recharged wells have also some weak points, such as:

low recharging quantities;

rather quick decreasing of recharging flowage;

high investment, difficult to maintain;

efficient using period is short.

- Dig shaft wells deeply.

Most of the kariz water comes from the surface aquifer, but the deep well water comes from the deep aquifer. In Iran, most of the deep wells were highly confined, once the well was dug, the water table was at the height of the shaft. If we dig shaft in such places for collecting and conveyance water by kariz tunnel is possible, thus it will increase kariz water quantity. This method of digging deep-shaft is one of the measures to reuse the dried kariz or augment the water yield in the working kariz.

- Lowering the surface water table:

In any of the river of fresh water lake neighbor an aquifer, and part of the tunnel or complete tunnel of one or several karizes that travels or neighbor the bottom of the river, then, the water that infiltrated from the river or lake will enter the kariz.

Result of the discussion:

Obviously from the above-discussed different method, to build a well, such a method is simple, easy, low investment and practical. To choose such a place with such a method needs not a complicated investigation, and even more the expense for maintenance will not be high.

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Bombas Manuais de PVC

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Resumo

A CPT - Comissão Pastoral da Terra de Caitité - BA oferece a trabalhadores rurais (que têm habilidade para trabalhos manuais) cursos para a fabricação da bomba de PVC (polyvinyl chloride).

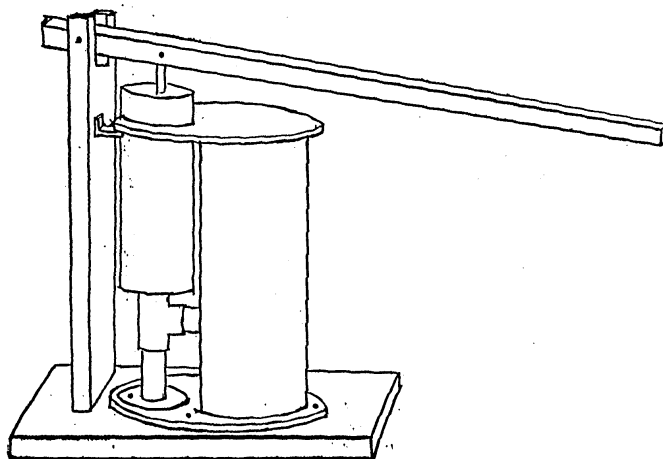
O PVC rígido soldável usado são tubos Classe 15, diâmetros de 160 e 110 mm. Este material é excelente para a confecção de bombas manuais pelos seguintes motivos:

- encontra-se com facilidade no mercado;
- durabilidade;
- resistência à pressão;
- amoldável à baixa temperatura;
- não exige equipamentos sofisticados;
- além de tubos de PVC usar-se somente madeira, couro, parafusos e cola.

Atualmente em alguns municípios esses agricultores fabricam essas bombas para uso próprio ou para venderem. Portanto as técnicas de construção e manutenção são de domínio dos agricultores que participaram do curso.

Os resultados conseguidos com a bomba são satisfatórios. Em locais planos, ela é capaz de bombear 3.200 l/h. elevando cerca de 8 m a vazão cai para 1.500 l/h. O limite máximo de sucção até agora é de 6 m, já conseguimos bombear água a cerca de 300 m. Usar-se a bomba manual de PVC para tirar água de cisternas e barreiras, elevar água de poços para outras caixas para uso doméstico e para animais, como também para irrigar hortas, pequenas áreas de feijão e fruteiras. Atualmente estão mais de 100 bombas em uso na região, elas não são mais difundidas por causa do baixo poder aquisitivo do trabalhador rural, uma vez que a bomba de PVC custa entre R\$ 90,00 e R\$ 100,00.

Em anexo segue o desenho da bomba e a descrição do material utilizado.



Relação do material para construir a bomba PVC:

- 1 = 45 cm de tubo 160 mm
- 2 = 17 cm de tubo 160 mm
- 1 = 10 cm de tubo 160 mm
- 1 = 30 cm de tubo 160 mm
- 2 = 12 cm de tubo 50 mm
- 2 = 4,5 cm de tubo 50 mm
- 1 = 6,5 cm de tubo 50 mm
- 1 = Joelho 50 mm
- 1 = Tee 50 mm
- 1 = luva rosca ou LC 32 mm
- 1 = adaptador 32 mm para mangueira
- 5 = parafusos francês $2 \frac{1}{2}'' \times 5/16''$
- 1 = parafuso francês $2'' \times 5/16''$
- 1 = parafuso francês $1'' \times 5/16''$
- 1 = parafuso francês $4'' \times 3/8''$
- 1 = parafuso sextavado $2 \frac{1}{2}'' \times 5/16''$
- 1 = pedaço de ferro $\square$ 34 cm $\times$ $1/2''$
- 2 = pedaços de sola 15 cm $\times$ 15 cm
- 1 = peça de madeira 60 cm $\times$ 18 cm $\times$ 4 cm
- 1 = peça de madeira 45 cm $\times$ 8 cm $\times$ 4 cm
- 1 = peça de madeira 120 cm $\times$ 4 cm $\times$ 3 cm
- 35 = parafusos funda 22 mm $\times$ 2.8 mm
- 8 = parafusos funda (paralela) 26 mm $\times$ 2.8 mm
- 16 = parafusos funda 16 mm $\times$ 2.2 mm
- 1 = Massa plástica
- 1 = Super bonder
- 1 = cola PVC grande
- 1 = adesivo de silicone

A Captação de Água de Chuva como Programa Educativo da APAEB

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Resumo

A APAEB – Associação dos Pequenos Agricultores do Município de Valente é uma entidade civil, sem fins lucrativos, fundada por um grupo de lavradores em 1980, a qual ao longo de sua existência vem buscando a melhoria da qualidade de vida da família rural. Perseguindo este objetivo, ao longo destes anos a APAEB tem efetivado diversos Programas, a exemplo de:

- Programa de Comercialização do Sisal (principal atividade econômica da Região)
- Programa de Convivência com o Semi-Árido, que envolve diversas ações educativas: a educação formal que acontece através da EFA - Escola Família Agrícola para os filhos dos associados da APAEB, e a educação informal como o Programa de Cursos e Treinamentos e “Dias de Campo” para os próprios associados. Portanto estas ações envolvem os aspectos sócio-econômico-político-cultural-educacional e também aspectos tocante à utilização de tecnologias apropriadas para a convivência com a região semi-árida (convivência com a seca).

A EFA que ensina tecnologias apropriadas para a Convivência com a Região Semi-árida para os alunos da APAEB - Associação dos Pequenos Agricultores do Município de Valente - BA, utiliza a captação e armazenamento de água de chuva na própria escola.

Atualmente a escola, possui 5 cisternas (de tijolos e cimento) com capacidade de 40.000 litros cada e uma outra com capacidade de 25.000 litros; todas captam a água dos pavilhões da escola. Possuímos também um pequeno açude com capacidade de armazenamento estimada de 9.000.000 litros e dois barreiros com capacidade total de 500.000 litros. Além disso, a escola possui 2 poços tubulares com uma vazão pequena de 1200 e 1300 l respectivamente de água salgada.

Visto que o consumo é grande, é indispensável o manejo da água de que a EFA dispõe:

- A água das cisternas só é usada para beber e cozinhar.
- A água das represas é usada para molhar as plantas, uso do minhocário, horta, banho e uso geral da cozinha.
- Por fim, a água salgada dos poços é usada nos vasos sanitários, lavar pocilga, abastecimento dos tanques da piscicultura e para o consumo dos animais. Em um poço foi instalado um dessalinizador solar, que pode fornecer 500 l de água potável por dia.

As cisternas fornecem bastante água de beber e cozinhar para os alunos da escola. A instalação do dessalinizador se tornou necessário porque a escola serve também para fins extra-escolares. O dessalinizador fornece água potável para eventos como reuniões e cursos dos sócios da APAEB que também são realizadas na escola.

Devido ao exemplo da EFA, 250 famílias (que são 80% dos associados da APAEB) já aproveitam a água de chuva em cisternas ou ampliaram os açudes. Os recursos para a construção de cisternas ou a ampliação dos reservatórios de água vieram da própria APAEB,

do repasse do FNE - Fundo Constitucional de Financiamento de Nordeste e do PRONAF - Programa Nacional de Financiamento da Agricultura Familiar.

Se o sertanejo começar a seguir os procedimentos adequados de como captar, armazenar e utilizar a água da chuva, ele diminuirá da dependência da "indústria da seca", a qual objetiva manter o povo nordestino dependente do poder político-econômico, e melhorará substancialmente sua qualidade de vida.

Trends in Water Demands and the Role of Rainwater Catchment Systems in the Next Millennium

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Abstract

The world's population has been constantly increasing and so has the water demand. However, global freshwater supplies are limited to a finite 2% of the total available water. The main aims of this presentation are to analyse global population trends, to identify the areas of major water use, to propose ways and means of reducing consumption and to appraise the potential for development of rainwater catchment systems in the next millennium.

On analysis, it is noted that demand is largely dependent on the changing requirements in the domestic, industrial and agricultural areas. Other factors that influence water demand are the ease with which it is available and its price. Population growths influence demand rates and, though populations will increase, rate of growth will decrease. Worldwide water demand has increased six fold between 1900 and 1995 though population has only doubled. However, almost 70% of water demand is from the agricultural sector.

Another phenomena that will have a great impact is the proliferation of megacities, where urban populations will predominate. By 2025, the population in these megacities is expected to double to 5 billion. That means two thirds of the world's population will be living in megacities out of which 90% will be in developing countries.

With the prospect of an escalating water demand, the search for augmenting supplies will be one of the major worries of humankind in the next millennium. The finite volumes available have to be managed optimally and it should be ensured that there is no friction between countries due to scarcity of water. Water use has to be cut down with special emphasis on agricultural practices.

With the emergence of quite a few megacities, there should be large urban populations and correspondingly rapid increases in water demand in the industrial sector. These urban populations will be sprawled over the megacities and are bound to encroach on catchment areas. As the urban poor will be quite substantial, particularly in developing countries, the catchment areas will be subjected to intense pollution. This will call for adopting effective measures to curb pollution and, as practised in water-scare Singapore, to extensively utilise urban catchments.

With high-intensity urban populations, there are bound to be large paved and

roof areas which are ideal for rainwater harvesting. Besides, medium-sized catchments areas in educational institutions, airports, army camps, etc. can be fruitfully utilised for developing individual schemes and the collected water applied for potable and non-potable uses. These smaller schemes should, preferably, be integrated with existing conventional water supply systems. The harnessing of water in megacities and the surrounding urban areas by utilising appropriate rainwater catchment systems should alleviate, to a large extent, the future water demands.

INTRODUCTION

Only about 2.5% of the total water available in the world is freshwater out of which hardly 0.3% can be considered to be renewable (Shiklomanov, 1993). This limited resource has been exploited, from time immemorial, and water has been abstracted from surface runoffs, rivers, lakes, groundwater, man-made impoundments, etc. Water demand has always been known to escalate and humanity is bound to stretch the finite quantity that is available. The main objectives of this paper are to establish the relationship between population increases and water demands, to identify the areas in which these increases predominate and to find ways and means to optimise the available sources in the next millennium with emphasis on the use of rainwater catchment systems.

WATER DEMAND IN RELATION TO POPULATION

The total water demand in any location is the sum of the sectoral demands. The sectors will vary according to the location and activity, which, in turn, will largely influence the magnitudes and trends of demands. Domestic water demand plays a crucial role, as potable water of an acceptable quality is essential for the survival of humanity.

Historical data clearly establishes that, at both national and world levels, the major factor that directly affects the quantity of domestic demand is population. Figure 1 shows the rate of increase of water demand in relation to the population increases between the years 1950 and 2050 (Engleman & LeRoy, 1993). The higher the population, the greater will be the domestic demand. There is a gradual upward trend in the population increase but annual increases appear to be progressively decreasing. If medium fertility rates were maintained, the world would reach a population of 9.4 billion in the year 2050 (World Resources, 1998).

URBAN POPULATION AND MEGACITIES

Urban migration

The world's urban population is currently growing at 4 times the rate of the rural population (UN, 1997). The change in urban population is drastic as shown in Figure 2. The growth in urban areas, up to 2025, in developing countries (Asia and Africa) is very positive. However, projections indicate that growth rates in rural areas in

developed countries have a definite downward trend whereas the growth rates are almost constant in urban areas of developed countries and rural areas of developing countries.

Emergence of Megacities

This phenomena of urban growth wherein there is an influx of people from the rural to urban areas has lead to the emergence of megacities (ADB, 1993) that are generally referred to as large urban areas having extensively industrialised zones with populations greater than 8 million.

Demographic patterns have indicated that in 1950 the only megacities in the world were London and New York. But, over a period of time, their numbers have increased considerably as shown in Table 1. (UN, 1997)

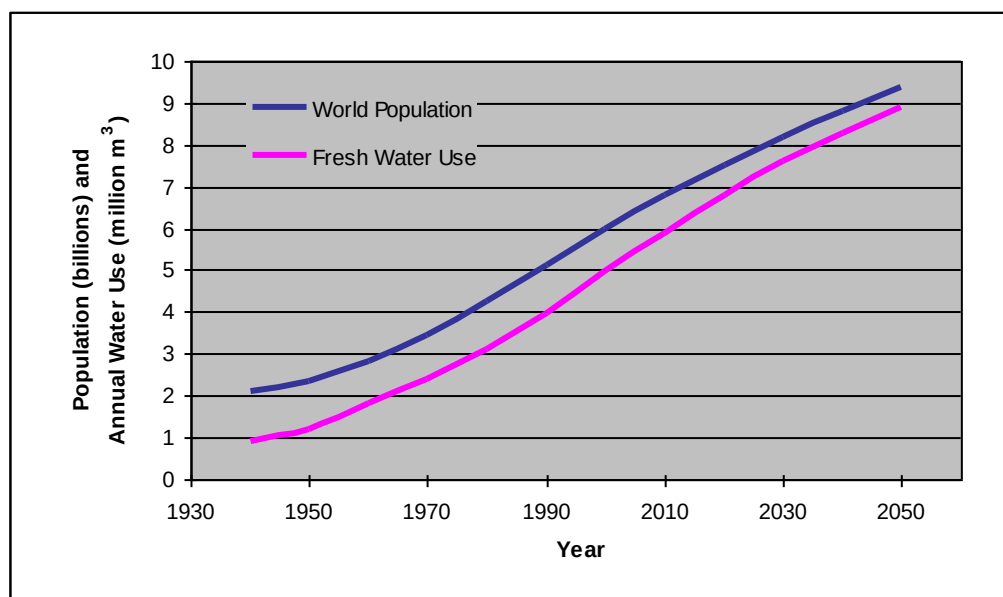


Figure 1: Population and Water Demand variations

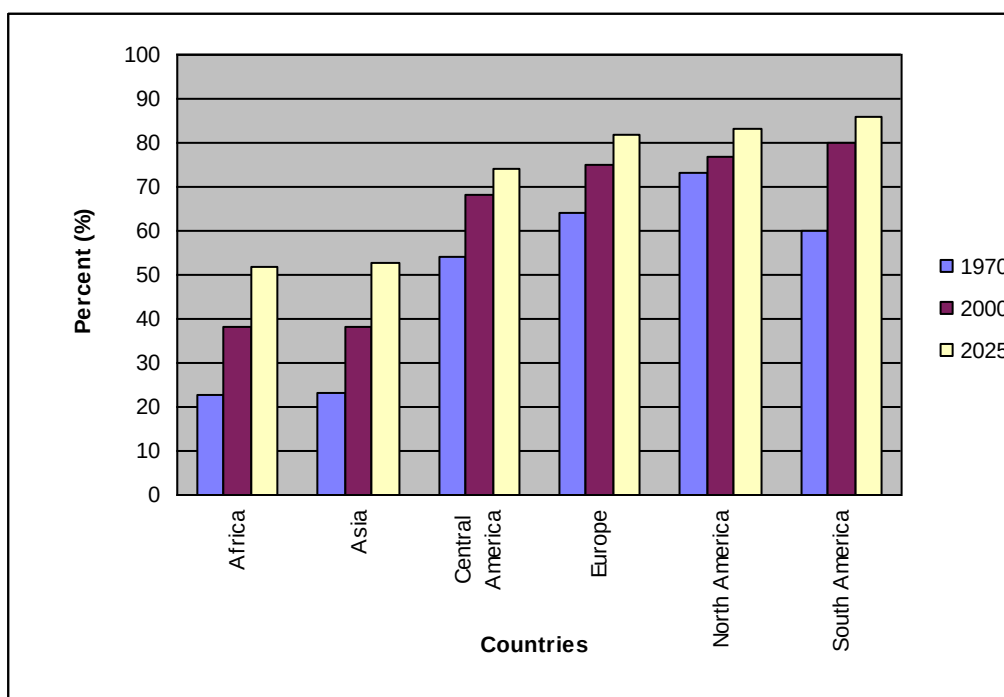


Figure 2: Urban Growth Rates

Table 1: Emergence of Megacities

Year	Megacities (in countries)		
	Developing	Developed	Total
1995	17	6	23
2015	23	13	36

Between 1990 and 2025, the number of people living in urban areas is projected to double to more than 5 billion. This means that by then almost 2/3 of the world's population will be living in such megacities. The most important statistic is that almost 90% of such increases will occur in developing countries (World Resources Report, 1996)

Problems in Megacities

When megacities grow, they will tend to expand and thus encroach into the adjacent hinterland. The social strata of the people who occupy these areas will vary. In developed countries, where such cities are appearing at a slower rate, the additional population will create an increased water demand, which has been met with by conventional and controlled means in the past. However, in developing countries, where such megacities are mushrooming at a rapid rate, the trends show that there is the ubiquitous presence of urban poor who have been actually migrating from rural areas to better themselves (Appan, 1998). Consequently, these megacities have a tendency to be inundated with an urban population that has access to very little potable water supply as well as suffering with poor sanitary facilities.

APPROACH TOWARDS COPING WITH RISING WATER DEMANDS

With the inevitable escalating water demands, there is the need to optimise all systems that are related to the supply and demand of water. The approaches taken should be to improve technology and operational methods associated with water supply, managed water demand, augment existing sources and look for new sources.

Technological developments have been progressing, resulting in improved reticulation systems, construction materials and modes of transfer, etc.

The management of water demand is another area that calls for extensive water conservation measures and exercising appropriate control over the supply and distribution systems to ensure minimal unaccounted for water.

The search for new sources has been primarily directed towards methods of desalination. These have included evaporation, reverse osmosis, etc. These techniques show great promise but have yet to reach the economic viability level of conventional water resources.

One of the main methods for augmenting existing sources is the re-use of sewage effluent. The technology is still being developed but there are considerable constraints in terms of type of use to which the water can be utilised. Another method that is fast developing is rainwater catchment systems. With the inevitable expansion and growth of megacities, the situation involves large areas of urban catchment with a high density of population. Particularly in developing countries with a large number of urban poor, there is the need to establish simple and cheap systems that will meet basic requirements. The requirements can be met best with rainwater catchment systems that can be adapted to urban areas, be they in developing or developed countries.

UTILIZATION OF RAINWATER IN MEGACITIES

In view of large increases in migration to urban areas and the emergence of megacities in the next millennium, it is imperative that supply systems should be evolved to cater for such a development. The two major sources that can best be utilised are:

urban runoff in larger catchments and
the development of rainwater catchment systems

In the case of both these sources, large quantities of runoff are currently going to waste because of water pollution problems in urban runoff or the lack of understanding of the potential for developing smaller systems. The quality of the runoff being tapped is a major issue in both the systems as a consequence of which the choice has to be made whether it can be used for potable or non-potable uses. Particularly in the case of rainwater catchment systems, there is sufficient flexibility to utilise systems that will be adaptable to suit all socio-economic levels of the population including the urban poor.

Utilisation of urban runoff in larger catchments

One of the major factors influencing the collection of surface runoff in conventional systems is the quality of raw water. In the case of highly urbanised areas, there is a tendency for the large areas to be paved, which could result in a change in pattern of runoff hydrographs, as the infiltration is limited. The major issue is the level of pollution in such runoff. During storms or heavy rains, there will be a tendency for the initial flush of rain to pick up all the debris in an urban catchment. Urban runoff generally has poor quality and so this issue has to be handled two-fold. Primarily, the pollution-causing factors have to be controlled and secondly, the dry weather flow and the initial first flush have to be diverted and not collected.

To reduce the level of pollution in such catchment, a sequence of operations involving a number of parties, government, quasi-government and private, who are associated with the cleanliness of the catchment, have to organise themselves well. The different parties have to meet on a regular basis and maintain a high standard of cleanliness so that runoff quality is maintained. A typical system that is operational is the Bedok Reservoir Scheme in Singapore (Appan, 1997).

In any case, the runoff collection system should incorporate small drains within the collection channels so that the dry weather flow can be diverted. This aspect is very essential especially in tropical countries. Another system of collection that has to be incorporated is the diversion of the first flushes of storms. The storm generally has a tendency to pick up a lot of the debris and this will have to be diverted by suitably designed systems.

The storm waters so obtained are collected in ponds. It is preferable that such urban storm water collection systems be integrated with a conventional collection system and the raw waters mixed so that overall quality of the raw water will be easier to maintain. A typical example of such mixed water in the Bedok Scheme is given in Table 2 (Lee & Nazarudeen, 1996). The parametric values for most physico-chemical parameters appear to be comparable to those in a protected catchment (Nature Reserves Act, 1951).

Development of rainwater catchment systems

These are generally smaller systems, which can be adapted to suit developing and developed countries in both rural and urban catchments.

In developing countries: The situation in developing countries is totally different from that in developed countries as the economic status of the people is of a lower order. Past experience indicates that a large exodus of rural folk to cities has led to problems associated with health, sanitation and a host of other issues like flood control or solid waste disposal (Appan, 1998b). While there is the critical need for provision of water to meet domestic and other demands, the major issues are the raising of finance and developing very simple and manageable systems and making sure that in case the basic requirements for establishing rainwater collection systems are not available, suitable arrangements should be made for provision of items like appropriate roofing material, gutters etc, so that basic water demands can be met with. The propagation of such systems varies from place to place and one has to take into

consideration the socio-economic and cultural factors. Consequently, methodologies have been developed to suit countries like Thailand (Heyssen, 1983), Indonesia (Aristanti, 1983), Philippines (Lee and Appan 1991). In all these schemes, the system is largely paid for by the user who also becomes the owner who has to maintain the system.

Table 2: Comparison of Raw Water Qualities

Parameter	Bedok reservoir	Protected catchment
Colour (Hazen)	12	20
Turbidity (NTU)	2.	2.9
PH	7.4	6.3
Total Alkalinity (CaCO ₃)	43	7
TOC	2.9	3.1
Total solids	205	25
Chlorides	56	4
Ammonia N	< 0.02	< 0.03
Phosphorus	< 0.03	< 0.03
Iron	0.04	0.52
Cadmium	< 0.0005	< 0.0005
Chromium	< 0.005	< 0.005
Lead	< 0.001	< 0.001
Coliform/100mL	18	14

Note: All parameters, except pH, in mg/L unless mentioned otherwise

Urban areas: These systems are located in either developing or developed countries and have smaller catchment areas of up to about 500 ha. It is possible to have working systems in which water is abstracted from both roof and land areas and it is used primarily for non-potable uses. Some typical examples are given below:

(i) Public Institutions: In smaller catchments in schools, colleges, army camps, shopping complexes, bus terminals etc., there is normally sufficient roof and land to make the tapping of rainwater economically viable. In a case study involving a polytechnic (Appan, 1998a), the rainwater from the roofs and grounds are being successfully collected and treated. The collection and storage tanks are below ground level and were all constructed as an integral part of the whole project. The collected water is partly subjected to chemical treatment and the water used in the sports field. The untreated water used for irrigation and the annual savings in water currently amounts to S\$74,000.00. A similar system has been proposed for the Nanyang Technological University in Singapore (Appan, 1998) wherein the monthly savings were computed to be S\$ 18,400.00 which amounted to 12.4% of the average monthly expenditure for water. In another example involving a bus terminus cum washing centre, all the runoff was collected and the system integrated with an existing bus washing service. (Appan et al, 1988). The water quality obtained was of a high order and could be used with the existing supplied water for washing of buses. The present worth savings in this scheme amounted to s\$215,000.00.

(ii) *High-rise buildings in high- density urban areas:* A working model was in existence from 1980 (Appan, 1982) and subsequent work has followed in a large housing estate consisting of multi-storey housing flats (Appan et al 1987, Appan et al 1997). In the 1997 study, an input/out model was used to compute the sizes of cisterns and to incorporate a dual mode system (DMS) to ensure that lack of rainwater did not hinder the non-potable use. Besides, the DMS ensured that there was no mixing of the potable and non-potable waters which is a breach of existing water supply regulations. The system involves the construction of a light sloping roof over the existing flat roofs and the overall cost of the water has been estimated to be S\$1.00 against the current price of S\$1.65 per m³ of treated water. The overall saving of water usage by adopting such systems is estimated to be about 4 to 6% of the total demand.

(iii) *Collection of rainwater in industrial areas:* Since even small scale planned industries have an area of about 2ha in Singapore, a proposal was put up to tap the water available from the roof and land area (Appan, 1989). The storage tank of 400 m³ was proposed to be kept underground with suitable arrangements for pumping. The water collected could be treated or used untreated according to needs. If water was not treated, 13% of potable water had to be supplemented and the annual savings worked out to be S\$10,500.00

In another industry where there was some aquaculture and ornamental plants being bred, rainwater and runoff was successfully collected and used and recycled in the operations. In this case, the water authority had insisted on use of such water, as the quantum used for processing was excessive. The water collected was far too excessive and helped largely to dilute the water within the other water bodies in the system that were being subjected to high nutrient loads.

(iv) *The use of runoff in airports:* In an existing project (Appan 1995, Appan 1993), the runway and rest of the area amounting to 530 ha in the Singapore Changi Airport have been fully utilised to obtain non-potable water that completely meets the requirements for non-potable uses like fire-fighting, washing of floors and toilet flushing in the airport. The scheme incorporates the provisions of two storage ponds to hold the runoff and the other to act as a buffer during the periods when the storm peaks coincide with incoming tide. Due to the proximity of the airport to the sea, there is the need for the buffer reservoir to hold a certain volume of overflowing runoff and incoming sea water during the worst condition of operation. One of the major problems encountered in this project is the quality of runoff, which could, at times, have higher oil and grease content. This has to be countered by good house-keeping and propagating the message in the airport that the runoff is being collected for further use.

DISCUSSION AND CONCLUSION

Population increases lead to increased water demands. Population growths in the future appear to be concentrated in urban areas and particularly in the megacities in developing countries. The need for potable water is one of the many requirements that have to be met within these megacities that will have to cope with the influx of large populations from rural areas.

As almost 90% of the migration of population to megacities are expected to occur in developing countries, there is the need to look into simple systems for augmenting existing water supplies. Rainwater catchment systems appear to be one of the most appropriate abstraction systems that can be adapted in emerging megacities in both developing and developed countries.

The two major areas where runoff from megacities can be collected successfully are tapping of runoff in urban catchments in major water supply schemes and, secondly, utilising smaller catchments fruitfully to abstract runoff for non-potable uses. In both these systems, the quality of the raw water bears paramount importance as it has been shown that there can be wide variations depending on surface area, collection methods, location, etc. (Appan, 1999).

In the case of the larger urban storm water collection schemes, there is the need for maintaining large tracts of the urban catchment so as to ensure that pollution levels are under control. Besides, it is advisable to avoid the collection of the dry weather flows and also the first flushes during storms. It is also preferred that such systems should be integrated with conventional collection systems so that quality control of raw water becomes easier.

For the smaller rainwater catchment systems, the same principles of design will apply wherein suitable relationships are established between the rainfall (inputs) and withdrawal rate (output) and the storage (water tank). There are quite a few successful cases where such systems have been adapted for use in public institutions, industries, airports, etc.

In the next millennium, the migration of people to urban areas, in both developing and developed countries, is inevitable. And the challenge of meeting the water requirements can be largely met by an appropriate understanding, study and application of rainwater catchment systems.

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Division Study of Rainwater Utilization in China

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Abstract

During the last two decades, there has been a dramatic increase in the application of rainwater catchment systems for domestic water supplies and agricultural irrigation, especially for rural areas in developing countries. Tens of millions of systems have been constructed worldwide, and interest in these is continuing to grow, even in urban and industrialized regions. An old technology is gaining popularity in a new way. Rainwater collection will play an important role in solving the water shortage problems in China. This study analyzes those areas most suitable for rainwater catchment in China and presents the ranking of fitness for rainwater catchment in China and its further development in the near future. A GIS is used to help identify and list the potential areas of rainwater catchment throughout China.

1. Rainwater Harvesting in China

Rainwater utilization has been a popular technique in China for thousands of years. In order to provide sufficient drinking water for people and domestic animals, the roof, court, ground, road were used for harvesting rainwater. For example, in Dong-zhi-yuan of Gansu Province and north of Weihe River, Shan-xi Province, rainwater wells and jars already existed about two thousand years ago (Mou, 1996). Rainwater harvesting can also be used in addition to existing water supplies.

Because of draughts caused by the uneven distribution of rain seasons and water shortage due to water pollution and huge demand, the water crises will be one of the most serious problems in China in the next century. People have realized that the direct collection and utilization of rainwater is a technique clearly in line with efforts aimed at developing sustainable societies in the future (He & Cheng, 1996).

One major goal of development in China is to reach a balanced development on its territory and reduce gaps between regions. Water is one important factor to impede the realization of the goal. In China, both surface and ground water is in short supply, especially in the west of the country. Under these circumstances, rainwater becomes a very important and reliable water source because it is accessible almost everywhere.

2. Previous studies on rainfall

There have been many studies on rainfall in China. They can be divided into four types. The first type is regional studies of precipitation. In 1935, Tu Chang-wang carried out a study on the distribution of China's rainfall (Tu, 1935). In *China's Physical Geography* five zones are divided according to the rainfall amount. There are rainfall rich zones (>1600mm), humid zones (between 800 and 1,600 mm), semi-humid zones (between 400 and 800 mm), semi-arid zones

(between 200 and 400 mm) and arid zones (<200mm). In 1954, Zhu Bin-hai studied China's rainfall division by the index of three months' rainfall in the summer (Zhu, 1954).

The second kind of rainfall study concerns watershed regions. In 1980, Guo Jing-hui calculated the total runoff volume of China according to the differences of rainfall in different river basins (Guo and Tang, 1980). The Ministry of Water Resources of China evaluated the state's water resources based on division of river basins and their rainfall in 1981. In the above studies, rainfall is considered as a main supply for the river's runoff and its characteristics such as distribution in space and time.

The third kind of rainfall study is humid-arid condition analysis. Some researchers studied droughts, agricultural climates and humid-arid divisions using precipitation as an important factor though they did not study rainfall directly (Wang 1988).

The fourth kind of rainfall study focuses on storms, rainfall fluctuations, rainfall changes, climate changes and so on. Different mathematical methods and models are used to distinguish changes in rainfall especially from the 1980's (Wang, 1987; Xu, 1989).

However, there have been no studies focusing on rainwater utilization and identifying potential rainwater harvesting areas in China using the GIS method. This paper is intended to do this.

Where should rainwater utilization be applied in China? In areas where no piped water supply is available, a dug well is not applicable (e.g. where there is no suitable aquifer) or where drinking water is urgently needed because potable (treated) water is too expensive. Sometimes, a lake, reservoir, river or stream is not close at hand or the soil is not deep enough to sink a well. In China, the zones where potable water is difficult to reach cover a vast area, including: 1) the agriculture zone (including rural areas) far from rivers; 2) semi-arid or semi-humid hilly land; 3) 6,620 islands in the 3 million km² territory waters (esp. coral islands and volcano islands); 4) 1,000,000 km² Karst territory; and 5) the territory with high-fluorine water (Liu and Mou, 1996). In these cases, rainwater utilization may be the best source for water supply.

3. Factors affecting rainwater harvesting

Several factors influence the rainwater harvesting potentials in China. In this study, precipitation, number of rain days, rainfall fluctuation rate and topography are considered as the main factors directly affecting rainwater harvesting.

3.1 The precipitation

The amount of rainfall in a region decides other factors of rainwater harvesting system, for instance, the catchment area, and volume of the storage tank and costs of the system. Rainfall's characteristics will affect the demand for rainwater harvesting. The impact on rainwater harvesting by the amount of precipitation will be discussed.

In China, the total average precipitation is about 6,190 billion m³ per year. The maximum annual precipitation is over 6,000 mm. The area with precipitation less than 300 mm covers one third of the whole country (Shen, 1996).

Rainwater is a kind of scattered water with characteristics of low intensity and widely distributed range. The scattered water is very important, especially in those areas that lack the concentrated water sources (such as rivers and reservoirs). In China, there are 100 million people living in areas lacking potable water and 140 million people have water sources affected by pollution. (Liu & Mou, 1993).

Where precipitation is small, rainwater harvesting is needed. However, according to related studies (Liu & Wei, 1991; Liu & Ren, 1988), if the precipitation is too small (less than 100 mm), there is no need to collect rainwater because human activities do not exist. For the areas where the precipitation amount is very large (more than 1000 mm), there is little demand for rainwater harvesting.

For an annual precipitation between 100 and 1,000 mm, the water demand increases with rainfall decreasing. This is the basis for the ranking according to annual precipitation (see table 1).

Table 1: Rankings for Rainwater Harvesting Demand According to Annual Precipitation

Order	Annual Precipitation (mm)	Rank
1	0—100	1
2	100—200	5
3	200—400	4
4	400—600	3
5	600—1000	2
6	>1000	1

3.2 Rain Days

The number of annual rain days also influences the need for rainwater harvesting. The fewer annual rain days or the longer the dry period in one region, the more the need for collection of rainwater in this region. However, if the dry period is too long in one region, big storage tanks will be needed to store the rainwater and the water quality is at risk for pollution and deterioration. The cost of construction and maintenance will be high. Therefore, the number of rain days is an important parameter for the system's design. The rankings for rainwater harvesting according to annual rain days is shown in table 2.

Table 2: Rankings for Rainwater Harvesting Demand According to Annual Rain Days

Order	Annual Rain Days (day)	Rank
1	0—60	3
2	60—120	2
3	> 120	1

3.3 Rainfall fluctuation rate

Another precipitation parameter-- annual fluctuation rate also affects the application of rainwater harvesting. China is situated to the west coast of the Pacific Ocean and on the slant of the Eurasian Continent that slopes to the Southeast. Due to the impact of monsoon climate on the terraces, rainfall follows a law of progressive decrease from south to north and from east to west. Given this general trend, however, the precipitation shows a great variation rate both within a year and between years. The function of rainfall variation acts as the rain days in influencing rainwater harvesting. The higher the fluctuation rates, the more significant are the collection and storage of rainwater, and the higher the demand of rainwater harvesting. The ranking of rainfall fluctuation rates for rainwater harvesting is shown in table 3.

Table 3: Rankings for Rainwater Harvesting Demand According to Annual Precipitation Fluctuation Rate

Order	Annual Precipitation Rate (%)	Rank
1	0—15	1
2	15—30	2
3	> 30	3

3.4 Topography

The types of topography also influence the application of rainwater harvesting systems. In general, there are concentrated water sources, such as rivers, lakes and underground water in the low plain areas. In the high mountains, precipitation usually falls as snow due to the low temperature. Moreover, because few people live there, there is little demand for rainwater harvesting. The people there usually can find springs for water supply. Over all, the hilly and mountainous areas need more rainwater harvesting systems than the plain areas while the arid areas need more rainwater harvesting than the humid areas in China. Rainwater harvesting demand rankings according to topographic conditions are shown in table 4.

Table 4: Rankings for Rainwater Harvesting Demand According to Topographic Type

Order	Topographic Type	Rank
1	Arid Basin	3
2	Arid/cold Hill	3
3	Cold Plain	1
4	Cold Plateau	2
5	Cold/humid Hill	2
6	Cold/humid Plateau	2
7	Desert/Prairie	4
8	High Mountain	1
9	Humid Basin	1
10	Humid/warm Hill	2
11	Humid/warm Island	2
12	Humid/warm Mountain	3
13	Low Plain	1
14	Semi-arid Plateau/hill	4
15	Semi-humid Hill	3
16	Semi-humid Prairie	4

3.5 Other factors

The areas where fresh safe drinking water (potable water) is difficult to reach are in great need of rainwater harvesting. The areas that are far from rivers and where underground water is not available also need rainwater harvesting. These include the small islands and Karst area and territory with high-Fluorine water. The data related to these factors are not available right now, and thus they were ignored in this study.

4. Method

GIS is useful in dealing with the objects consisting of different factors such as rainwater harvesting demand and it has a strong ability to identify, list, analyze, and assess the potential areas of rainwater utilization. Therefore, GIS, which involves the integration of geographic data from multiple sources within a computer environment, is applied to evaluate the potential of rainwater harvesting in China.

Geographic information systems are good at overlaying and expressing the result in a dynamic way. In this study, GIS is used to do the rainwater harvesting demand area division analysis. The software used is Arc/Info (UNIX Version) and ArcView (PC), both from ESRI.

Four layers were selected: annual precipitation, annual rain days, annual precipitation fluctuation rates and topographic types. The boundaries of the provinces are also selected to see the final location of the application potential areas of rainwater harvesting. The source of this information is the Atlas of Chinese Physical Geography. The distribution maps and respective rankings for rainwater harvesting are shown in Fig. 1 to Fig. 4.

The layers are digitized into Arc/Info. The attribute tables based on the above factor analysis are established. Then the individual factor ranking maps are achieved (see Fig. 1 to Fig. 4). Overlays of the four layers are made to get the final demand rank area of rainwater harvesting in China. In this study, the four factors are equally weighed because there is no evidence that one factor is more important than the others. The final rankings are achieved by the addition of the four individual rankings. The final ranks range from 5 to 14. In order to get a clear idea of which part is in higher demand of rainwater harvesting, the final ranks are re-coded to four scales (1-4) and the result is shown in Fig. 5.

5. Results

The region with red color is the first class of the areas where rainwater harvesting is most demanded and the conditions are suitable to application for rainwater collection. From Fig. 5, we can see that the highest demand of rainwater harvesting is in the north, northwest and southwest of China. It can be divided into following different geographic units (Fig. 5): northwest part of Yellow soil plateau, middle and east parts of Inner Mongolia; middle and east parts of Qinghai province; area around North XinJiang; south oases of Tianshan Mountains; south top of Taihang mountains. The resulting patterns are conformed to the tradition and current practice of rainwater harvesting in China. The northwest part of the Yellow soil plateau has the longest history of rainwater collection and today it is the most advanced area of rainwater harvesting. The middle and eastern area of Inner Mongolia is China's most important pasture of fully rain-fed grassland. The middle part of Qinghai is also a rain-fed pasture. The East of Qinghai, the south of Sanxi and the south of Gansu are also traditional rainwater harvesting areas. The south oases of the Tian Mountains are advanced agriculture areas using rainwater. North Xinjiang is a rain-fed arid pasture.

For the area of high rainwater harvesting demand, rainwater can be used for both domestic use and agricultural use. In fact, in the Yu-Zhong-Bei hilly land of Gansu province, a project named '121' has been successfully carried out under the lead of the provincial government.

There are also three areas of exception among the above regional areas (Fig. 5). However, the exceptions indicate some reasonable and rational points of the above divisions. The first exception is located in the middle of NingXia. Local people developed a self-running irrigation system next to the Yellow River, and rainwater harvesting is not necessary for irrigation. The

second exception is He-tao irrigation region in the middle of Inner Mongolia. The third exception is the bottom of Zhunger Basin an arid, thinly populated desert.

The second class areas of rainwater harvesting are the northern and western parts of Hebei, Shanxi, Ningxia, Gansu, east part of Qinghai, east top of Inner Mongolia, around area of Tian Mountains, the middle part of Tibet, part of Yunnan and Guizhou (Fig. 5). These areas are either relatively arid or hilly or both. All of these areas are relative poor and undeveloped. The water resource shortage has been blamed for their underdevelopment. So rainwater harvesting will be an important way for these areas to develop their economy and improve peoples' lives.

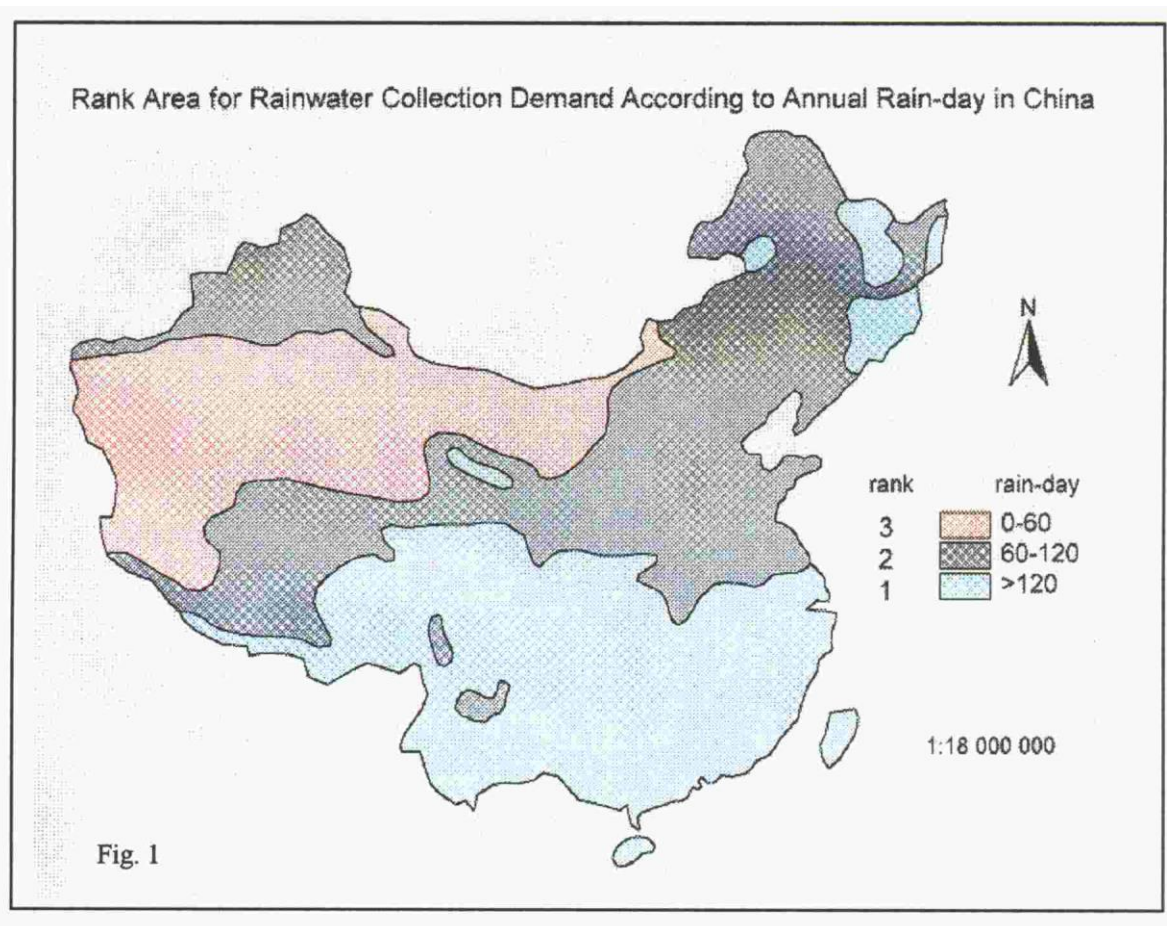
The fourth rank areas are where rainwater use is not encouraged. It only indicates that there is no condition or no need for rainwater harvesting in this area, for example, arid desert and cold high mountains. Or the areas where the surface or ground water is rich, for example, Sichuan basin, volley plain and deltas of Liaohe, Hai-luan-he, Yellow River, Huaihe, Yangtze and Pearl River. The fluvial plain is in low demand of rainwater harvesting, especially in south China. These areas are humid and relatively flat and have access to concentrated water sources.

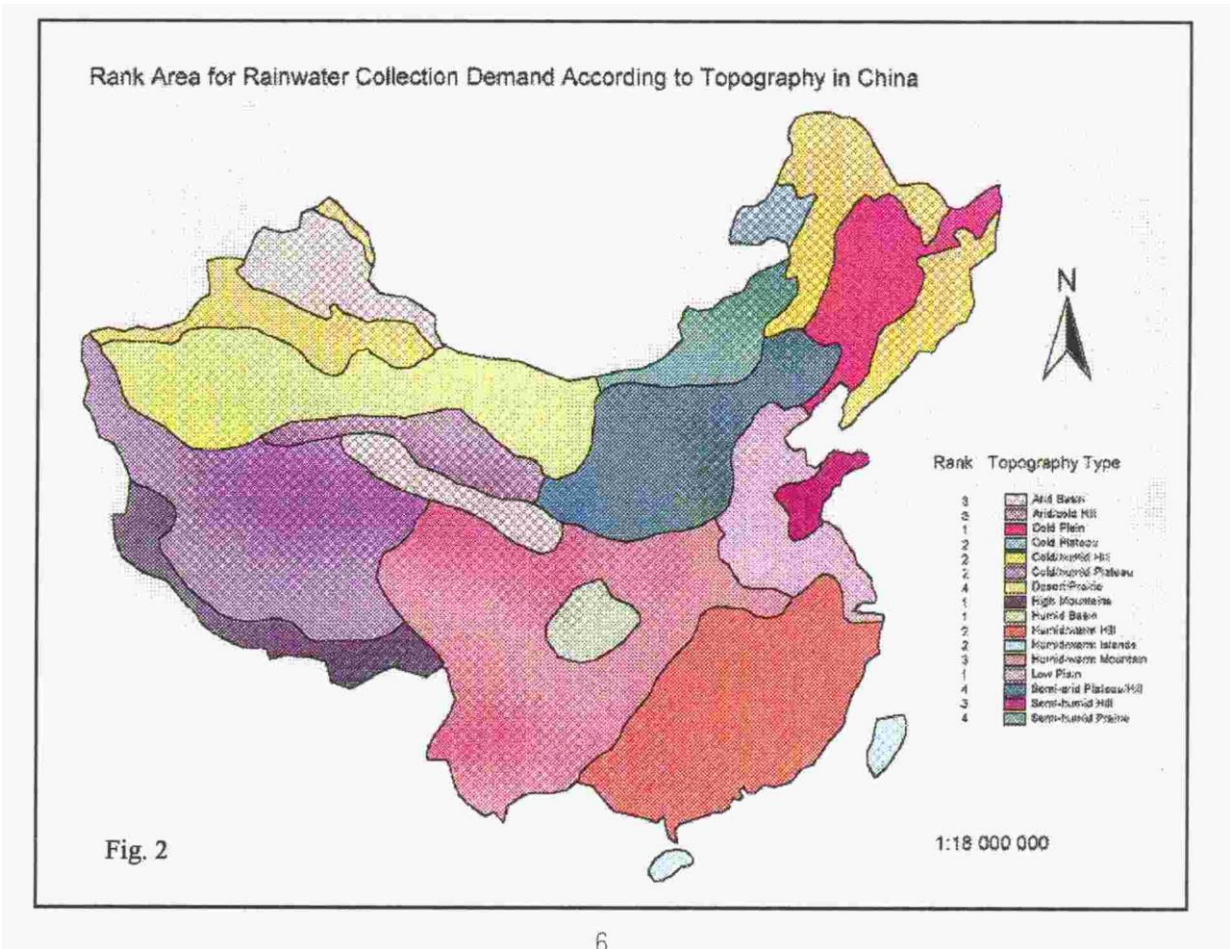
In general, this study has provided a clear division for rainwater harvesting suitable for the hydro-geographical conditions of China. It is useful to guide the application and planning of rainwater utilization in China.

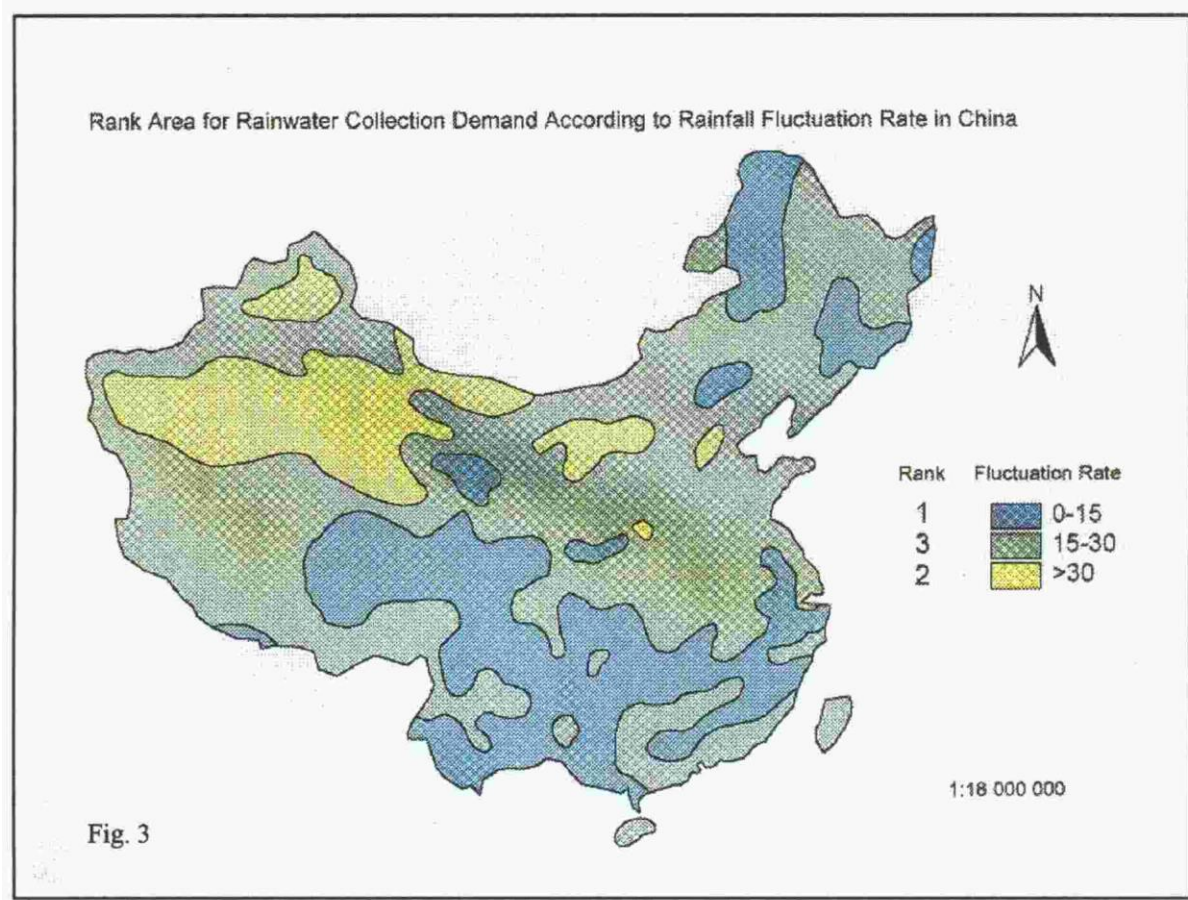
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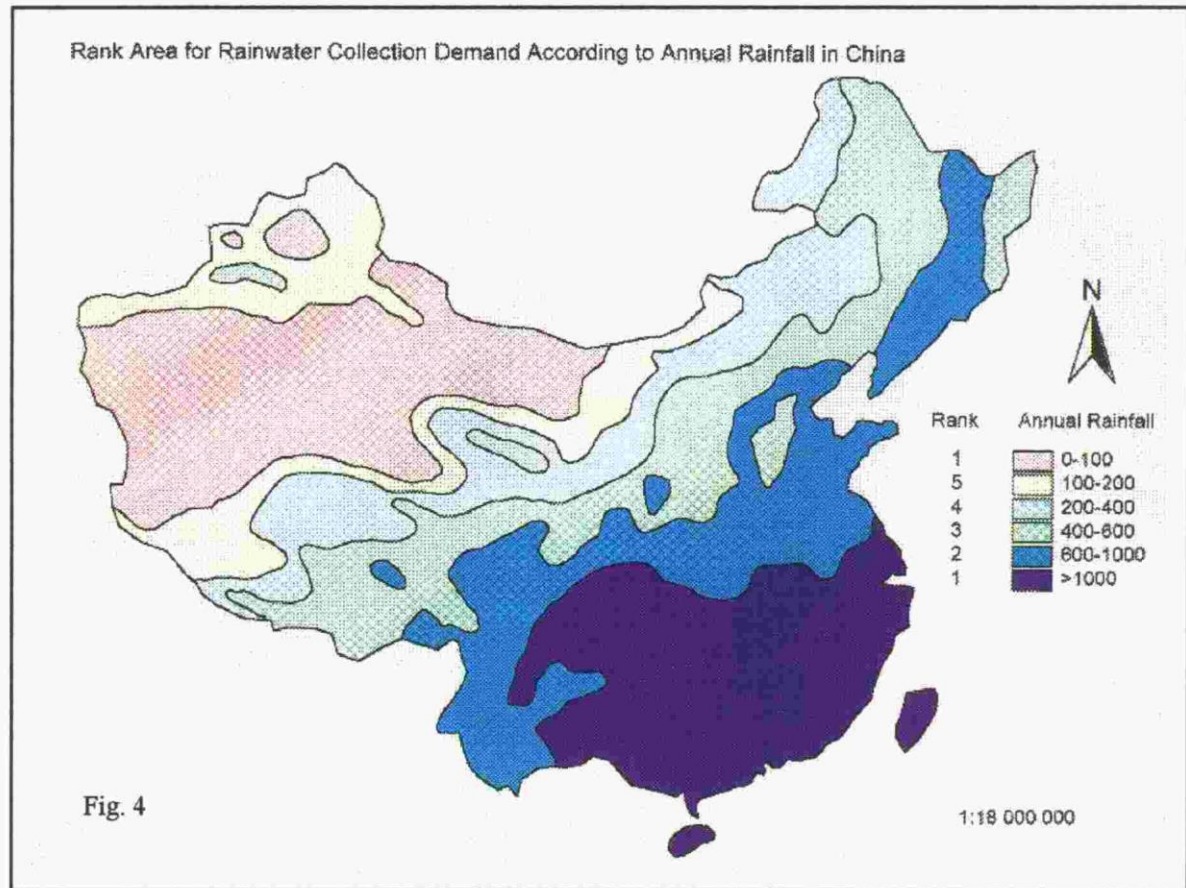
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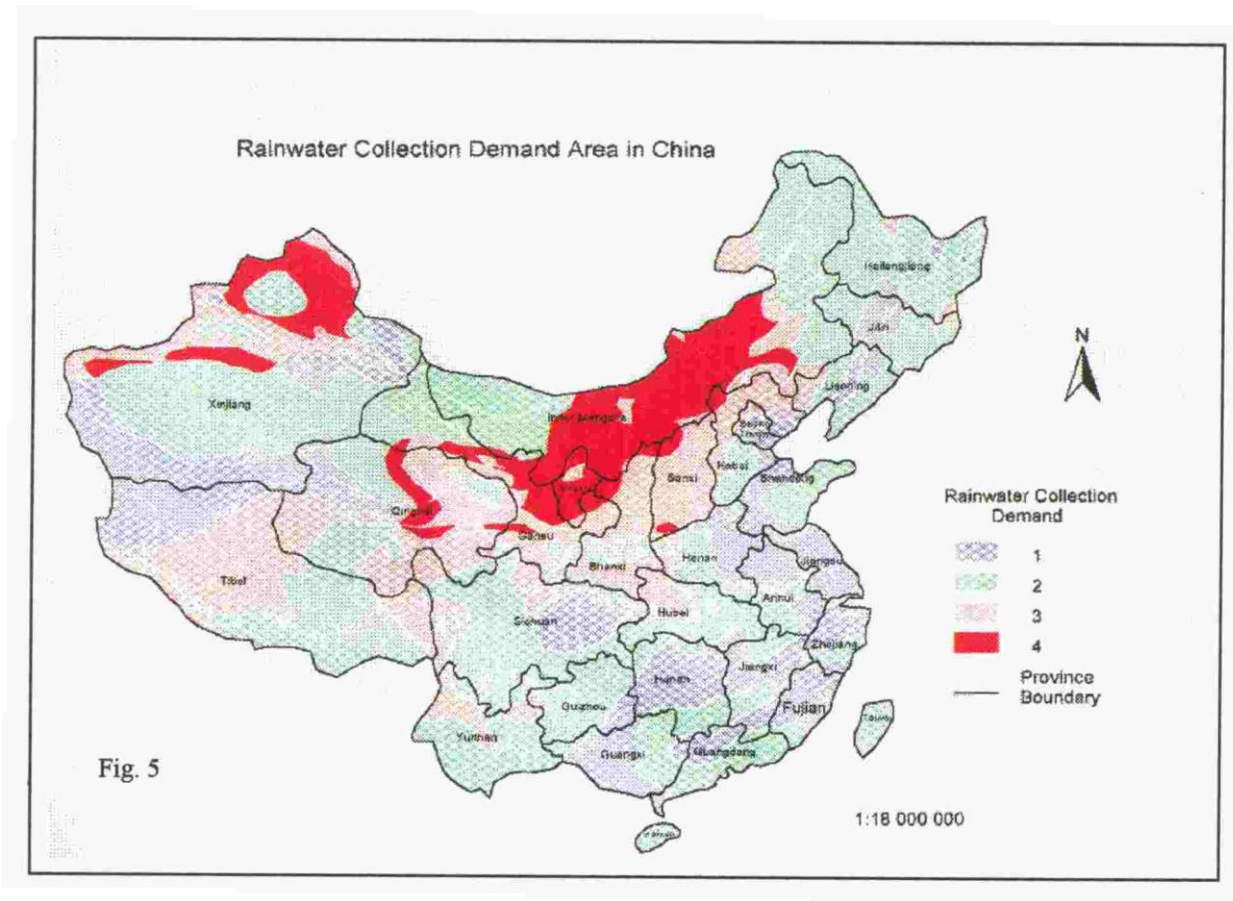
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Problems and Prospects of Rainwater Catchment for the 21st Century in Sri Lanka

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Abstract

Though Sri Lanka receives an annual average rainfall of 1,400 mm, 70% of the rural population is without clean drinking water. With a projected deficit for growing future water demand due to population growth as well as industrial and agricultural use, Sri Lanka's intention of providing clean drinking water for all by the year 2010 appears to be bleak.

Rainwater harvesting as a rural water supply option is a recently introduced technology in rural Sri Lanka. It has been accepted and adapted by many households where other water supply options failed due to technical or financial reasons. The Rainwater Harvesting programme was implemented on a 80% grant and 20% equity. The equity contribution was mainly in terms of labour and house guttering and down pipes. The latter components could be as high as 30% depending on the roof area.

The high cost of a unit compelled the programme to be subsidy driven. This approach, though financially appealing, threatens its own sustainability. Besides this problem, the "project approach", adopted by implementers, limited the programme to a construction phase. While mastering the technological component, awareness and management of the systems were left to the beneficiaries. This resulted in poor maintenance of systems leading to contamination and inadequate water. As a consequence, average water security was only up to 43% even by those owning rainwater harvesting systems. Less than 10% of the households used rainwater for drinking, indicating a dislike or mistrust for the quality of rainwater.

In the next millennium the major efforts will be on promoting rainwater harvesting on a "need base system" with an open market orientation. The focus will be on awareness creation on maintaining quality of water, managing the system as a complete water supply unit and cost reduction of rainwater harvesting units.

Introduction

Traditionally, people in Sri Lanka have been collecting rainwater for domestic use. This water was mainly limited to drinking and sometimes sufficient for cooking. In 1995, the Community Water Supply and Sanitation Project (CWSSP), a World Bank sponsored

project, introduced organised rainwater harvesting in three districts in Sri Lanka. A 5 m³ tank was designed to store water harvested through roof runoff. The technology was well accepted by people who had no other option to obtain good quality water at their homestead. These people had to trek long distances or in difficult terrain to fetch water for domestic use. The success of this project was disseminated to other districts by several NGOs working in rural development in Sri Lanka.

The rainwater users were satisfied with the technology since they are having access to better quality water and improved water security. Only 10% of the users consume rainwater even after boiling, another 20% may be using it for cooking. Thus, the major use of rainwater is for personal washing and toilet purposes with animal husbandry and small-scale home gardening taking a significant proportion of collected water. The main reason for the existing pattern of water use is user perception of rainwater quality. Though there has been no significant E-coli contamination in stored rainwater, total coliform has been reported in many rainwater samples. The principal attributory reason for this situation is poor management of rainwater harvesting units.

The user perception on water quantity has been one of the reasons for limited achievement in water security. These two aspects, along with cost and durability of the rainwater harvesting units would possibly decide the future for rainwater harvesting technology in the next millennium. This paper discusses the present rainwater harvesting technology in Sri Lanka, its implementation, dissemination, problems and prospects for the future.

Present Water Status

The Comprehensive Assessment of the Freshwater Resources of the World (1997) predicts that 2/3 of the world's population will experience water stress condition by 2025. (ADB 1998) According to UN studies, countries whose water withdrawal against available resources exceed 40% would experience high water stress conditions, thus needing urgent management of water supply and demand (ibid 1998). In South Asia withdrawal against available resources is 48%, thus, Sri Lanka too could experience an acute shortage of water if stringent measures are not adopted to manage demand and supply of water.

Predictions for Sri Lanka are that by the year 2000, there will be a water deficit of 1400 MCM in the Northern dry zone and in the capital city water demand would double from present 97 MCM/year (Arrienns et al 1996). Thus, the over all situation is that provision of good quality drinking water is becoming a challenging task, with drying up of water sources, pollution of water, growing conflicts among users and growth in demand due to population pressure. (Ariyabandu 1998).

Though Sri Lanka receives a mean annual rainfall of 1200 mm, high variability and non uniform distribution creates periodic shortages of water for both irrigation and domestic use. At present 60% of the rural population has access to safe drinking water (Minnatullh et al 1998). However, there is a significant population in rural Sri Lanka where none of the conventional water supply sources can provide water due to financial, technical or

management reasons. Rainwater harvesting has proved to be the only option available for these communities provided they are prepared to contribute as equal partners in the implementation process.

Traditional Rainwater Catchment Methods

To mitigate the inadequacy of good quality drinking water, rural communities in Sri Lanka have adopted their own indigenous methods to harvest rainwater. My study on "Traditional Rainwater Harvesting Systems in Sri Lanka" reveals, that there are three basic categories of harvesting rainwater.

1. Roof water harvesting using various types of indigenous material as gutters.
2. Rainwater harvesting using tree trunks.
3. Open air direct rainwater harvesting techniques.

These methods were used by people to harvest rainwater mainly to satisfy the demand for drinking water. However, the quantities collected using traditional methods have been limited due to poor organisation and management. Often rainwater is collected into small household vessels that lasts only for 4-5 days. Only a few have constructed at least rectangular open brick tanks that could store water for 10-15 days.

Introduction of Organised Rainwater Catchment

The foregoing discussion indicates the need for, and the experience of rural communities in Sri Lanka with rainwater use. In 1995, under the World Bank sponsored CWSSP, rainwater harvesting technology was introduced as an option to supply water to rural communities in difficult rural settings. CWSSP introduced 5m³ storage tanks of two types: a surface ferro-cement tank and a brick dome underground tank. Both designs were highly accepted by people. Some of the main reasons for acceptance were improved water security, lessening the drudgery of carrying water and proven technology. At present approximately 4,000 of such tanks have been constructed under the project and an additional 100 tanks have been constructed by rural communities with the assistance of NGOs in a number of dry zone districts in Sri Lanka.

Cost and Subsidy

The present cost of a 5m³ ferro-cement tank is approximately Rs. 10,175 (US\$ 156) and that of a brick dome tank, Rs. 8,245 (US\$ 127), including unskilled labour. According to the above cost estimates, 80% of the cost is a grant by the project while 20% is community contribution in terms of unskilled labour. However, in subsequent projects undertaken by NGOs the cost sharing has increased from 41% to 50% in terms of community contributions. Increased community contribution in latter projects indicates the "need" for improved water security and the approach adopted by NGOs as against state implemented projects.

Reducing Costs Through User Participation

Cost of a rainwater harvesting unit is one of the biggest impediments to the natural up take of the technology. The total cost of a complete household unit including gutters and down pipes is approximately Rs. 16,000 (US\$ 239). In some of the NGOs implemented projects, communities have contributed up to 50% of these costs. As such it is not possible to expect rural communities to contribute any further towards the cost of a rainwater harvesting unit. The community contribution in terms of cost can be reduced by about Rs. 2000 (25% of community contribution), if indigenous guttering like Bamboo or Kitul (*Caryota Urens*) can be used in place of more expensive PVC or GI guttering and if polythene can be used in place of PVC down pipes. While both these low cost options are possibilities and have been in use, their maintenance and management have to be more intensive than using costly PVC gutters. The other option of reducing the unit cost of a rainwater tank is to experiment on another structural design which could reduce the over all cost. At present the major portion of the structural cost is cement (9 bags @ Rs. 300) skilled labour (@ Rs. 350 per day or Rs. 2000 per tank) and cost of the hand pump (Rs. 1500) in case of under ground brick - dome tanks. While skilled labour cost cannot be reduced, quantity of cement and cost of the hand pump can be reduced depending on new structural designs. Hence, in the next millennium we will have to focus on research and development to reduce the unit cost of a rainwater tank.

Problems and Prospects

After nearly five years in operation, researchers have identified problems and constraints threatening the sustainability of rainwater harvesting (RWH) technology in Sri Lanka. However, it is heartening to note that most of these problems can be resolved with basic interventions in the technology adoption process.

1. Project Orientation

The technology intervention should move from "donor driven" approach to a more need base "demand driven" approach. Though the present project approach is expected to be demand driven it is only limited to a request application. In the future the demand driven approach should include enhanced community participation, where the donor and the community should contribute as equal partners. This could facilitate more wider distribution of RWH units in a locality.

2. Awareness on Technology Intervention

At present there is a lacuna in technological awareness among the rainwater users. This inadequacy has led to substandard construction by masons, poor guttering and installing down pipes, wrong operation of first flush systems etc. This situation could be rectified by post construction operation and maintenance, training and subsequent periodic awareness programmes.

3. Cost and Subsidy

The present subsidy disbursed structure should be changed to enhance more community contribution. This could be on an equal partner basis. The project subsidy should be limited to cement, skilled labour and hand pumps (where applicable). However, it is mandatory to ensure that the tank lid (cover) is included in the subsidy component. In the past, exclusion of the tank cover from the subsidy resulted in users covering the tank with material such as polythene, old fertiliser bags, galvanised sheets etc. These improvisations have caused water contamination leading to limited use of stored rainwater.

4. Construction of Tanks

Past experiences indicate that there is a possible problem in respect to the structural durability of tanks due to substandard constructions. There had been cases reported where cement meant for tank construction had been used in other household constructions, thus, threatening the durability of tanks. This can be negated by either appointing a construction supervision committee among the users in large scale projects or strengthening the technical knowledge of beneficiary users.

5. Quality of Rainwater

Quality of stored rainwater is one single factor that threatens the sustainability of RWH technology. Many users do not use rainwater for consumption purposes due to the notion that it is unfit to drink. Though microbiological assessments have indicated that it is safe to drink after boiling, user perceptions deter use of rainwater as a drinkable source. Some of the main reasons for this situation are

1. Non use of fitters or under utilisation of fitters
2. Poor maintenance of roofs and gutters
3. Wrong management of RWH units promoting access of biological fauna into water tank
4. Mosquito and other insect breeding in gutters/tanks
5. Ineffective use of first flush systems

All these negative factors can be rectified if the RWH units are properly operated and maintained. One of the main reasons for roof litter is overhanging branches. While this problem can be easily rectified by cutting overhanging branches, at times, users hesitate to cut branches of trees like lime and oranges which are economic crops for subsistence survival. Mosquito and insect breeding can be minimised by regular cleaning of gutters and closing the water tanks securely. One of the contributory factors in this regard is the heavy weight of the tank cover. As such, women, who are the main users of rainwater, found it difficult to manipulate the tank cover every time they need water. Thus, they kept it open during the day, once it had been opened in the morning. This practice promoted mosquito breeding, algal growth and contamination with organic matter. Sometimes this also encouraged small biological fauna contaminating stored water. A simple solution to this problem would be to include a hand pump in the RWH unit. Incidentally, in subsequent constructions, hand pumps were included though functioning of the same had problems due to technological defects.

Institutional Arrangement

While most of the problems in propagating RWH technology can be rectified with minimum intervention, it is prudent to identify a responsible institution(s) for future monitoring and management. Unfortunately, the government implementing agencies lack the capacity to institutionalise post construction supervision and advice. In the future this task will be the responsibility of the Lanka Rainwater Harvesting Forum (LRWHF). The LRWHF is a newly formed NGO directly dealing with rainwater harvesting for domestic use in Sri Lanka. It is expected that the LRWHF will grow in the future and expand its capacity to monitor all RWH technological interventions for domestic use in Sri Lanka.

Conclusion

RWH technology is well accepted as a rural water supply option. However, only less than 10% of the users consume rainwater due to wrong notions and personal beliefs that deter the use of rainwater. As a result water security stands well below 50%. Future efforts on awareness creation to shed the misnomer on rainwater, will witness an improvement in consumption levels and water security, which is expected to increase beyond the present fifty percent.

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O Potencial de Água do Semi-Árido Brasileiro :Perspectivas do Uso Eficiente

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Resumo

Na zona central do região Nordeste a pluviometria média varia entre 500 e 800 mm/ano e tem regime muito irregular. Ademais, a combinação desse quadro meteorológico com o domínio do substrato geológico formado por rochas cristalinas sub-aflorantes e praticamente impermeáveis resulta em rios temporários e condições edafoclimáticas de semi-aridez sobre cerca de 10% do território nacional.

A visão de rios perenes fundamenta a síndrome da abundância, enquanto a de rios temporários no Nordeste semi-árido engendra síndrome da escassez. Vale salientar, todavia, que síndromas de abundância e escassez resultantes da visão de rios perenes e temporários, respectivamente, são tão falsas quanto o geocentrismo fundamentado na visão do deslocamento do Sol de um lado para outro do nosso horizonte.

Efetivamente, as condições físico-climáticas que predominam no *Sertão* do Nordeste do Brasil podem, relativamente, dificultar a vida, exigir maior empenho e maior racionalidade na gestão dos seus recursos naturais em geral e da água, em particular, mas não podem ser responsabilizadas pelo quadro de pobreza amplamente manipulado e sofridamente tolerado. Destarte, o que mais falta no Brasil em geral e no Nordeste, em particular, não é água mas determinado padrão cultural que agregue confiança e melhore a eficiência das organizações públicas e privadas envolvidas no negócio da água.

Nossa motivação básica neste trabalho recusa o determinismo físico-climático que tem servido de justificativa à cultura da crise da água no Mundo ou no Brasil, bem como à *cultura da seca* na região Nordeste.

Introdução

O Brasil é o único país de dimensão continental – 8.547.403,5 km² – sob condições de clima equatorial/tropical úmido na sua maior extensão. A combinação desse quadro meteorológico - caracterizado por uma pluviometria média anual entre 1000 e 3000 mm/ano - com um substrato geológico formado por rochas cristalinas cobertas por um manto de alteração e/ou sedimentos detríticos de 4 milhões km² e espessura média de 50 metros, e depósitos sedimentares de 3,9 milhões km² e espessura média perto de 1000 metros, resulta rios perenes sobre cerca de 90% do seu território.

Todavia, na zona central da sua região Nordeste a pluviometria média varia entre 500 e 800 mm/ano e tem regime muito irregular. Ademais, a combinação desse quadro meteorológico com o domínio do substrato geológico formado por rochas cristalinas sub-aflorantes e praticamente impermeáveis resulta em rios temporários e condições edafoclimáticas de semi-aridez sobre cerca de 10% do território nacional.

A visão de rios perenes fundamenta a síndrome da abundância, enquanto a de rios temporários no Nordeste semi-árido engendra síndrome da escassez. Vale salientar, todavia, que síndromes de abundância e escassez resultantes da visão de rios perenes e temporários, respectivamente, são tão falsas quanto o geocentrismo fundamentado na visão do deslocamento do Sol de um lado para outro do nosso horizonte.

Efetivamente, as condições físico-climáticas que predominam no *Sertão* do Nordeste do Brasil podem, relativamente, dificultar a vida, exigir maior empenho e maior racionalidade na gestão dos seus recursos naturais em geral e da água, em particular, mas não podem ser responsabilizadas pelo quadro de pobreza amplamente manipulado e sofridamente tolerado. Destarte, o que mais falta no Brasil em geral e no Nordeste, em particular, não é água mas determinado padrão cultural que agregue confiança e melhore a eficiência das organizações públicas e privadas envolvidas no negócio da água.

Nossa motivação básica neste trabalho recusa o determinismo físico-climático que tem servido de justificativa à cultura da crise da água no Mundo ou no Brasil, bem como à *cultura da seca* na região Nordeste.

Peculiaridades Geoambientais da Região Nordeste

A macrorregião geoeconômica Nordeste (1.561.178 km²) é a segunda do país em população, estimada em 55 milhões de habitantes no ano 2000 (SUDENE/ÁRIDAS, 1994). O Nordeste tem sido com frequência confundido com a zona de incidência das secas, o chamado *Polígono das Secas* (936.993km²), delimitado – Lei nº 1348 de 10 de fevereiro de 1951 – como área oficial de incidência periódica do flagelo e de atuação do Departamento Nacional de Obras Contra as Secas – DNOCS.

Para efeito da política desenvolvimentista da Superintendência do Desenvolvimento do Nordeste – SUDENE – a região Nordeste compreende uma área de 1.663.230km², tendo em vista abranger a parte do *Polígono das Secas* que penetra no norte do estado de Minas Gerais. Esta região Nordeste apresenta sub-regiões bem definidas em seus contornos físico-climáticos, ressaltando-se o *Sertão*, cuja área abrange cerca de 55% da extensão regional. Neste domínio central de 912.208 km², também referido como semi-árido, a pluviosidade média varia entre 300 e 800 mm/ano. Todavia, esses valores médios anuais de chuvas podem ocorrer num só mês ou se distribuir de forma irregular - tanto no espaço com no tempo - nos 3-5 meses do período chuvoso dos anos normais. Na prática, o *flagelo da seca* neste contexto decorre da distribuição das chuvas de forma incompatível com as necessidades hídricas das culturas de subsistência da população rural, que, mesmo em anos normais, já vive em condições limite da pobreza.

As características hidrológicas gerais e edafoclimáticas do *Sertão* são semelhantes às de outros semi-áridos quentes do mundo: secas periódicas e cheias frequentes dos rios temporários, solos arenosos, rasos, salinos por vezes e pobres em nutrientes essenciais ao desenvolvimento da biomassa natural ou cultivada. A vegetação básica do *Sertão* é rala, a *caatinga*, mas apresenta grande variedade de formações, todas adaptadas à prolongada estação seca, a qual dura entre 7 e 9 meses em anos normais.

Vale ressaltar, todavia, que o contexto físico do *Sertão* é bem peculiar, comparativamente à outras regiões áridas ou semi-áridas do mundo, à medida que tem cerca de 50% (400.000km²) do seu domínio ocupado por afloramentos rochosos, sem possibilidade de grande armazenamento de água subterrânea. Em consequência, os rios localizados totalmente nesse

contexto geológico são temporários, ou seja, regra geral escoam apenas durante pouco tempo após o período chuvoso. Nesta área do embasamento rochoso subaflorante - que limita a vegetação, impede a infiltração, reduz o escoamento ao plano da superfície, sem descarga subterrânea - a regularidade da oferta de água só poderá ser garantida mediante um manejo integrado e eficiente das águas dos açudes, das zonas aquíferas e outras formas de armazenamento, uso e conservação das chuvas que caem neste domínio territorial.

Fortaleza é a cidade mais populosa do nosso contexto semi-árido, com cerca de 1.800.000 habitantes (IBGE, 1991). Não obstante, os seus habitantes se comportam como se houvesse água aos borbotões para abastecê-los. Esta síndrome da abundância admite e tolera os desperdícios, dá pouca ou nenhuma prioridade à reutilização não potável – urbana, industrial ou agrícola – das enxurradas de águas pluviais do meio urbano e dos seus esgotos que deságuam nos rios e lagoas da cidade ou são lançados na sua orla marítima, tornando a frequência de suas praias perigosa à saúde.

Para manter os níveis de desperdício e de baixa eficiência dos usos atuais, a solução apontada pelo balanço de ofertas e demandas é um plano de obras extraordinárias para trazer água de açudes situados a várias centenas de quilômetros, os quais deverão ser alimentados pelas águas transportadas dos rios perenes localizados a milhares de quilômetros de distância. O litoral oriental é formado por uma faixa úmida conhecida como Zona da Mata. A sua pluviosidade varia entre 1000 e 2500mm/ano, os rios são perenes e há importantes reservas de água subterrânea. Na zona litorânea estão localizados os maiores centros urbanos da Região, destacando-se as cidades do Recife (perto de 2 milhões de habitantes) e Salvador (perto de 3 milhões de habitantes). Neste contexto, as cidades em geral padecem de problemas de abastecimento, os quais são engendrados, principalmente, pela baixa eficiência das empresas de água, grande desperdício dos usuários e falta de uma gestão das águas subterrâneas, integrada aos abundantes recursos superficiais disponíveis. Entrementes, obras extraordinárias são propostas, como trazer água de rios distantes, tais como Paraguaçu, Piranhas-Açu, do rio São Francisco, ou instalar usinas de dessalinização da água do mar. Entre o litoral úmido e o sertão, estende-se uma área de transição – o Agreste – com clima subúmido e produção agropecuária, principalmente. Os problemas de água nesta área decorrem, fundamentalmente, da baixa eficiência de uso dos recursos de solo/água e biomassa disponíveis.

O Meio Norte constitui a área de transição amazônica, com pluviosidade variando entre 1000 e 2000mm/ano e quadro geológico sedimentar, resultando em condições hidrológicas que se tornam, progressivamente, mais promissoras no sentido leste para oeste.

Os rios dessa área são perenes, existe grandes reservas de água subterrânea e condições favoráveis à gestão ativa dos aquíferos para garantir um desenvolvimento de atividades produtivas regulares. Não obstante, os habitantes apresentam níveis vexatórios de pobreza, que são agravados pelas doenças de veiculação hídrica de origem sanitária.

Potencialidades Hídricas do Nordeste

A chuva representa a única fonte de água renovável do Nordeste, cujos valores normais no conjunto de 24 unidades hidrográficas de planejamento, variam entre 640 e 1840 mm/ano, representando 1778 bilhões m^3 /ano (SUDENE/ÁRIDAS, 1994). Todavia, a previsão segura das quantidades de água precipitada – P é um problema complexo, porque depende de fatores meteorológicos situados fora da região e variam, sensivelmente, tanto no espaço como no tempo.

Regra geral, torna-se necessário a realização de medidas durante um longo período de tempo e numa rede de estações distribuídas de forma adequada na atmosfera, nos oceanos, no território em apreço, no país ou no continente sul americano, principalmente.

Ademais, no plano geral do Nordeste, a região é uma verdadeira estufa climática - normal de temperatura anual do ar de 27°C e de grande regularidade, brisa relativamente intensa e bastante regular, normal de umidade relativa do ar de 70%, normal de insolação de 2800 horas/ano e quase permanente. Nesse quadro, as taxas de evaporação situam-se entre 1500 e perto de 3000mm/ano. As taxas de evapotranspiração potencial variam entre 1306 e 1899 mm/ano nas 24 unidades hidrográficas de planejamento, média de 1655 mm/ano ou 2700 bilhões m³/ano. Isto significa que as taxas de evaporação ou de evapotranspiração potencial anual são superiores as quantidades de chuvas anuais (SUDENE/ÁRIDAS, 1994). Além disso, as chuvas podem ocorrer num só mês ou se distribuir de forma irregular - tanto no espaço com no tempo - nos 3-5 meses do período chuvoso dos anos normais.

Entretanto, o fato de chover em poucos dias quase toda a média precipitada num mês da fase invernosa torna-se positivo para a região, uma vez que somente assim ocorrem excedentes hídricos que deságuam nos rios, infiltram nos terrenos para satisfazer o déficit de umidade dos solos e realimentar os aquíferos. Com as quantidades de chuvas regularmente distribuídas ao longo do ano, os processos de evaporação intensa transformariam o *Sertão* num deserto. Portanto, uma vez que a ocorrência e distribuição das chuvas envolvem fenômenos complexos, ainda imprevisíveis, que os custos de regularização da oferta mediante o transporte de água de rios perenes situados a milhares de quilômetros de distância, de tratamento ou de dessalinização de águas impróprias ao consumo, ainda são relativamente elevados, é mais prático trabalhar com os “pés no chão”, considerando as águas territoriais que molham os solos, escoam pela sua superfície e/ou se acumulam nos açudes e no seu subsolo, durante os curtos períodos chuvosos.

Em termos práticos, a umidade do solo constitui uma reserva localizada de água, à medida que é consumida onde ocorre a chuva que lhe dá origem. Seu maior ou menor aproveitamento sócio-econômico depende das características edáficas do contexto em apreço, da compatibilidade do regime de ocorrência das chuvas com a fisiologia da vegetação natural ou cultivada, dos níveis tecnológicos das práticas culturais e do manejo do binômio solo/água. Historicamente, verifica-se que o nordestino, nas diversas formas de ocupação do território, fundamentou a sua economia no aproveitamento do potencial hídrico localizado, explorando de forma extensiva tanto a agricultura quanto a pecuária. Contudo, face ao baixo nível tecnológico/organizacional, dentre outros fatores, não conseguiu condições de consolidação econômica dessas atividades. Por sua vez, as condições primitivas de uso e ocupação do meio físico muito têm contribuído para a destruição do solo, o empobrecimento das pastagens nativas e a redução das suas reservas de água.

Os fluxos de água nos rios e aquíferos, bem como os volumes neles estocados, natural ou artificialmente, constituem as reservas moveis de água à medida que podem ser utilizadas fora dos locais onde caíram as chuvas que lhes deram origem.

As lâminas médias totais escoadas nas 24 unidades hidrográficas de planejamento do Nordeste (Fig. 1) variam entre 52 e 352 mm/ano, com uma média de 150,5mm/ano, representando um volume médio de águas territoriais renováveis de 207 bilhões m³/ano. Os fluxos subterrâneos representados pelas descargas de base dos rios são da ordem de 58 bilhões m³/ano (SUDENE/ÁRIDAS, 1994).

Neste particular, a região Nordeste compreende dois contextos hidrogeológicos distintos: 979100km² de rochas do substrato geológico cristalino de idade PréCambriana, subaflorantes e praticamente impermeáveis, salvo nas suas zonas de rochas fraturadas; e 648130km² de rochas sedimentares, cujas idades vão do Período Siluriano ao Terciário, com permeabilidade intergranular generalizada, onde ocorrem reservas de água doce nos seus aquíferos estimadas em 20.000km³ (Rebouças, 1997).

Mercê da baixa permeabilidade do embasamento rochoso subaflorante sobre cerca de 400.000 km² do *Sertão* e das suas feições lito-estruturais, aí se instalou uma densa rede hidrográfica, a qual propicia um sem número de locais favoráveis à construção de açudes. Esses reservatórios de água à vista constituem significativa reserva de água estimada em 22 bilhões m³, e adquirem valor simbólico, à margem de sua efetiva e concreta importância, como feição marcante da paisagem do *Sertão* nordestino.

Tal como já ocorre noutros contextos semi-áridos do mundo, onde há predominância da geologia sedimentar, a *gestão ativa dos seus aquíferos ou Aquifer Storage Recovery* vem proporcionando a utilização racional das águas subterrâneas para regularizar a oferta nos períodos de escassez, pratica a sua recarga nos períodos de excedentes hídricos ou de enchentes dos rios para proteção contra as grandes perdas por evaporação, pratica a reutilização de água no meio urbano, nas atividades industriais e agrícolas para recuperar aquíferos sobreexplorados, controle da interface marinha e de reconstituição das reservas de água disponíveis.

Perspectivas de Manejo Integrado

O plano de Aproveitamento Integrado dos Recursos Hídricos do Nordeste – PLIRHINE – SUDENE (1980), reavaliado e atualizado pelo Grupo Regional de Recursos Hídricos do Projeto ÁRIDAS (1994) representa significativo avanço nas formas de abordagem da problemática da água no Nordeste.

Os valores referentes às vazões totais médias de longo período dos rios têm sido universalmente aceitos como boas avaliações do potencial hídrico territorial renovável que pode ser utilizado, em termos de limite superior, em dada bacia hidrográfica, estado ou região geoeconômica de planejamento. A expressão destes potenciais em termos de m³/hab/ano, melhor compatibiliza a grande variabilidade da distribuição geográfica da água com aquela da população e é aqui chamado de *potencial hídrico social*.

Por sua vez, a análise dos níveis de conforto e desenvolvimento alcançados pelos países membro das Nações Unidas indica que 2000 m³/hab/ano são suficientes para usufruto de uma boa qualidade de vida e obtenção de um desenvolvimento sustentado. Potenciais inferiores a 500m³/hab/ano indicam “escassez de água” e entre 500 e 1000m³/hab/ano significam condições de “estresse de água” (Margat, 1998).

Por outro lado, a necessidade de gestão integrada configura-se à medida que a demanda evolui, atingindo determinados níveis destas potencialidades. Uma avaliação da experiência dos países membros da Nações Unidas revela o quadro seguinte: (1) demanda de água representa menos de 5% dos potenciais de água renováveis do território em apreço, pouca atividade de gestão é exigida; (2). índices entre 5 e 10%, indicam situação ainda confortável, podendo ocorrer a necessidade de gestão para solucionar problemas locais; (3) índices entre 10 e 20% significa que gestão já se torna uma atividade indispensável, exigindo a realização

de grandes investimentos; (4) a situação torna-se crítica com índices superiores a 20%, exigindo gestão e investimentos intensivos (Falkenmark & Lindh, 1976).

Considerando os dados da Tabela 1, verifica-se que em cerca de 12% das unidades hidrográficas de planejamento do Nordeste as condições já são de “estresse de água” e em mais 25% os potenciais são apenas regulares, ou seja, entre 1000 e 2000m³/hab/ano. Nos 62,5% restantes das unidades hidrográficas de planejamento os potenciais hídricos sociais variam entre 2184 e 30252 m³/hab/ano.

Por sua vez, nas bacias hidrográficas da transição amazônica os índices de demandas são inferiores a 5%, significando a pouca necessidade de gestão nesta área. Todavia, nas bacias hidrográficas do domínio semi-árido os índices superiores a 20% significam necessidade urgente de gestão. Vale ressaltar que o índice ligeiramente superior a 10% no Nordeste em geral significa que a atividade de gerenciamento das águas da região já é indispensável, para solução dos problemas de abastecimento, sobretudo graves no meio urbano e no seu domínio semi-árido.

Vale salientar, todavia, a experiência internacional que mostra ser possível lograr uma boa qualidade de vida e um desenvolvimento sustentado com, pelo menos, metade das taxas adotadas para consumo urbano/industrial e irrigação, principalmente.

No Nordeste em geral, e no *Sertão*, em particular, a utilização das águas subterrâneas é a mais social e flexível das fontes permanentes de água, pois podem ser captadas, quase sempre, lá onde se fazem necessárias e estão naturalmente protegidas da evaporação. Para tanto, todavia, os poços deverão ser locados, construídos e operados com um mínimo de qualidade e eficiência técnica.

O equívoco é espalhar e expor indiscriminadamente as águas territoriais em micros e pequenos açudes rasos ou barreiros, sem nenhum critério hidrológico, fazendo do sol inclemente o maior consumidor das águas assim acumuladas. Estas obras nem sequer resolvem o problema do abastecimento, pois até nos anos normais a maioria destes reservatórios seca no período de estiagem. Em tal caso, a equação da sobrevivência à seca é estocar as águas dos rios em açudes com superfície de evaporação (espelho hidráulico) bastante reduzida e profundidade bem superior à altura da lâmina média anual evaporada, entre 2 e 3m.

Por sua vez, a idéia de que a condição semi-árida está diretamente relacionada com a baixa produtividade agrícola é totalmente falsa e exemplos não faltam para mostrar o contrário. Efetivamente, a região semi-árida do Brasil não é pior, em termos de potencialidades agrícolas, do que muitas outras áreas semi-áridas do mundo, notadamente o Centro-Oeste dos Estados Unidos, a maior economia de todos os tempos desenvolvida numa região árida com um coração desértico.

Outro fator que tem gerado idéia errônea sobre as dificuldades de solução dos problemas sócio-ambientais atribuídos às secas está na imensidão da área oficialmente definida de incidência periódica do fenômeno. Entretanto, como há décadas já assinalam alguns estudiosos, o *Sertão* não é uma região homogênea. Estudos mais recentes, desenvolvidos pela EMBAPA-CAPTSA, apontam para a existência de 172 unidades geoambientais, distribuídas em 20 paisagens distintas (Rebouças, 1996).

Tal diversidade de ambientes edafoclimáticos representa vantagens comparativas com reflexos vários sobre as potencialidades de produção no semi-árido. São, sobretudo, novas oportunidades de negócios agrícolas, impossíveis de serem conseguidos nos outros domínios geoambientais do Nordeste e até em outras regiões do Brasil. A existência de ilhas de sucesso e prosperidade no contexto semi-árido do Nordeste brasileiro indica ser extremamente viável a ocorrência de significativas mudanças no seu cenário agrícola.

Conclusões

Estamos acostumados a ver o Primeiro Mundo e o Brasil de rios perenes relativamente mais desenvolvido como ideais a alcançar. Isso, em geral, obscurece as potencialidades do Nordeste de rios temporários. Entretanto, as síndromes da abundância e da escassez resultantes da visão de rios perenes e temporários, respectivamente, são tão falsas quanto o geocentrismo fundamentado na visão do Sol caminhando de um lado para outro do nosso horizonte.

A síndrome da abundância induzida pela visão de rios perenes no Brasil desenvolvido é culturalmente tão dominante que, para se combater o *flagelo das secas* no Nordeste, propugna-se como premissa a perenização dos seus rios temporários, mediante o transporte de água dos rios São Francisco e Tocantins (p. ex.) por meio de canais, túneis, aquadutos, dentre outros projetos de obras extraordinárias.

Entretanto, o primeiro passo para aproveitar os potenciais do Nordeste é compreender sua natureza, identificar com clareza os diversos elementos que interferem na região em geral o no semi-árido, em particular. Afirmar que chove pouco no Nordeste em geral e no seu semi-árido, em particular, não é tecnicamente correto. O diagnóstico mais correto é que evapora muito, entre duas e três a altura média das chuvas anuais.

Nestas condições, só o manejo eficiente e integrado da água territorial disponível - que é recolhida de formas variadas, que molha o solo, que escoar nos rios temporários, que se acumula nos açudes e nos aquíferos rasos e profundos - permitirá à região vencer os desafios de produção e as vantagens comerciais sobre os mercados de outras regiões. Sem ganhar da evaporação intensa, mediante um uso muito eficiente da água disponível, não será possível tirar proveito da série de condições naturais, que, se exploradas adequadamente, poderão proporcionar resultados positivos e convivência equilibrada com o fenômeno climático das secas periódicas.

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Tabela 1- Potenciais de água nos rios do Nordeste, potenciais sociais e índices de demandas

Ups- Unidades Planejamento	Área Km²	**Potenciais Água Rios x10⁶ m³/ano	Demandas Totais *** x10⁶ m³/ano	Potencial Social m³/hab/ano	Índice % Demanda
1 Tocantins	32 900	5 955	137,4	13 252	2,3
2 Gurupí	50 600 *	17 800	299,2	30 357	1,7
3 Mearim-Grajaú-Pindaré	97 000	17 570	628,5	7 568	3,6
4 Itapecuru	54 000	9 300	254,2	12 052	2,7
5 Munim-Barreirinhas	27 700	8 810	216,3	21 190	2,4
6 Parnaíba	330 000	40 120	1 807,8	11 942	4,5
7 Acaraú-Coreaú	30 500	5 270	224,2	5 853	4,2
8 Curú	11 500	2 360	214,1	6 127	9,1
9 Fortaleza	14 700	2 270	678,8	846	29,9
10 Jaguaribe	72 000	4 150	975,2	2 472	23,5
11 Apodi-Mossoró	15 900	820	187,8	1386	22,9
12 Piranhas-Açu	44 100	2 720	465,0	2 184	17,1
13 Leste Potiguar	24 440	1 680	401,2	997	
14 Oriental Paraíba	23 760	2 190	482,0	1 030	22,0
15 Oriental Pernambuco	25 300	4 330	2 037,2	1 010	47,0
16 Bacias Alagoas	17 100	3 080	844,0	1 570	27,4
17 S. Francisco	487 000 *	41 100	9 148,8	6 384	22,2
18 Vaza-Barris	22330	1 200	196,3	1 177	16,4
19 Itapicuru-Real	46100	2 080	217,1	1 476	10,4
20 Paraguaçu-Salvador	81 560	8 420	1 173,4	937	13,9
21 Contas-Jequié	62 240	5 560	594,0	3 914	10,7
22 Pardo-Cachoeira	42 000	7 160	268,0	5 172	3,7
23 Jequitinhonha	23 200 *	6 110	81,4	27 254	1,3
24 Ext. Sul Bahia	27 300	6 241	332,2	14 653	5,2
NE-SUDENE	1 663 230	207 030	21 863,6	4 722	10,6

* Área da UPs dentro do NE-SUDENE ** ÁRIDAS, 1994; *** irrigação com 18000m³/ha/ano e 30% de retorno; demanda urbana entre 100 e 150 m³/hab/ano; população IBGE, 1991- in ÁRIDAS, 1994

Rainwater Harvesting Possibilities and Challenges in Kenya

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Abstract

This paper examines the possibilities and challenges of rainwater harvesting in both rural and urban areas of Kenya. The problems of water shortage in urban areas and the high costs of developing new surface water sources, the scarcity of ground water supplies in arid and semiarid lands (ASALs) and the unmanageable operation and maintenance costs of large piped water supplies are alarming. Therefore the willingness of the people, particularly in arid and semiarid areas, to embrace low cost initiatives like rainwater harvesting. The solutions suggested emanate from the grassroots community projects, the author's experiences in water sector as an engineer and recommendation from household rainwater harvesting workshops.

Introduction

Rainwater harvesting technology is an old established art in Kenya, whose abundant knowledge has not been applied to its full potential, especially in urban informal settlements and its neighbourhoods due to various challenges and constraints experienced by community based organisations. Observations in most of our urban centres show that rainwater-harvesting structures are not integrated into the building but are added as an afterthought. This is due to the existing by-laws and lack of awareness by planners, policy makers, beneficiaries and many engineers.

The high potential of rainwater harvesting in Kenya lies in three factors namely: -reliable seasonal rainfall, the quality of roofing materials, and the high demand for clean water supplies. The housing quality in Kenya based on roofing materials is such that about 84.7% of the housing units in central province, 69.7% in Nairobi, 48.1% in Eastern, 39.8% in Nyanza, 36.9% in Rift valley, 33.1% in Western province, 29.3% in coast province and about 12.4% in North Eastern province are made of iron sheet roofs, asbestos cement sheets, concrete or clay tiles. (CBS 1994). This combined with high costs of conventional water sources makes rainwater harvesting a viable alternative water source particularly in developing urban centres and rural areas.

The Kenya Rainwater Association (KRA) in conjunction with community based organisations have identified some of the challenges and constraints that commonly affect replicability and sustainability of rainwater harvesting technologies and through group discussions suggest some possible solutions (KRA 1998a, 1998b, HRWH Reports Review). Modern technologies for obtaining and using water are concerned chiefly with expensive exploitation of river systems and ground water resources by means of wells and boreholes. This is due to supply responsive approaches propagated by External Support Agencies (ESA).

Sustainability of most of these projects after the donor withdrawal has been found wanting and unmanageable by the beneficiaries particularly in the rural parts of Kenya. In spite of the great efforts in the area of water resources development, with the construction of large water projects, there is still under-provision of water for domestic use particularly in the rural and slum areas of Kenya, as more than 67% of rural household still have no access to clean and safe drinking water.

The problems of irregular water supply due to poor maintenance, lack of funds, broken facilities and rapid population increase, among other factors, have now reached a critical state.

Water Supply and Consumption Levels

Depending on climate and workload, the human body needs about 3-10 litres of water per day. The amount and purpose varies widely, and is greatly influenced by the type and availability of the water supply. In rainwater harvesting large surface areas (catchments) and the storage tank is required to provide sufficient supply for the dry seasons. Cultural habits, pattern and standard of living, methods of withdrawal, cost and quality of water will greatly influence the use of rainwater for domestic purposes. The per capita water consumption in the rural areas of developing countries as given by IRC (1983) is as follows:

Table 1.0 Typical domestic water supply and usage

Types of Water supply	Water consumption Litres/person/day	Range in L/person/day
Communal water point (e.g. village well, public standpoint) at a distance more than 1000m	7	5-10
at between 500-1000m	12	10-15
Village well at less than 250m	20	15-25
<i>Communal standpipe at less than 250m</i>	30	20-50
Yard connection with a tap	40	20-80
House connection		
-single tap	50	30-60
-multiple tap	150	70-250

It can be noted that water for drinking purposes range from 3-10 litres per day while for general domestic uses it varies between 5-250 litres depending on distance and type of source or mode of withdrawal. Thus a rainwater tank will be the same as a yard connection with added advantages of extra storage to balance demand vs. supply, hence increasing per capita consumption to the benefit of consumers.

Possibilities and Challenges

Various challenges and possibilities in making Rainwater harvesting a viable alternative to conventional water supply sources were identified during the household rainwater harvesting district workshop (HRWH) and could broadly be classified as: - *policy issues, technical challenges and managerial constraints.* (KRA 1998 a)

1. Policy Issues

In many instances community based organisations, non-governmental organisations, government departments and even some donor agencies lack policy guidelines in support of rainwater harvesting. Those that have are generally inadequate, and unsuitable to the prevailing local conditions. For example the Ministry of Water resources in Kenya have no mechanism of approving the construction of a ferrocement tank or water jar since they do not have design standard drawings. The city council by-laws only allow for effective disposal of rainwater from roofs to avoid dumpiness and drainage problems but not to collect for beneficial purposes. Thus,

most of the rainwater harvesting projects, particularly in Central, Eastern, Coast and Nyanza provinces evaluated by the KRA are faced with some of the following challenges:

Inadequate legal advice in projects formation and outlined objectives as per relevant constitutional framework;

Limited policies and by laws in funds and fundraising strategies to allow for effective project implementation and management;

Lack of collaboration and networking amongst stakeholders;

Limited community mobilisation policy for water related activities;

Low rate of community participation and contribution to project development;

Inadequate water quality improvement structures, control and usage;

Limited training and technological transfer in rainwater harvesting at project level;

Lack of operation and maintenance guidelines for rainwater infrastructure such as gutters, tanks catchments and fittings.

There is high potential of rainwater harvesting both in rural and developing urban centres particularly in countries like Kenya due to the rapid population growth and the need for alternative water sources that are simple, effective, low cost and environmentally sound. The annual seasonal rainfall patterns in Kenya coupled with adequate roofing materials makes rainwater harvesting a possibility in both urban and rural areas. The current political system of democracy is creating an enabling environment for collaboration and training in community mobilisation and participation. However the new water policy, local council by-laws and various Acts need to be amended to effectively address some of these issues. The community's willingness to participate in RWH is seen as a positive challenge in the development of the water sector policy. Thus with suitable water policy implementation plans and by-laws, rainwater harvesting can be enhanced and improved to overcome the above said challenges in supplementing conventional water supply sources, particularly for isolated homes in ASALs and in upcoming urban centres where water shortage problems are rampant.

2. Technical Issues

No matter how well designed a rainwater harvesting system, if it is not technically efficient, it will not deliver or perform the anticipated functions. Many projects, particularly in the rural areas, are not sustainable or cannot be replicable due to inadequate technical interventions, e.g. construction of roof catchment system, shallow wells, tanks and VIP latrines requires detailed technical instruction for effective implementation. The absence of such technical instructions at project level implies inadequate technological transfer and poor project management resulting in a high failure rate.

A 1998 survey by KRA of 16 community based water projects indicated that lack of technical interventions is the major cause of project failures. Assessment of the infrastructure shows that the communities were not fully involved in the planning and technology selection. The method of fixing gutters, taps, tank construction valves and operation and maintenance guidelines are not fully understood nor issued to the community on the commissioning of the project.

Technology selection by a community means acceptance, implying an understanding and willingness to be associated with it, irrespective of some shortcomings in community participation. Technical challenges facing many local initiatives in rainwater harvesting projects particularly were identified as follows:

Inadequate construction guidelines for tanks, gutters, filters, etc.;

Inadequate technological transfer to the beneficiaries;

Lack of suitable training programmes in rainwater harvesting;
Poor technical selection and usage of local materials;
Sizing of storage tanks, with respect to rainfall data and costs;
Lack of water quality improvement structures and control;
Inappropriate guttering system in design, construction (support) and maintenance.

Technological challenges in rainwater harvesting could be turned into realities by adopting pragmatic approaches like creating awareness through exposure (CATE), involving other stakeholders, use of appropriate designs in the rainfall data, guttering systems, sizing of storage tanks and use of locally available resources. It is estimated that about 60% of the failures in Kasaye Rainwater Harvesting project are attributed to inappropriate guttering systems. (KRA Report 1999). If rainwater harvesting were considered a supplementary source of water supply in small urban centre and arid and semi-arid lands (ASALs) of Kenya, then accessibility and coverage of safe drinking water would increase to over 74%. Presently it is estimated that only 32.5% of households in rural parts and 93.3% in urban centres of Kenya have access to safe drinking water. But accessibility does not in any way mean availability and reliability, (CBS 1994).

Managerial Issues

The KRA carried out a preliminary survey in 6 districts (Bungoma, Kiambu, Taita Taveta, Siaya, Kakamega and Kajiado) of low cost individual and or small community based water projects i.e. springs, shallow wells and rainwater harvesting. Compared to the existing piped water supply in most in those districts, household community-based water supplies are much more efficient than centrally controlled large piped water schemes. There is a sense of ownership, community participation and contribution in the management of community based water projects unlike in the government projects where the water managers have little or no enthusiasm in the management affairs. The managerial issues of major concerns that were raised included among others:

Limited use of local resources;
Inadequate community participation and contribution – due to approaches;
Inadequate project management skills, by community organisation;
Poor financial management and bookkeeping resulting in financial loss;
Lack of proper water usage and control measures;
Lack of awareness and unwillingness to obtaining legal status due to taxation;
Donor dependency syndrome;
Political interference within the community projects.

Experience in low-income housing areas show that it is relatively easy to arouse people's interest in rainwater tank construction; since they are perceived as desired improvements to their homesteads and a symbol of status particularly in the rural areas. For example for the Kasaye Water and Sanitation Project, one criterion used to select a beneficiary for RWH tank construction is to have an iron sheet roofed houses. (KRA, 1999) This has led to the community members improving their housing and consequently improving general community development. New housing schemes in urban areas should be encouraged to incorporate RWH tanks for emergency supply and other general usage of water.

The large government owned water projects have a high potential in overcoming managerial challenges of low cost community based water projects. Legally formulated by-laws and registration of self -help water projects, improvement of financial and management skills through local training will enhance effective and proper water usage and control.

Solutions to managerial issues as suggested by various communities based organisations included:

Increased community mobilisation at project levels;

Awareness creation through exchange visits;

Community training in project management;

Use of demand responsive approaches in project initiation and technology selection.

The essence of appropriate technology is that equipment and techniques selected particularly in RWH should be relevant to local resources and needs, feasible to organise and suitable for the local environment and above all more efficient than the one existing.

Community water supply –urban case study

Providing water supply to a community involves tapping all sources of water available, ensuring that it is fit for human consumption and supplying it regularly and in adequate quantities. The per capita quantity of water used by a family varies with physical and socio-economic conditions and consequently, varies widely between and within a neighbourhood. The level of service provided has also been found to have a marked influence on water usage. Where water has to be carried over long distances e.g. in ASAL's district, or when waiting for too long hours at water kiosks especially in developing urban centres before being served, the daily consumption may be as low as 5 litres per person.

In many developing towns and informal settlement housing like Kibera and Mathare Valley in Nairobi, besides other urban centres like Mombassa, Kisumu, Ngong, Kitui and Nakuru, people are almost entirely dependant on licensed kiosks and water vendors for their daily water requirements. The kiosks and water vendors sell water at rates that are much higher than the normal tariffs levied by the water undertakers. This contributes generally to the low levels of water consumption, hence making many slum dwellers vulnerable to water related diseases. People in these areas are thus forced to resort to unhygienic sources such as polluted shallow wells, burst pipes, unprotected open dams, etc, with high incidents of water borne diseases. Reasons for not meeting expectations include inadequate managerial and technical skills, lack of tools and qualified personnel and inadequate policy guidelines in operation and maintenance and lack of funds due to donor dependency. (Ladu, 1993)

Conclusions and Recommendations

Being individual or community-based, the introduction and application of rainwater harvesting technologies would be easy to implement and environmentally friendly for the following reasons:

It is easily understood with relatively little technical knowledge required;
It has many advantages over the existing systems, especially in operation performance, it creates jobs through labour-intensive methods particularly in rural areas;
It relies on locally available resources, personnel and materials;
It is economically feasible compared to other sources, such as boreholes and river system;
It is socially acceptable at grassroots levels;
It improves the drainage and sanitary conditions of the home states;
High sense of ownership improves sustainability of the system;
It can be integrated easily in many development programs such as housing food security, water supply etc.

A major advantage of rainwater collected from roofs is that it is usually free and much cleaner than water from streams, burst pipes and dams. Therefore rainwater offers considerable advantages when used for various domestic purposes such as drinking and cooking. However, it should not be assumed that water from roofs is totally free from contamination. In some case birds' droppings, rotting roofing materials and wind-blown dirt may all contribute to some pollution. Also poorly managed systems may be a source of other problems related to drainage and diseases.

The following guidelines are therefore recommended in rainwater harvesting:

- That water running off the roof during the first 3-5 minutes of a storm should not be used for drinking purposes but discarded or used for crop production. If this is not done the tank should be cleaned out more often as there is every chance that organic matter in the tank will promote the growth of bacteria bad and other organisms, likely to cause contamination.
- There should be some form of coarse screen between guttering and the delivery pipe, and a finer screen or filter at the point where water enters the tank to improve quality of water harvested.
- Gutters should be free from depressions and bends in which water is left standing, as these points become mosquito-breeding sites.
- All openings into the tank, such as overflow, water level indicators, and vent pipes should be fitted with fine plastic gauze to prevent entry of insects and rodents.
- Operation and maintenance of the system fittings such as valves and taps are very important, as this will ensure sustainability and efficiency of water delivery system.
- Proper design and selection of the guttering system, i.e. shapes size and slope to be adopted, so as to ensure maximum collection and delivery of the rainwater.
- Programmes should be designed to help low-income groups in water development activities and thus have improve the bad state of the housing, including roofs, should receive adequate support to promote rainwater harvesting.

In many parts of Kenya people cannot be expected to improve their current living conditions without adequate water supply. For any development, may it be industrial, commercial or agricultural, water is needed for it to succeed. We cannot be indifferent to these situations; it is up to us, at all levels in society, to do something in our respective fields. Rainwater harvesting is just one of the solutions in the provision of supplementary water sources in the coming millennium.

Therefore rainwater harvesting should be introduced as a bylaw in the building guidelines and any new development should be encouraged to explore and apply the rainwater harvesting technologies, not withstanding policy managerial and technical challenges.

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Rainwater Catchment in Nepal: An Answer to the Water Scarcity Problem of the Next Millennium

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Abstract

For the past two decades, provision of safe drinking water facilities for the population has been given high priority by both governmental and non-governmental agencies. Water has been brought closer to communities thus saving people much time and energy.

Catchment and utilisation of the tremendous natural rainwater resource is one of the right choices in Nepal's present context. Advantages of utilising rainwater can be summed up as: women and children benefit first; quality of rainwater can be maintained with simple and minimal efforts; catchment systems are independent on a household level; simple construction and easy maintenance; low environmental impacts; reduction of soil erosion and flood hazards by intercepting roof run off; and, improvement of the ground water table due to reduction in abstraction.

Introduction

Since the last two decades, provision of safe drinking water to Nepal's population has received high levels of attention and been a major program by both governmental and non-governmental agencies. Facilitating communities by providing closer water sources, undoubtedly saves time and energy being spent on fetching water from long distances; thus it is a wise school of thought heading in the direction of poverty eradication.

As a result of collective efforts made in the past from sector agencies, the national water supply coverage figure of 63% was obtained at the end of 1997 in Nepal, as a result of huge amounts of investments in the form of governmental subsidies, grants from friendly countries, and normal and soft loans from various countries and banks. A co-ordination gap between and among the sector actors always remained very wide in the past. Ad hoc scheme selection, task duplication and repeated budget allocations are some of the examples that often were faced and need more attention in the present also. Another factor noted from past experience is that there has been quite a lack in innovation. Traditional technologies like gravity flow water systems in the hills, and tube wells in plain areas have been commonly used technologies from ancient times which have omitted a large number of the population from the coverage point of view.

Although a national coverage figure of 63% in water supply till the end of 1997 provides some ray of hope for the future, looking at the poor service levels of a provided facility in

terms of quality shows that there is sufficient room for questioning the improved health status of the community. Further, findings in Lumbini zone (one of the 14 zones of Nepal, in the 1992 RWSSP survey) reflect the situation that nearly 14% of the total population is facing acute water shortages and are completely devoid of water resources to establish any type of water supply scheme. Population settlements along the ridges, hill tops and bhabar area (southern foot hills of Shivalik range) result in the most hardship, where women and school-age children live a very tiresome and disappointing life.

The demand for water has been increasing day-by-day with the rapid growth of population, urbanisation and changing lifestyle of the people. Due to unavailability of water, sanitation conditions remain always at a low level, thus resulting in higher health risks. Furthermore, depletion of available quantities of water from surface sources and from groundwater sources has been a nagging issue, necessary to be discussed, studied and taken care of in the near future. It is thus very clear that finding alternative technologies to address the above situation is an urgent need. Otherwise, the population of hill tops and bhabar areas will remain in the same alarming situation for decades to come.

Harvesting and utilisation of the tremendous natural water resource in the form of rainwater would be one of the right choices and solutions in the present context of Nepal. Advantages of utilising rainwater can be summed up as: women and children benefit first; quality of rainwater can be maintained with simple and minimal efforts; harvesting systems are independent at household level; simple construction and maintenance of the system by the users; low environmental impacts by reduction in soil erosion and flood hazards by intercepting roof run off; improvement in the ground water table due to reduction in abstraction; time and energy saving, etc.

Traditional practices on rainwater utilisation

Rainwater catchment systems have been used since ancient times. Using roof catchment and storing run off from the hill sides for both domestic and agricultural purposes has been a centuries old practice in different parts of the world. The art of rainwater collection as a principal source of water undoubtedly is becoming more and more popular in many countries of Africa, Latin America and Asia with the successful implementation of rooftop collection, particularly in rural communities.

The practice of rainwater collection and its uses for household needs has been a age-old practice in the context of Nepal as well. Evidence of many traditional water collection ponds, especially in the hill villages, date back to the historic kingdom time of Nepal (Baise Chaubise Raja's time). Many water collection ponds were made during that era and the technique has become more developed since then. Water is deposited in the ponds during the rainy season and is used during the dry spells in many domestic needs including washing, bathing, drinking, etc.

The technology of rainwater collection from rooftops in ferrocement tanks for domestic purposes is becoming more and more popular in the remote households of Nepal, after its

successful pilot project in Daugha, through the Village Development Committee (VDC) of Gulmi district by the Rural Water Supply and Sanitation Project.

Efforts of rural water supply and sanitation projects: an introduction of rainwater catchment systems in Nepal

The Rural Water Supply and Sanitation Project (RWSSP), jointly funded by the governments of Nepal and Finland, is being implemented in the six districts of Lumbini zone. The project gathered information on the drinking water situation during 1992-1993, from all the villages (nearly 3,100 villages of 408 Village Development Committees in Lumbini.Zone) to determine the relative hardships of different areas. Level of hardship is the main criteria used in selection of areas for water supply projects in the RWSSP so as to prioritize the area in real need, which also helps to avoid any possible external influence in the selection of projects. *(Hardship is a function of Service Level which is determined on the basis of quality, quantity, accessibility, reliability of the source and continuity of the facility)*

Criteria Used for Determining Water Supply Service Levels:

Requirement to be met (the poorest characteristic decides the service level)					
Category	Quality	Quantity (l/c/day)	Accessibility (min)	Reliability (mon/year)	Continuity (hr/day)
Service Level 1 Good	Protected Source	>45	<15	12	>6
Service Level 2 Acceptable	Acceptable Source	>25	<30	>11	>5
Service Level 3 Poor	Any source	>15	<60	>10	>4
Service Level 4 Very Poor	All other water supplies				

The overall hardship ranking is calculated using the method as follows :

HS = (0xL1 + 1xL2 + 2xL3 + 3xL4) where,

HS = hardship score

L1 = % of people falling into service level 1

L2 = % of people falling into service level 2

L3 = % of people falling into service level 3

L4 = % of people falling into service level 4

As a result of analysis based on explained assumptions, Daugha Village Development Committee of Gulmi district was found to have the most hardship in Lumbini Zone with respect to drinking water situation. Having no other feasible options, people of Daugha and the RWSSP agreed upon to introduce the rainwater collection system at the household level on a pilot basis. With the promising outcome of the pilot program, the technology is being replicated to other neighbouring villages and districts in the near future. Until the end of March 1999, nearly 1,700 ferrocement tanks of 2000 litres capacity have been constructed in 20 Village Development Committees in the hills of Lumbini.

Implementation policies

Mobilisation of local resources (money, materials, manpower); training of local people on building the system; and involvement of private sector organisations in the program as a partner are the main policy issues in rainwater harvesting projects which eventually ensures sustainability.

Key issues defined and followed by the RWSSP are explained briefly here under:

Information Base

The database related to water supply was established at the Village Development Committee and district level, to identify the existing water situation and the respective hardship of the communities, which ultimately eased the process of project selection and prioritisation, thus avoiding other external influences.

Community participation

Besides the hardship criteria, another essential criteria of the RWSSP in project selection is the commitment of the beneficiaries for their participation in the program, both in cash and kind. It has been made a prerequisite that apart from labour contribution, the beneficiaries also must contribute some money for investments and implement a fund raising system for operation and maintenance purposes.

Private sector involvement

Involvement of local NGOs/CBOs and other private firms has been considered important and useful in assisting communities for program implementation. The concept is in-line with the principle of institutionalisation, rather than to merely obtain a certain goal.

Step-by-step process

The RWSSP, with its long experience in water and sanitation related activities, has been able to design a step-by-step procedure flow chart to successfully implement a project. Furthermore, this step-by-step flow chart is gender-sensitised and incorporates various environmental-friendly aspects.

Capacity building at local the level

Capacity building at the local level is the key to sustainability. Transfer of technology by the training of local people in various technical and managerial related issues has been the main thrust of the RWSSP in the water harvesting programme.

Cost sharing by different stakeholders

Stakeholders at various levels need to collect their commitments to match the set percentage amounts of the project cost. This has been made a prerequisite in the RWSSP program for project selection. The same commitment needs to be materialised before the project enters the implementation phase.

Collecting rainwater from thatched roofs

Water collected from a thatched roof was not accepted by the population. Hence to start the program, it has been agreed that those households which have CGI roofs will construct two water collection jars, whereas households with thatch roofs will receive 180 sq. ft. of CGI sheet and initially construct one jar.

Revolving funds

The objective of the establishment of a revolving fund is to facilitate lending of financial resources for construction of additional jars. A household with 6 members needs at least 6 jars to meet present consumption of 100 litres a day. Revolving funds are to be established at each ward of the Village Development Committees, which will be loaned to the needy people and be administered by the Water User's Committee.

Monitoring & Evaluation

The RWSSP has developed project monitoring and evaluation guidelines in consultation with the district level authorities which clearly explains Who?, Why?, When?, How? and Where?. The stage at which the M&E team should visit the project areas has been fixed in the project flow chart.

Technology and the steps of the program

Technology:

The technology developed is aimed to reach the individual households in the community, in which 2000 litres capacity jars are constructed to collect rainwater from the guttered roof eaves. Ferrocement jars are constructed of thin-walled reinforced concrete, commonly constructed out of cement mortar and reinforced with closely spaced layers of wire mesh.

Technical designs have been made based on:

Dr. Reissner's Theory
Carpenter's Theory
assuming base and walls are monolithic

To check:

the hoop tension resistance;
water tightness.

Steps:

Design of the rainwater collection system;
Testing phase on pilot and demonstration basis;
User demand through Village Development Committee and priority setting;
Feasibility studies (Technical, Social, Health...);
Formation and registration of Water User's Committee;
Training of Water User's Committees on managerial aspects;
Program implementation (jar making program);
Training of local people to serve as capable Mistri to construct the jars;
Establishment of revolving funds;
Jar construction activities on a continued basis;
Initiate sanitation related activities;

System cost and its sharing

As explained earlier, an average household with six family members needs six jars to reach the basic service level, for which an investment of nearly US \$ 56 per capita is needed. To initiate the program with 2 jars of 2000 litres capacity per household, an investment of US \$ 24 per capita is calculated. The remaining number of jars needed to reach the basic service level are to be added by the households themselves. With this concept, the system has become a self-reliant water supply system, where more than 2/3 of the total amount is provided by the community. All the stakeholders in the program are required to contribute to reach the amount of US \$ 24 per capita, as follows:

Cash:

US \$ 5 per capita from Village Development Committee contribution;
US \$ 5 from each household (it is nearly US \$ 1 per capita) from the beneficiaries;
US \$ 18 from the district water supply and sanitation fund. The district funds are constituted on the basis of 50-50 matching grants from the governments of Nepal and Finland.

Kind:

Collection and transportation of local materials by the beneficiaries;
Transportation of provided materials from the nearest road head to the construction sites;
Provision of unskilled labour for construction of the rainwater collection system.

Institutions involved

The principle strategy of the RWSSP involves many locally-based NGOs and CBOs working together in the districts as partner organisations. There are 21 rainwater collection projects presently being implemented in the Lumbini hill districts where 10 locally based NGOs and 21 Water Users Committees are involved as partners. It is interesting to note that some of the NGOs and Water User's Committees have attained quite a high managerial and technical level of knowledge in the rainwater harvesting program in a rather short period of time, as a result of the partnership venture.

Conclusions

There are clear indications from the communities that people have started internalising the rainwater harvesting technology as an appropriate one for the hardship areas. Therefore, the technology should also be replicated to the other parts of Nepal, where water resources are also not easily accessible. It is also common knowledge in Nepal that water scarcity and the most hardship effects mainly the underprivileged people. Therefore, *the rainwater harvesting program has also the credibility of serving the poorest of the poor of society.* Rainwater needs to be recognised as a potential drinking water resource from the government agencies; as well, they should place an equal emphasis to launch such programs in the most needy areas. To address the water scarcity problem, harvesting and utilisation of rainwater may be the right choice and answer for the next millennium.

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Sustainable Water Resources Management in Arid and Semiarid Regions of the World: A Case Study in Iran

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Abstract

Water tension is growing with the growing population of the world. The demand for healthy and adequate food in any sustainable development is among the most important sustainability indexes. In this context, water resource management plays a very important role. At the present time, most of the countries in the Middle East and North Africa are under water tension. In a sustainable development, a sound management of water resources is crucial in the socio-economical development of these countries in these regions.

The objectives of this paper are 1) to review the present state of water resources management and water tension in the Middle East and North Africa, 2) to review the water resource management in Iran, 3) to discuss some case studies in the central desert arid condition of Iran.

The definition of sustainability with regard to arid and semiarid conditions is discussed here. However, sustainability as used in the environmental policy and research arena is indeed a complex issue. In general, sustainability even on a local level has to address and relate to global issues. With the advances in technology, the water utilisation has boosted the underground water resources. The sustainability of the present state of utilisation with the emphasis on the groundwater resources could be very questionable. In the Middle East, for example, Syria, Iraq, Lebanon, Jordan, Israel and the Occupied Territories (The West Bank and Gaza) have a combined population of nearly 42 million. Of these people, an estimated 41,5% rely on transboundary streams and 52% utilise springs, wells and rivers supplied by local precipitation. The remaining 6 % turn to water pumped from deep wells. At the present time these water supplies are being taxed to their limits.

Introduction

Demand for water is on the rise everywhere in the world, particularly in arid and semiarid countries including Iran. A general increase in the standard of living over time has created a gap between access to and the need for water. Rapid population growth and expansion of irrigated farmlands during last 2 decades in Iran have imposed more pressure on the water resources. Over 2/3 of the total area of Iran suffer somehow from the lack of precipitation. Low recharge rates of underground resources lead to the negative balance of 5 km³ per year for the aquifers and rapid drops in water tables (Siadat 1994, Jahani 199). Therefore there is an urgent need for finding ways and means for solving the conflicting interests of urban, industrial and agricultural sectors in utilisation of water. Since new resources of fresh water are very limited, proper water resources management plays a very important role. Concern about future food production and environmental degradation has increased awareness of sustainability. Although an abundant literature is now available, some fundamental questions have not yet received adequate answers. This paper intends to address some issues concerning

the definition, assessment and implementation of the concept of sustainability, specifically in relation to land management for agricultural purposes. The semiarid regions of Iran are under increasing pressure to supply the staple grains (wheat and barley) required by the steadily growing population of the country. A population of 150 million is expected in 30 years time, which means that 30 million tons of cereal will be needed. The present production of wheat is about 5.5 million tons and that of barley amounts to 2.5 million tons, almost all produced in semiarid conditions. It is clearly a complicated matter. We need more water to reach to such a record.

Definition issues

Sustainability, as used in the environmental policy and research arena is a complex & sometimes controversial concept. When applied to agriculture, complexity is compounded, since the term “sustainable farming system” has many connotations. Qualifiers of farming systems such as “low input”, “ecological”, and “organic” are often used interchangeably with sustainability (Lockerets 1990). Because of this confusion, some authors who believe that an improved model of agricultural development and a sustainable land management system cannot be properly implemented without previous conceptualisation, continue searching for a multifaceted, though unifying and consensual definition (Brown et al 1987; Francis and Yaungberg 1990). Others are more involved in production fields, demand action and implementation, rather than further conceptual refinement (Allen et al 1991). Sustainability attempts to address global issues, such as resource degradation, deforestation and ozone layer depletion etc. but also local issues, such as the maintenance of specific eco-sociosystems or combination of these.

Dimensions of the issue

The perspectives of sustainability and sustainable land management depend on one's specialisation. Ecologists concentrate mainly on the stability (or fragility) of the ecosystems as a function of beneficial constituents of the environment. The agronomic point of view might be considered comparatively narrow. They are still aiming at the maximum productivity. In contrast, sociologists take a broader view, striving for social welfare and emphasising social variables such as the organisation of labour, unemployment, migration and so forth. (Allen et al 1990). To many economists, economic efficiency, usually associated with political issues, controls sustainable development. Profit maximisation through conservation of money into goods or services could just as easily be taken as objective since sustainable systems maximise resource conservation subject to a profit constraint by minimising degradation (Ikard 1990). Politicians' viewpoints are often confined to short-term plans. To many politicians, particularly those in some developing countries, stability within time spans of 3-5 years, rather than sustainability, is the issue.

It is multi-scalar

The concept of sustainability has different meanings at different spatial levels (local to global), according to the geographic variations in natural and human resources. Since sustainable agriculture and land management aim at reducing the use of external inputs, the quality and properties of the natural resources base become much more important. For example, the term of agro-ecologic sustainability vary from arid areas, where sustainable land management is controlled by the efficient harvesting and application of water, to humid tropical areas, where this is done by nutrient conservation and cycling. Similarly, the geographic diversity of social, economic and institutional conditions determines the spatial variability. At international levels, while industrial countries are swinging from conventional,

highly mechanised and specialised production systems to more integrative, low-input farming to promote sustainable agriculture and land management, developing countries have embarked on the opposite strategy, to promote aleatory development. At the national level, the terms of sustainability may also vary.

Time variability

The term “sustainability” refers to the productive performance of a system over time. The questions are: how long can a system last without being disturbed? and how long does a disturbed system need to recover? The length of time, whether for disturbance or recovery, depends on the intensity and kind of land management, the latter being a function of population pressure and type of land use. Under natural conditions, most land systems are intrinsically long-term sustainable. In the not-too-distant past, land use was governed by respect for long-proven rules for sustainability, such as fallow periods and other traditional soil and water management practices and was so for water resources systems as well. Time was available for soil resilience and for agro-ecosystems to be maintained. With increasing population pressure, land has to be used more intensively and more marginal land has to be put into production. So more water has to be used. Water quality decreases gradually. Both conditions endanger the short- and medium-term sustainability of land quality.

Sustainability Indicators Are Required

Sustainability is a concept and cannot be measured directly. Therefore, appropriate indicators should be selected, tested, and validated to determine levels and durations of sustainable land and water resources management. An ideal indicator should be unbiased, sensitive to changes, predictive, referenced to threshold values, data transformable, integrative, and easy to collect and communicate (Liverman et al.1988). It is unlikely that all potential indicators would fully satisfy these quality requirements.

Implementation Issues

Finally, conceptualisation and assessment of sustainable land and water resources management have to be translated into applicable alternative models, which have to be tested and monitored under practical conditions.

System quality criteria

To be sustainable, a land water resources management system is expected to incorporate a set of intrinsic properties, such as those proposed by Altieri (1989). It should be diversified in time and space, dynamically stable, self-promoting, productive and self-sufficient, based on economic potential, adjustable to socially and culturally acceptable technology; provide self-help potential; and promote the conservation and regeneration of natural resources.

Water Resources: An Emerging Crisis

The problem of water shortages in the Middle East and Northern Africa is a developmental issue, since water limitations are seriously impeding the economic growth and development of countries in the region. Even countries that are quite advanced technologically are experiencing restraints on their future development. Water scarcity in the Middle East / Northern Africa region is rapidly becoming part of a widespread environmental concern for the region. The twin phenomena of depletion of existing water resources together with pollution of these resources is causing growing hardship in the area. Land deprived of its scarce water resources, either by natural phenomena or human activities, produces devastating consequences as recent events in the sub-Saharan region of Africa demonstrate. At the very

least, water scarcity creates an environment where sustainable development is severely limited in the Maghreb (Libya, Tunisia, Algeria & Morocco) and in the worst case, extreme water shortages can create an environmental climate that exacerbate serious conflicts, as evidenced by water-related conflicts in the Middle Eastern region. Jordan faces possibly the worst water crisis in the Middle East (Al Fatafath & Abu-taleb 1992).¹ Egypt is a key country in the region, serving as a link between the Middle East and Northern Africa, as well as being the main water user of the vast Nile Basin River for its water resources, with irrigated agriculture accounting for the vast majority (84%) of all the water used. Since the Nile River drains from nine countries, at great distances from Egypt, any major change in the water-use pattern in these countries, would have a dramatic effect. In addition to water quantity consideration, indicators show that environmental degradation of the Nile Waters is increasing (M. Abuzeid 1992).²

Human dependence upon limited water supplies underlies any consideration of water resources management in the Middle East. The population of this region utilises a combination of local springs, wells and rivers. Of the population of the region, 41.5% rely on transboundary streams flowing from non-Arabic countries, 52.5% utilise springs, wells and rivers supplied by local precipitation. The remaining 6.0% turn to water pumped from deep wells (table 1).

Table 1 - Middle East Population (1000s) and the water resources upon which they depend.

Country	Current Total population (yr. 2020)	Transboundary Rivers	Local Springs, Rivers & wells	Deep Aquifers (non renewable)
Iraq	16,000 (41,808)	10,800	5,200	-
Israel	4,400 (6,643)	1,400	2,900	100
West bank & Gaza	1,800 (4,200)	-	1,000	800
Jordan	3,450 (9,964)	1,650	700	1,100
Lebanon	2,500 (4,433)	-	2,500	-
Syria	10,500 (26,094)	2,200	8,000	300
Total	38,650	16,050 (41.5%)	20,300 (52.5%)	2,300 (6.0%)
Turkey	55300 (83,849)	-	55,300	-
<i>Iran</i>	<i>75,000</i>	<i>500</i>	<i>26,300 plus 23,000 (qanats)</i>	

Refer to Canadian Journal of Development Studies; 1992. ¹

Refer to Canadian Journal of Development Studies; 1992. ²

Table 2 shows the distribution of water from surface and underground sources. As will be seen, these water supplies at the present time are being taxed to their limits.

Turkey and Iran are essentially self-sufficient with regard to water. At the same time, the former is the source of 98% of the flow of the Euphrates and 43% of that of the Tigris River. The Zagros Mountains on the border of Iran & Iraq, form catchments for waters of tributaries entering from the left bank of the Tigris in Iraq.

Table 2- Dependency upon Surface and Underground Sources

Country	Population	Surface	Subsurface	other
Iraq	16,000	15,680 (98%)	320 (2%)	-
Israel	4,400	1,760 (40%)	2,508 (75%)	132 (3%)
West Bank & Gaza	1,800	300 (17%)	1,500 (83%)	-
Jordan	3,450	1,760 (51%)	1,690 (49%)	-
Lebanon	2,500	875 (35%)	1,625 (65%)	-
Syria	10,500	8,715 (83%)	1,785 (17%)	-
<i>Total</i>	<i>38,650</i>	<i>29,090 (75%)</i>	<i>9,428 (24%)</i>	<i>132 (1%)</i>

Considering gathered datum & reports, it can be seen water tension is increasing nearly all over the world, particularly in arid & semi-arid regions. In fact water war and struggle has already begun. Governments put forward new plans and projects and these plans change existing balances. There is no need to say water tables are dropping rapidly etc. But we should search for new ways of using existing water.

Conclusion

In many countries (including Iran), environmental degradation is a by-product of development, along with land deterioration from conventional agricultural practices. In contrast, sustainable land and water resources carry a strong commitment to environmental quality. In conclusion, the choice of sustainability indicators and the determination of threshold values have to take into consideration the spatial variability of the natural and human conditions controlling sustainability. A crucial question is how to evaluate the time component of sustainability and estimate the longevity of a land system under specific management practices. Lal et al. (1990) proposed periods of 5-10 years for agronomic productivity and 5-10 decades for soil and environmental features. Fresco and Kroonenberg(1992) suggest the time scales of both internal and external processes acting on the system should be considered for agro-ecosystems at local and regional levels. In Iran, for example, traditional water management practices (Qanats, Bands, Pot irrigation, etc.) that evolved over a long time into a socially and ecologically integrated system, quickly collapsed when agriculture underwent modernisation (Farshad and Zinck 1993). It is the point of view of the author that we should consider ancient integrated systems as sustainable ones. Sometimes we forget that our ancestors formed frameworks of our present knowledge. Land use evaluation should be considered as the main and initial decision-making factor. If one were to evaluate these systems it would take a long time, and is beyond this paper's objectives.

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Promotion of rainwater catchment in Southern Africa

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Abstract

Southern Africa is a drought prone region, and has suffered two severe droughts in the last 10 years. However, the use of rainwater harvesting in Southern Africa, even as a supplementary source of water is not generally promoted by government policies and practices in the region.

Regional Rainwater Harvesting Programme

A programme to promote the use of rainwater harvesting, for both domestic use and crop production, has been initiated by 2 South Africa based organisations, The Mvula Trust, a large water and sanitation NGO, and the Disaster Mitigation for Sustainable Livelihoods Project (DiMP), based at the University of Cape Town. The programme is one of three disaster mitigation/risk reduction initiatives being promoted by DiMP with support from the Department for International Development, London.

Goals and Objectives of the Programme

The goals of the programme are

- a) To influence community water supply policy and practice in Southern Africa, towards the increased use of rainwater harvesting techniques.
 - b) To encourage best practice in the implementation of rainwater harvesting initiatives.
- The focus of the programme is on development organisations directly involved in project implementation.

The participating countries are Namibia, Botswana, South Africa, Mozambique, Zimbabwe and Zambia.

Rainwater harvesting in the region

Most rainwater harvesting activity in the region is being promoted by the NGO sector. Domestic rainwater harvesting activities, using above and below ground storage, has been promoted in Botswana since the late 60s. In Zimbabwe, a few NGOs have successfully introduced rainwater harvesting for crop production with small farmers in a few pilot areas. Rainwater harvesting is traditionally practised in several areas in Mozambique, and NGOs are promoting improvements to existing techniques. In some areas in South Africa, particularly the Eastern Cape, households use galvanised iron tanks to collect water from roofs with little external support. In Zambia, the Ministry of Agriculture and Forestry, together with NGOs, supports the construction and rehabilitation of small dams and weirs for small-scale irrigation and water for domestic use.

Organisation of the programme

The programme will run at two levels. Regional activities, to be held throughout the duration of the programme, will be attended by representatives from all participating countries. These will consist mainly of workshops and planning meetings.

In each country there will be a country programme. One of the main activities will be the evaluation of existing rainwater harvesting projects in that country. In addition, there will be workshops that will often mirror the regional workshops.

The approach is to encourage knowledge and skills among development organisations, and to advocate rainwater harvesting at a policy level.

Activities

A 3-day regional workshop has been held in Zimbabwe, and a second workshop is planned for September 1999. Country programmes are currently being planned.

Namibia

Namibia is a very dry country, with seasonal and generally variable rainfall. Mean average rainfall varies from below 50mm on the coast to 700mm in the far north east of the country. Evaporation rates are high.

In 1993, the government embarked on the Water and Sanitation Policy (WASP) which emphasised community based management of water supplies, with cost recovery a key aspect of the policy. Irrigation schemes have to comply with stringent environmental studies to minimise depletion of surface water sources.

The WASP programme has had considerable success in extending water supplies to rural areas. However, for both urban and rural water supplies, there has been considerable reliance on large schemes, drawing water from both surface and subsurface sources.

Rainwater harvesting for Windhoek, the capital city, was considered in an official report written in 1996. The report specifically rejects the encouragement of rainwater harvesting for Windhoek, largely due to high capital costs involved.

There are a few NGOs involved in rainwater harvesting for rural communities. UNICEF has supported construction of water tanks in schools in the Ovambo region on the northern border with Angola, RISE Namibia has implemented a pilot domestic rainwater harvesting project in the Erongo region in the north west, and IBIS is supporting rainwater harvesting initiatives in the north as part of an ecological housing project.

There is a growing movement of institutions involved in community based natural resource management activities, and this could provide a solid base for rainwater harvesting for agricultural purposes. (Programme country contact – Ronny Dempers, RISE, Box 50155, Bachbrecht, Windhoek)

Botswana

Like Namibia, Botswana is dry particularly in the southern, central and western areas. Most of the population lives in the north east of the country. Government schemes have supplied larger towns with water mainly from dams, and have implemented an extensive borehole-drilling programme for rural areas.

In the agricultural sector, government policies recognise the role of rainwater harvesting in promoting sound use of natural resources and enhancing agricultural production.

In parts of Botswana many people are dependent on sand rivers and hand dug wells for their supply. Rainwater harvesting is a tradition still practised in parts of the country where reliance on hafirs and small earth dams is widespread.

Rainwater harvesting has been promoted in Botswana for a number of years. Hafirs were promoted in the 1960s and 70s. Harvesting techniques were introduced for both domestic and agricultural water, using above ground and below ground storage, using a design from the Arable Lands Development Programme, ALDEP. This design was taken from the traditional practice of digging pits for water for cattle and domestic use. Organisations involved in these

initiatives, notably Botswana Technology Centre and Rural Industries Innovation Centre, are still active. However, rainwater harvesting has yet to be accepted by the government as a reliable and safe water supply source, with water quality being an important concern. (Programme country contact – Rule Opelo, Botswana Technology Centre, P/Bag 0082, Gaborone, Botswana)

South Africa

South Africa has well developed water supply systems for formal urban areas. However, there is considerable evidence of rainwater tanks being constructed decades ago before municipal services were available. Commercial farms, now mainly supplied by boreholes, also have evidence of old rainwater tanks, which are sometimes still used.

At the time of the 1994 democratic elections, rural South Africa was very poorly served with water supplies. A severe drought in 1992 highlighted the weaknesses in the operation and maintenance of such systems that had been installed. Since then, the Department of Water Affairs and Forestry has embarked on a programme to provide a water supply service to everyone, at a minimum level of 25 litres per person per day within 200 metres walking distance.

The prevailing assumption that everyone will receive a piped service, while politically popular, clearly does not encourage rainwater harvesting for domestic consumption. However, there are situations where rainwater harvesting offers at the very least an important supplement to existing or traditional sources. In many rural areas, homesteads are very scattered, making reticulated supplies prohibitively expensive. In parts of the semi desert Karoo area, where subsurface water is very deep and sometimes of poor quality, rainwater tanks are also a logical solution for supplementary supplies.

In some parts of the Eastern Cape province, many householders have installed corrugated iron rainwater tanks of their own accord, with no external support or assistance.

There are very few NGOs promoting rainwater harvesting for domestic purposes. Similarly, rainwater harvesting for crop production is not promoted by many organisations. Agricultural extension for poor rural farmers, generally neglected under the previous government, is informed by conventional modern agricultural practices, and few NGOs are involved in this area. The permaculture sector is probably the most active in this field. (Programme country contact – Nzwana Konco, Rural Development Services Network, rdsnetwk@wn.apc.org)

Mozambique

Surface water in Mozambique is relatively scarce and unevenly distributed. Rainfall is seasonal and irregular. In drier areas, women and children spend much time and energy fetching water.

The National Directorate for Water recognises rainwater harvesting as a supplementary source of water. The Directorate is moving away from implementation of water services to policy formulation and co-ordination, leaving implementation to NGOs and the private sector. There are close working relationships between the various agencies involved in water supply.

Rainwater harvesting is a traditional technique that is still widely used, especially in the drought prone central provinces. The most common practice is the construction of uncovered clay lined wells situated to collect surface run-off. Where affordable, mortar covers are used.

In some areas, the trunks of living baobab trees are used as reservoirs.

Several NGOs, such as CARE Mozambique, Oxfam and Lutheran World Federation are now promoting improved rainwater harvesting systems, building on traditional techniques, primarily with the use of ferro-cement/cement mortar tanks. (Programme country contact – Elijah Rusike, ITDG, itnyanga@samara.co.zw)

Zimbabwe

Since Independence in 1980, rural water development in Zimbabwe has taken place under a variety of institutions. The Department of Water Development has installed reticulated supplies to urban areas and larger rural settlements. Other rural areas have been served primarily by a longstanding borehole programme implemented by the District Development Fund, while the Ministry of Health has been involved in a successful hand dug family well programme, with the assistance of a number of NGOs. Large parts of the country have a relatively high water table (a depth of less than 20 metres), making hand dug wells an appropriate, sustainable solution to the water supply problem. Agriculture has been served by Agritex, under the Ministry of Lands and Agriculture, which has an active extension programme.

Most recent rainwater harvesting activities in Zimbabwe have been for crop production. The Intermediate Technology Development Group (ITDG) has for a number of years been promoting rainwater harvesting as part of a broader land use and crop production programme in Chivi in Masvingo province. Other NGOs have been doing similar work in other parts of the country. The intention of these programmes is to pilot extension models that promote low input methods and drought resistant traditional crops.

Permaculture is actively promoted in the country, led by the NGO, Fambidzanai.

Rainwater harvesting for domestic water in rural areas has been hindered by the widespread use of thatch as the roofing material. However, the Blair Research Institute, attached to the Department of Health, has begun a programme to promote domestic rainwater harvesting. It is co-ordinating a network of organisations, most of which are involved in domestic rainwater harvesting.

Zambia

Zambia is a relatively urbanised country, which experiences good rainfall in the north, declining towards the south and southwest. Rural water supplies comprise mainly dams, small weirs, boreholes and shallow wells. A national water policy, formulated in 1994, emphasises sustainability, affordability and equity. Rural water supply and sanitation policies focus on community-based approaches, cost recovery, appropriate technology and effective training. Water and sanitation programmes are co-ordinated nationally by a National Water, Sanitation and Health Education Team (N-Washe). There are equivalent district D-Washe committees that co-ordinate the water and sanitation activities of government agencies and NGOs.

Rainwater harvesting activities are primarily agricultural, and are co-ordinated by the Ministry of Agriculture, Food and Fisheries (MAFF). Techniques such as graded terraces, tied ridges and potholing are commonly employed. NGOs are primarily involved in dam and weir rehabilitation, with wells dug adjacent to dams for domestic water use. Most of their activities are in the drier Southern Province. The NGOs involved are Africare, Care International and World Vision International. (Programme country contact – Bob Muzyamba, Africare, africare@zamnet.zm)

Organisation of the programme

The programme will run at two levels. Regional activities, to be held throughout the duration of the programme, will be attended by representatives from all participating countries. These will consist mainly of workshops and planning meetings.

In each country there will be a country programme. One of the main activities will be the evaluation of existing rainwater harvesting projects in that country. In addition, there will be workshops that will often mirror the regional workshops.

The approach is to encourage knowledge and skills among development organisations, and to advocate rainwater harvesting at a policy level. This will be done:
through workshops and technical exchanges which will provide technical input from outside and inside region.
through evaluation of completed projects, and developing approaches to best practice.
by identifying policy constraints in participating countries, and lobbying for policy changes.
by engaging with relevant government officials in participating countries, and lobbying for promotion of rainwater harvesting in government programmes.

Regional and country networks

In each of the participating countries, activities involving a network of participating organisations are being promoted, drawing on existing capacities and skills within the country. No formal networks are being supported directly by the programme, but the programme strongly promotes co-operation with existing regional and country networks.

Programme Activities

An initial meeting was held in October 1998, attended by all participating countries except Botswana, at which the programme was launched. This meeting endorsed the programme, and reviewed the state of rainwater harvesting in the various countries.

The main activity to date has been a workshop in Masvingo, Zimbabwe. The objectives of this meeting were:

Continue networking

Introduction of the resource booklet, "Rainwater Harvesting Information Resources For Southern Africa," produced by John Gould

Country Presentations – case studies

Field visits

Presentations on other regional initiatives, and RWH in East Africa

Decide upon the objectives for project assessments

Decide methodology for assessments (working group)

The meeting highlighted the diversity of rainwater harvesting practices in the region, and confirmed the commitment of participants to its promotion.

One of the highlights of the workshop was the field visit, hosted by the Intermediate Technology Development Group (Zimbabwe) and the Zvishavane Water Project. In both instances, delegates were hosted by farmers whose implementation of rainwater harvesting techniques had demonstrably improved crop yields. The primary techniques employed were the use of contour bunds and infiltration channels, together with inter-cropping and the growing of traditional drought resistant crops.

Another highlight was the participation of Dr Maurice Ndege and Mr John Mbugua from Kenya, whose enthusiasm and experience was a source of inspiration for southern African delegates.

An interesting aspect of the workshops was a common commitment to participative techniques in implementation of projects and programmes.

Future of the programme

The current phase of the programme consists of activities within participating countries. Workshops are planned in each country, with the intention of widening informal networks and further promoting rainwater harvesting. In addition, within each country, two or three existing rainwater harvesting initiatives will be assessed, with the intention of arriving at recommendations for good practice in various contexts.

A further regional workshop is planned for September 1999, at which the project assessments will be reviewed. A final conference, concentrating on country policies and practices, will be held in 2000.

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Considerations for developing guidelines for rainwater catchment systems in the U.S. Virgin Islands

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Abstract

The United States Virgin Islands (USVI) is one of the few areas in the world where harvesting of rainfall contacting roof surfaces and subsequent storage of this water is required by law. High construction costs as well as standards of living with high demands for potable water, require that the mandated rain harvesting systems are designed, constructed, operated and maintained as efficiently as possible. The USVI has collaborated with the Federated States of Micronesia (FSM) to compare design practices that are utilized in the USVI and FSM. The USVI and Hawaii also collaborated on an examination of legal, economic, and institutional factors affecting rainwater systems in Hawaii and the USVI. These collaborations reveal that much is to be gained through detailed examination of practices and standards for rainwater harvesting systems that evolved independent of each other but with the same primary goal. While the long and many experiences with these highly developed systems in the USVI provide the other countries with options for future courses of actions, the USVI can gain much by the fresh and novel approaches taken by these countries in order to improve its rainwater utilization practices.

Introduction

The United States Virgin Islands (USVI) are part of the arc of islands separating the Atlantic Ocean from the Caribbean Sea. They are located about 1,000 miles east southeast of Miami, Florida and 2,250 miles northwest of Petrolina, Brazil. The islands in general are relatively small (none having an area exceeding 90 square miles) and are for the most part of volcanic origin and hilly. The economy is presently supported principally by tourism. Most of the tourists come from North America by cruise ships and airline carriers and are attracted to the islands by the warm climate, pristine coastal waters, relaxed life style and the many shopping bargains at these duty free ports. Expectations of visitors to the USVI are very high for travel to the islands and accommodations are quite costly.

Residents of the Virgin Islands enjoy a standard of living very much like that of a resident of an average American city. This is partly due to the fact that many residents are relocated Americans

and also to the ready accessibility that islanders have to the U. S. mainland for both business and pleasure. Long-term associations with the U. S. mainland also occur because of education and work opportunities. Building materials, vehicles, home appliances, clothes and even food are all imported for consumption in the USVI. Even water for general use has at one time been imported to the Virgin Islands. The very high cost of living in the USVI has been attributed to the shortage of locally produced consumables and the subsequent need for importation of necessities.

Rainfall in the USVI averages about 44 inches annually. Rain occurs principally as brief intense tropical downpours with the longer and more severe rainfall occurring between August and November coinciding closely with the hurricane season. Steep hillsides, thin soil layers and fractured igneous rock preclude natural catchment of rainfall as a means of ground water replenishment. The little ground water that occurs on the few alluvial coastal flats must be managed carefully to avoid contamination from seawater. In the rare inland valleys where some ground water might occur, this resource is being increasingly threatened because of bacterial contamination from septic tanks and chemical pollution from commercial and industrial sources.

The steep hillsides and relatively small surface area of the islands result in there not being any significant perennial streams in the islands. Surface water supplies in the past were limited to very small earthen dams built for cattle watering and other agricultural purposes. High evapotranspiration rates that have been estimated to return over 96 percent of the rainfall to the atmosphere also make conditions unfavorable for existence of meaningful surface water.

Desalination is a principal source of water for satisfying particularly commercial water demands in the USVI. While this technology is a high consumer of costly imported fossil fuels, it has proven to be a reliable source of desirable volumes of high quality water. A principal shortfall of this approach though has again to do with the small size of the islands and their geography. Economies of scales cannot be realized with usage of the plants in the islands. Not only because the islands' populations are separated by miles of deep water, but also even within an island desalinated water cannot be practically conveyed by pipelines because of the mountainous relief and the spread of each island's population throughout the island. Desalination plants are sized and built to meet water demands in proximate service areas based on engineering, demographic and topographic considerations. The result is that demands outside the service areas must seek alternative means to obtain water. For major complexes such as hotels, installation of small seawater desalination plants is an often-utilized alternative.

In most cases, surface water, ground water and desalinated water are not options available for use by individual residences. The alternative source of potable water in the Virgin Islands is commonly what is the preferred and mandated source of water – rooftop harvesting. Virgin Islands' law requires that buildings provide for harvesting of runoff derived from rooftops and storage of the harvested water on site. (Title 29, Section 308, V. I. Code). This law requires that typical one story family homes provide ten gallons of storage capacity for each square foot of roof area. An average single family home in the Virgin Islands has a footprint of approximately 1,600 square feet. This necessitates that a cistern with a capacity of approximately 16,000 gallons must be constructed. Approximate cost of constructing these cisterns are about \$1.25

(US) per gallon of storage capacity. Cisterns are a principal contributing reason for the high cost of home construction in the Virgin Islands.

A typical rainwater harvesting system at a residence in the USVI consists of a rooftop water-harvesting surface, a conveyance system for the harvested water, a cistern for storage of the water and a means of distributing the water to the point of use. The collection surface usually is corrugated galvanize but also may be concrete, or plywood coated with an elastomeric membrane. The runoff from this surface is collected by means of gutters around the roof's perimeter that conduct the harvested water to the cistern. Occasional use is made of simple devices to divert the first flush of water from the roof to waste and in some instances point-of-use treatment devices are installed to enhance water quality. (Sello, 1997).

Most cisterns in the USVI are built as part of the foundation of the houses in much the same manner as a basement is an integral part of the foundation of houses in the United States. These window-less basements are constructed either from specially designed concrete blocks fortified with steel reinforcing bars that are filled with concrete or by cast concrete. Occasionally, reinforced fiberglass tanks are used. Fiberglass tanks though do not form part of the house's foundation and often are not favored because they present increased space requirements. Cisterns all have access ports for inspection and maintenance and manual removal of stored water. They also are fitted with overflow ports to discharge excess inflow. A common design consideration is a separation wall that divides the cistern in half. This permits isolation of one side from the other allowing the user options for cleaning, leak isolation, etc. The insides of concrete tanks are coated with special preparations to preserve the quality of the stored water.

A person in a house utilizing a cistern in the Virgin Islands usually does not notice any difference in how they get water for use. The house's plumbing includes a pump that takes water from the cistern to a pressurized holding tank that supplies the water on demand from taps within the residence like would be found with conventional plumbing. An occasional slight change in pressure differences or the occasional noise of the pump motor running might be the only indication that the cistern is the supply to the house.

Routine maintenance might require paying attention to keep the catchment surface clean and free from debris. The cistern is cleaned at a frequency proportion to its likelihood of contamination and occasional chlorination of the water is recommended. The water pump sometimes becomes water logged and this is attended to quite simply. The cistern's inlet and the overflow ports are screened to prevent access to the water by detritus and animals.

A properly maintained and operated cistern provides many benefits. Certainly cisterns provides a means of a safe, reliable water supply that is available when there are no other options. Virgin islanders also cherish the independence that cisterns provide to their users. Users are not dependent on others for water and this is particularly cherished in times of natural disasters such as hurricanes when individual homes may become isolated. Until recent times, one reason that cisterns were preferred sources was because the users were more confident in the quality of his water than in the water coming from a source that they had no control over.

Aside from these readily observable benefits of using cisterns in the Virgin Islands, other less noticeable benefits have been proposed in the use of cisterns. Dr. Marci Bortman did extensive research on the effects of land use practices on coastal water quality and found that while in general greater urbanization leads to increased runoff from land surfaces, that might not be the case in the USVI. Bortman found that cisterns actually reduced the volume of runoff leaving a development area and lessened the impact of non-point source pollution on a coastal area. (Bortman, 1997). Rooftop harvesting of water reduces the amount of rainwater that impacts the ground surface and has the potential for causing erosion and eventually despoilment of coastal waters. Additionally a cistern user is very conscious of her water usage. Also, with reduced water usage there is a corresponding reduction in wastewater production resulting in less contamination of ground water and other non-point pollution.

While cisterns have been in use in the USVI for many years and remain the preferred source of water for many residents, changing times require that a fresh look be taken at these sources of water. Attention is being directed to several areas not previously considered.

Materials used in rainwater harvesting systems must be given special attention. As with other water supplies, improved technology and recent medical findings require new consideration of materials that have been used in the past. Questions are now being raised about the quality of water that these systems provide. There are opportunities for contamination of the water at every point that the water contacts the collection, conveyance and containment surfaces. Proper maintenance of the surfaces is essential but so too is the material form which these surfaces are made from. A survey was made of the materials used in water harvesting systems in the USVI and it was found that consumers and vendors give little consideration to the applicability of materials used in cistern systems in relation to water quality preservation. (Smith, 1996).

In our developing societies, there are opportunities for contamination of the rainwater even before it contacts any collection surface. Residual airborne products from burnt fuels have been found to be a potential source of contamination of cistern water supplies in the USVI. (Wrensford, 1996).

Cistern usage is practiced more in the developing countries of the world and this presents a peculiar problem with assessments of water quality. Indicators of water quality used in the more developed areas of the world might not be appropriate for use in tropical water systems. (Toranzos 1991). Proposals have been made for alternate indicators that would provide more reliable means of assessing the quality of cistern water supplies. (Ruskin, 1996).

Proper sizing of cisterns is also a concern. There is no documented rationale for the basic sizing requirements for cisterns in the USVI. There has been some concern expressed as to whether the sizing requirements provide for too much storage. While a large storage system might be pleasant to boast about, the security it might seem to provide could be false. If the system is oversized it might never become filled and/or it might never be emptied. In both instances there is excessive wasted capacity and investment of resources that might have been better used elsewhere. Particularly when the systems are being used to supplement other sources of water as part of a conjunctive use scheme, sizing considerations must reflect this. (Smith, 1985). Recent provisions in Virgin Islands' law consider this by relaxing cistern storage requirements in areas

served by the public water distribution system. Title 29, Chapter 5, Section 308, Subsection (b)(1) of the Virgin Islands Code now provides that for dwellings having an access to the potable water system “no cistern is required.”

Conclusions

Rainwater harvesting will continue to be a principal source of potable water in many areas of the world. While the design and operation of these systems might vary with location, there are certain factors that must be considered in developing guidelines for use of these systems. Evolving use of cisterns require new research considerations. Attention must be given to the types of materials used in their construction for the health of their users can depend on this. Similarly ambient air quality will effect the quality of water yielded from the cistern systems. Lastly, sizing requirements must not only consider the quantity and seasonal availability of rainfall but also the availability of supplemental sources of water.

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Rainwater Harvesting in the Loess Plateau of Gansu, China and Its Significance

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Abstract

China has been facing serious water shortage problems that caused great economic and environmental losses. The water condition is even much worse in the loess plateau of Gansu, located in northwest and north China, where runoff and groundwater is very scarce. Agriculture in this region relies mainly on rain and most of the people have suffered from thirst for centuries. This is one of China's poorest areas. To promote social and economic development and to improve peoples' lives, it is necessary to change the water condition. The only potential water source in this area is rain. Since 1988, efficient rainwater catchment techniques have been tested and from 1995 to 1996, the local government implemented a "121" rainwater catchment project, solving 1.2 million peoples water problems. Follow-up rainwater catchment irrigation projects have been carried out to change the basic agriculture condition of the area. Gansu's experiences show that rainwater catchment and utilization (RWC) can provide an effective means to alleviate poverty and allow a breakthrough for dryland farming.

Introduction

China is one of the world's largest countries and has enormous water resources. Ranking 6th in the world, the total precipitation on the continental is 6190 km³, which produces 2710 km³ of river runoff and 130 km³ of groundwater. However, owing to the large population, the water resources per capita are only 2300 m³, 1/4 of that in the world. The water resources available for cultivating land in China are 2100 mm, compared to 3500 mm worldwide. Moreover, the water resources are unfavorable distributed both spatially and temporally. Water resources per capita can be more than 20000 m³ in the southwest China but only 200 m³ to 300 m³ in the north. On the temporal aspect, China is known for its monsoon climate. The distribution of river runoff is very uneven within a year or between years. Sixty to seventy percent of runoff is concentrated in the flood period from July to September. This kind of distribution pattern causes seasonal water shortage even in the semi-humid and humid area. It is predicted that along with the rapid growth of social and economic development and the increasingly demand on improving peoples' lives, water scarcity will be much more critical in the 21st century.

The situation is even more serious in the loess plateau of Gansu province in the northwest China (Zhu and Wu (B), 1995, Zheng et al, 1995). Water is the key factor

for development in China's all over China, but in Gansu province the situation is very critical. This is one of the driest and poorest regions in China, with an area of about 100 000 km². The annual precipitation reaches 420 mm, however, owing to the deep loess soil layer, which is characterized by high vertical infiltration rate, and the very low humidity, most of the rain is absorbed by the soil and then evaporates in the air. The runoff coefficient is only 0.05. Due to the geological condition, groundwater is also very scarce. Water resources per capita in the area are only 230 m³, 1/5 of that in the province and 1/10 of that in the state. The topographic condition is very unfavorable for water diversion from rivers to land. Crisscross distributed ravines and gullies and the high altitude of land make the water conveyance system and irrigation network almost impossible to build. The agriculture in this region mainly relies on rain. The unfavorable distribution of precipitation during the year causes frequent draughts and a very low crop yield. According to the annals and records, 634 draughts occurred in the past 1400 years, on the average, one every two years. In the last 41 years there were 36 draughts. The crop yield averaged 1000kg/ha. In a dry year, the yield does not compensate for the purchase of seeds. People were not able to plant cash crops due to the lack of water. Life in the area was very poor. Annual income for a 5-member family is as low as US \$ 250-300. Moreover, most of the people in the region have never gotten enough drinking water. In most years, the local government has to dispatch trucks to transport water from far away to supply drinking water. Water shortage became the root of poverty and threatened the existence of human beings.

To help local people to get rid of poverty and to promote the socio-economic development, the key measure is to change the water condition. As pointed out before, the only potential water source in this area is rain. However, utilization of rainwater faces unfavorable condition. There is little rain in this semiarid area and it cannot produce runoff on the natural soil with very high vertical infiltration capability. Moreover, most of the rain cannot be used owing to the uneven temporal distribution pattern. It is estimated that 5%-8% of precipitation forms the runoff, 15-20% of rain is absorbed by the crops, the remaining 75-80% returns to the air without use. The low extent in use of rain forms a sharp contrast with the serious water shortage in the region. The local people have a tradition to use rainwater, as their drinking source, which can be traced to thousand years ago, but the water harvesting efficiency is so low that even the drinking demand cannot be met. To raise the rainwater utilization efficiency and to meet the demand of poverty alleviation and social-economic development, the Gansu Research Institute for Water Conservancy (GRIWAC) has carried out systematic experiments on RWHU in this area and set up many pilot projects to show the profit (Zhu and Wu (A), 1995). Based on these experiment and demonstration work, a so called "121" rainwater catchment project (the government supported each family to build **one** piece of water collection field, **two** storage and **one** land to plant cash crop) had been initiated by the local government in 1995. The project has successfully solved the drinking problem for 1.3 million people (260,000 families) and their 1.18 million livestock. Since 1997, a rainwater catchment and

irrigation project has followed up, aiming to supply water for supplemental irrigation with a high efficient water saving method. The results were also proved to be successful. RWHU has become a strategic measure for the social and economic development in this semi-arid region.

Technical aspects of the projects

The RWHU project is mainly composed of 4 parts, namely, rainwater collection fields, storage, water supply and irrigation system and agriculture facilities (Zhu and Li, 1998).

1. In the traditional rainwater catchment techniques, the rainwater collection field is mostly the natural soil, threshing yard and road, which has low efficiency in collecting rainwater. The new system adopts seepage control measures for the rainwater collection field. In the drinking project, the previous mud-straw roof was replaced by cement tile and used for water collection. When the roof area or the rainfall is not sufficient to produce enough water, the courtyard is lined with concrete slabs. According to testing, rainwater collection coefficient (RCE) of these two kind of material can reach 0.75 to 0.8. In general, 100 m² of roof and concrete yard is enough to collect water for a 5-member family in the area with annual rainfall of 400 mm. For the irrigation project, the nearby villages use the paved highway. For those who do not have a highway passing by, compacted loess soil, threshing yards or village roads are used but with low RCE ranging from 0.15 to 0.3. In some villages, the farmers divide the field into 4 parts. Each year one part is covered with plastic film to collect water for irrigating the other 3 parts. Then in the following years, the other 3 pieces of land are used subsequently for water collection. Polyethylene film with thickness of 0.01 mm is used in one year of service life. The RCE can be over 0.9. Concrete slab is sometimes used for the cash crop fields when the output can pay for the investment.
2. In most cases, a water cellar, an underground bottle-shaped tank is adopted for storage. Many water collection fields are on the ground. Besides, water kept underground will have low temperature thus maintaining good quality. In the drinking project, storage is built inside the courtyard. The loess soil can sustain itself in a vertical section as high as 5 m in dry condition. So, the wall of water cellar is just pasted with cement mortar with a thickness of 3 to 4 cm, good enough for protecting the soil from erosion and controlling seepage loss. The top and bottom of the cellar are built with plain concrete in an arch shape to support the overburden and water weight. When the soil is sandy, a plain concrete wall of 30 cm thick is needed instead of cement mortar. Storage capacity for drinking water supply ranges between 15 and 20 m³, while for irrigation purposes, 30 m³ storage is necessary for two applications in 1 mu (Chinese land unit, equal to 1/15 ha.) of land.
3. A hand pump, affordable for most farmers, is used for water supply for irrigation purpose. For irrigation, various methods are used according to the available fund but

under a unique principle: highly efficient in water saving. At the moment, most farmers use manual hole irrigation. This is labor costly but very effective and cheap. In some region, the seeding machine equipped with tank supplies water through a pipe together with the seeds feeding into the soil during sowing. The water applied is only 6-8 mm but it can ensure the emergence and growth for more than 1 month. Other methods include irrigation under plastic film, pipe irrigation and water injection into the root zone by using a fertilizer injector. In case the fund is available, drip and seepage irrigation is used. To save cost, the movable and semi-movable system is adopted. In the latter case, the main pipe is fixed while the lateral pipe with emitters can be moved to irrigate crop line by line. To use the limited rainwater efficiently, the principle of supplemental irrigation is adopted. Water is applied 2 to 3 times at the critical growth period. In the area with annual precipitation of 400 mm, 45-75 mm is enough for one harvest to get a satisfactory yield.

4. To ensure an effective use of water and a high output, several agriculture measures are taken. The field is covered with plastic film to avoid evaporation loss. Sometimes, to increase the soil moisture around the plant, the crop is planted in the ditches between ridges, which is covered with plastic film. Then rainfall concentrated in the ditches will supply more water to the plant. Green houses for vegetable cultivation are now a common practice to make the highest benefit of the rainwater. The plastic roof of green house can also collect rainwater for the vegetables inside. According to some testing, RCE during flood season amounted to 0.8-0.9. Water collected from the top can basically meet the water demand in the area with annual precipitation of 400 mm.

Project benefit

1. The "121" project has preliminarily solved the drinking water problem for 1.2 million people (Gansu Bureau of Water resources, 1995). In a normal year, each day one person can get 10 liter and the large animal can get 30 l/day. For the human beings, this is a low quota. But, taking the local condition into consideration, it is realistic and is happily accepted by the local people. It can be expected that with economic development, people will be able to enlarge rainwater catchment systems through their own forces thus improving water supply. The RWHU system has proved to be reliable. In the year of 1995, the draught was particularly severe. Families who had built a RWHU system had enough water for their own use and were even able to help those who didn't have the system. The water quality is also generally accepted. According to tests, rainwater is a clean source even after it has been stored in an underground tank over half year. The only two problems are a little turbidity and the colon bacillus. The local people are advised to boil the water before drinking. Furthermore, before the RWHU project was built, the inhabitants had to fetch water from far away. Investigation showed that each family spent an average of 70 working days to carry water. Since women and children were the ones fetching water, they were happy about the changes.

2. While the RWHU drinking project satisfied the basic needs of the local people, the

irrigation project opens up ways for economic developments and general life improvements. The supplemental irrigation water, although in small amount, has a miraculous result on the crop yield. According to an experiment, 2 application of 10 m³/mu (15 mm) each can increase the yield of wheat in plastic film covered field by 100 kg/mu (1500 kg/ha.). The water use efficiency (WUE) reached 1.1-1.4 kg/m³ (including natural rainfall), irrigation water productivity (IWP, yield increase per irrigated water) amounted to 4-6 kg/m³. For corn, because there is enough rain in the late growth period, the results are more significant. The same application can increase the yield by 200 kg/mu (3000 kg/ha.). WUE and IWP reached 3.5 kg/m³ and 10 kg/m³, respectively. The even larger benefits brought by the RWHU project are the possibility to grow cash crops to increase farmers' income. In this area, owing to the dry and cold weather (the altitude in most areas is over 2000 m), the fine vegetables cannot grow. As soon as the farmers got water from rain, they try every way to make full use of the valuable resources. Green houses to grow vegetables and raise pigs have become increasingly popular. In a 300 m² green house, income from vegetable sale amounted to about US \$ 1,000. Thus the investment is returned within one and half year. The production value per irrigated water reached US \$ 6/m³. If each family owns a green house, their income can be doubled. So the RWHU project is an effective way to eradicate poverty.

3. The RWHU project is also beneficial to the environment. The soil erosion intensity is very high in this region. The annual eroded soil for each square kilometer of land amounts from 5,000 to 10,000 tons. Up to now, it is estimated that more than 80 km² of rainwater collection field has been built, which can reduce the soil erosion by 500,000 tons of sediment every year. More important though when crops and trees are grown, there will be more ecological diversity in this semiarid mountainous area. Tiled roofing of houses and concrete lining of courtyards and the cultivation around the houses enable the farmers to enjoy their residential environment. The RWHU projects have been changing the face of this impoverished countryside.

Main experiences

1. The project has followed the participatory principle from beginning to the end. Farmers have contributed a lot to this project. They provided labor, local material and its transportation. The government subsidized a small part, mainly for cement. According to some rough calculation (Wu et al, 1995), for the drinking project of a 5-member family, the total cost is about 1023 Rmb yuan (US \$ 124). The subsidies from government were 400 yuans (US \$ 48) and the farmers contributed the remaining 61%. For the irrigation project, the farmers shared more than 80 % of the total input. This kind of input mechanism has the advantage of not only reducing the government fund, but also makes the farmers the project masters. This will be beneficial for the maintenance and the sustainable operation of the project. The farmers made these contributions, of their own will. In the very beginning of the project, farmers were not so confident in the project profit. The pilot projects were firstly built in some "scientific" farmers' home with their share of input. Only after

one-year demonstration, the nearby farmers saw the benefit. They rushed to apply for the subsidy. They even borrowed money from the bank to build their RWHU system when the government fund was not available.

2. The project implementation took the procedure of experiment, demonstration and training and then extension. It took 4 years for GRIWAC to finish the feasibility study of the project and to establish pilot projects (Zhu and Wu (A), 1995). Thirty-three testing plots were set up to test the RCE of different materials for water collection field under various rainfall conditions. Data of more than 50 rainfall gauges were collected and yearly RCE for different rainfall and field situation was worked out with simulation models. Economic evaluation was conducted to verify the benefit. The North Hill Region in Yuzhong, a county close to capital of the province, was taken as a demonstration base. At the same time, training for the agro-technicians were conducted. More than 200 courses were held and technical guidelines were issued, which later became a provincial specification (GBWR and GBTS, 1997). Only when the above jobs achieved good results, the decision to extend this technique was made. After another 3 years of demonstration and small scaled extension, the "121" project was in place. This procedure ensured a scientific decision-making.

3. Although farmers undertook 60-80% of the total input, the remaining part still amounted to much. To achieve the goal of the "121" project — solving 1.2 million people's drinking problem, one hundred million yuans (US \$ 12 million) of subsidies were needed. The government could only raise 70 million yuans. The government and media mobilized a donation movement for the project. A total of 53.28 million yuans (US \$ 6.4 million) was collected from all over, ensuring the smooth execution of the project.

Conclusions —significance of RWHU

1. At the household level rainwater catchment systems can provide an effective means to alleviate poverty of which water shortage is often the root cause. Particularly in many arid hilly areas, people have little access to water from river or groundwater sources and frequent droughts cause low and unstable crop yields. People in these regions have suffered from chronic water shortage for centuries. RWHS enable people to get a clean, reliable and cheap water source using simple techniques at a household level for domestic use and irrigation, resulting in raised agricultural production and an overall improvement in people's lives (Zhu and Wu (B), 1995).

2. RWU can also provide a breakthrough for dryland farming (Zhu and Liu, 1998). For a long time, people tried many methods to increase rainwater use efficiency to raise crop yield within the scope of rain-fed agriculture. However, the effects were limited, especially during recurrent droughts such as those typical of the mid-1990s when crop yields dropped seriously in most dryland areas. In the past, the principles of dryland farming have been to adopt cultivation methods or create a microenvironment (meteorological, soil, etc.) that enables the crop to adapt to the rain condition to a maximum extent. The approach used with rainwater catchment system is a thoroughly new idea, and that involves the control and regulation of precipitation to meet the crop

demand. Results with rainwater catchment projects for providing supplementary irrigation in dryland areas have been extremely promising and it is expected that RWHU will play an increasingly important role in enhancing food production in areas of rain-fed agriculture in the future, particularly in mountainous regions. The facts also show the great potential of a combination of RWHU and agricultural water conservation in the development of rural areas.

3. RWCS are also becoming a new trend for water resources engineering (Zhu and Liu, 1998). In the past in China and in many other countries, attention was paid mainly to the surface and subsurface water exploitation and less to precipitation itself. Most modern water resources projects have been characterized by their large scale, concentrated development of water resources, complicated water diversion and distribution systems, high input, long construction cycles to bring profit. However, in the vast, remote and mountainous areas, the local people can hardly benefit from these huge projects owing to the long distance, unfavorable topographical conditions and the high costs for water supply. For these areas, the best solutions are decentralized and simple ones that involve the use of appropriate technology. Rainwater is available in all areas, where as rivers and groundwaters are not generally available. RWHU has the advantages of requiring no water conveyance, low input for its exploitation, and simple construction and management techniques. This makes it ideal for the scattered, impoverished inhabitants in the mountainous areas of developing countries such as those in northwest China. Moreover, such developments help to reduce dependence on large water resources projects and groundwater exploitation with their numerous ecological and environmental problems threatening the sustainable development of whole regions. Owing to their decentralized nature and small scale RWU technologies are environmentally friendly.

4. The new RWHU techniques being adopted represent a major innovation in the concept of water resources development in China and even the world. Precipitation is the origin of all water resources, however, in China and elsewhere, the term water resources is often equated with river runoff and groundwater. As shown above, runoff coefficient in the loess plateau of Gansu province is only 0.05. It is unreasonable not to regard the other 95% as water resources when the water shortage is so serious that even the existence of human beings was threatened. Although the intensity of precipitation is low as compared with river runoff, it can be intensified by artificial concentration measures to meet the purpose of water supply (Zhu and Li, 1998). Rainwater can be concentrated enough spatially and temporally to become a necessary supplement to the surface and subsurface water. Such is the process of turning rainfall into a usable resource (Mou, 1996). Research and development into these practices could create many new ideas and methodology of water resources evaluation and utilization and could even result in the evolution of a new and independent branch of water science (Liu and Mou, 1998).

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Ancient And Contemporary Water Catchment Systems In Mexico

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Abstract

Mexico is rich in ancient and traditional technologies (dating back to the Aztecs and Mayas) on natural resources management; however, a growing demand for water and increasing costs of water supply for domestic use and agriculture production are resulting in a need for Mexicans to maximize the use of diverse water supplies.

In the near future it will be necessary to reinforce programs and projects to face the increasing demand for water and to avoid serious social problems.

Mexico, a country with 200 million hectares, an average annual rainfall of 700 mm and a population of 100 million people, has 1 400 000 million m³ water from rainfall. This gives an annual average of 14 000 m³/person, enough for domestic use and agriculture production.

Currently different water catchment systems are used in Mexico: 1) for domestic use (water collection from roofs and paved land surfaces) and 2) for agriculture production (microcatchments, contour ridges, trapezoidal bunds, permeable rock dams, water spreading bunds, contour stone bunds and others).

1. Introduction

Optimum rainwater catchment systems in arid, semiarid and sub-humid ecosystems are essential for rural development and food production. Mexico is rich in traditional and indigenous technologies developed by Aztec and Maya civilizations.

Agriculture has long been recognized as an unstable sector of the national economy. In today's world every country should be self-sufficient in food production, otherwise poverty, misery and migration will have a drastic affect on rural developments.

Evidence shows that rainfall has been collected since memorial times for agriculture, livestock, and human purposes. Technologies on rainwater catchment systems have been developed empirically rather than scientifically.

Mexico currently farms 22 million ha of its land, 70% under rain-fed conditions. This is a potential dangerous situation since, giving the projected population of 105 million by the year 2000 and an upper limit of farmable land of about 24 million ha, the country will have an average of only 0.23 ha per capita at its disposal. If adequate measures are not taken, misery, migration and famine will surely result.

Rainwater catchment systems merit consideration as a component of a large-scale water resource development; it is a need to establish national and municipal programs for the diffusion of alternative technologies. Mexico has already dynamic growing demands for water, mainly for basic crops and forage production.

2. Desertification in Mexico

Mexico's vast arid zones are prone to desertification caused by soil erosion, which makes the land more vulnerable to the ravages of the wind and sun. Intensive agriculture leaves the soil less fertile. Poverty and inadequate education make introducing effective land management systems difficult (Anaya, 1997).

Arid and semiarid areas make up 70% of Mexico's land mass, which is three times the size of Texas. The 20 million Mexican farmers who live in these parched regions harbor little hope to persevere on the land that their ancestor have tilled for centuries. As result, each year, about 900,000 of these long-time rural inhabitants migrate to Mexico's urban centers or cross the border into the United States, seeking a better life.

3. Drought in Mexico

Droughts are unavoidable, provoke natural disasters, reduce yields of agricultural crops, and affect human cultural patterns. Unfortunately, studies of climatic change do not provide an adequate understanding of cycles of recurring droughts.

In Mexico during the period from 1521 to 1910, 127 droughts took place. The most severe started in 1901 and lasted 3 years, affecting the central part of the country. In 1923, 1925, and 1927, other severe droughts occurred. In 1982, due to a severe dry condition, Mexico had to import 7 million kg basic grains. In 1998, hundreds of thousands animals died due to a severe scarcity of forage, seriously affecting the nutrition levels of rural communities. Drought and irregular rainfall patterns produced severe damages in agriculture production.

4. Water Catchment Systems in Mexico

4.1. Ancient water catchment systems in Mexico The key feature of ancient water catchment, namely, its close association with the key staples of pre-Columbian diet: corn, beans, squash and a drink (*pulque*) made from agave (*maguey*).

The dense populations and cities of central Mexico were probably the result of favorable rainfall conditions permitting a wider range of moisture management strategies to come into play, including irrigation and intensive lakeshore cultivation.

Contour terracing, a common rainwater catchment system technique, has been documented at archaeological sites. Check dams have been discovered at numerous sites throughout the central highlands of Mexico.

Many water catchment systems have survived the Spanish Conquest, the introduction of new crop varieties and livestock, the agrarian reform, the green revolution and are still widely practiced by Mexican farmers on lands that other groups consider too marginal for their needs, mainly in the central part of Mexico.

The labor requirements for most water catchment techniques were modest, mostly within the capabilities of individual households or small communities. Unlike other technologies, water catchment did not require a large-scale centralized power structure for its construction, operation and maintenance. Moreover, many water catchment structures were constructed incrementally,

frequently built over several decades or generations. However, an evaluation of the adequacy of water catchment must recognize its vulnerability to seasonal fluctuations in rainfall.

In the central highlands of Mexico the rich ecological mosaic provided opportunities for a complex integration of moisture management alternatives. These included permanent rain-fed farming, small and large-scale irrigation, drained field agriculture, river bottom farming, intensive lake cultivation (*chinampas*) along with a full range of water catchment technologies. Two types of rainwater catchment –contour terracing and bordered gardens- were the most important for ancient agriculture.

Simple rainwater catchment techniques such as contour terracing were widely practiced and possibly provided the main stay of agricultural life for many people throughout sub-humid areas.

Contour terraces (also termed linear borders, terraces, semi-terraces slopping terraces, *trincheras* and *metlepantli*) were constructed by placing long rows of stones spaced at intervals along the contours of a slope. Run off captured behind these barriers also allowed for the retention of soil, thereby serving as an erosion control measure on gentle slopes. In contemporary examples of contour terracing these modest structures are frequently reinforced by earth embankments or economically useful plants such as the agave (*maguey*) and opuntia (*nopal*). In Mexico, ancient contour terraces have been surveyed in the Rio Gavilan (Chihuahua), the Tehuacan Valley (Puebla), and the Nochixtlan Valley, (Oaxaca). Average annual precipitation measures between 450 and 500 mm falling in short, intense summer rains or hail storms. Three types of water catchment were in use after 1,000 AD: contour terraces, check dams, and bordered gardens.

The most extensively practiced form of water catchment in pre-Columbian and Colonial Mexico was contour terracing on gentle slopes in which slope runoff was trapped behind low stone structures, earth embankments, or hedges of agave '*maguey*' plants placed in long rows at even intervals perpendicular to slope gradient. The series of parallel elongated fields forms in this fashion are known as *metlepantli* or *bordos*.

Metlepantli are thought to have contributed (along with other water management techniques) to the support of the astonishingly high population densities (up to 180 persons per square kilometer) reached in pre-Conquest Mexico. Contour terracing can be highly sensitive fluctuations in the availability of labor for maintenance and can be of serious ecological consequences.

With contour terracing in Mexico, it is possible that this water catchment strategy was a response to the increasing population pressures on the existing farmlands of the highlands.

4.2. Contemporary water catchment systems

4.2.1. Terracing. Terracing is a simple application of rain catchment but on a large-scale. Low walls are built along the contours of the slope from stones and rock fragments. Their uphill sides are filled with soil collected from the slope between terraces (UNEP, 1997).

The water was either stored in the soil of the cultivated area, or sometimes artificial storage facilities were constructed, such as open, lined tanks or closed cisterns. In some cases the storage capacity was increased by very large columns.

A growing number of studies focusing in detail on contemporary terraces include Patrick's work in Tlaxcala (1977); West's work in the Valley of Mexico and Hidalgo (1970); Johnson's work in the

Mezquital Valley (1977); Sanders' and Carlton's (1970), work on the Teotihuacan Valley; and Wilken's (1976), review of traditional forms of slope management.

The main aim of these structures is to interrupt and retain slope runoff and alluvium. Over time, alluvium builds up behind the barriers thereby increasing infiltration and enhancing the soil moisture storage capacity of the fields.

One of the most important aspects of contour terracing in Mexico is that it requires very low investments in capital and relatively low investments in labor. Wilken (1976), observing a government-sponsored contour terrace project in Tlaxcala, Mexico, describes the process in the following manner:

On the gently to moderately sloping agricultural lands, *ejidatarios* cut trapezoidal drainage ditches (*zanjas*), 60 cm deep and 80 cm wide at the top sloping to 40 cm at the bottom. *Zanja* lines are laid out along contours then precisely cut with shoves, spades and picks. Dividing strips 50 to 60 cm wide, but only 30 to 40 cm high, are left every few meters to prevent water flow in the *zanjas*. Excavated material is piled immediately up slope in geometrical *bordos* 40 cm high and 80-90 cm wide at the top, sloping to 130-140 cm at the bottom. Material in the *bordos* is not compacted except by incidental foot traffic and thus has larger volume than the *zanja* from which it came. After *zanja-bordo* construction is complete, young maguey from nurseries are planted along embankments at 3 m intervals.

Workers are paid by the government on the basis of *tareas* or *jornales*, a fair or normal amount of work that can be done in six hours. *Tareas* are based upon working conditions including types or work, terrain, and material. For example, the following are representative *tareas* for excavation and *bordo* construction in Tlaxcala, Mexico:

Material	Tareas for <i>zanja-bordo</i> construction		
	Tarea in linear meters	Approximate cubic meters (cross section = 0.36m)	Labor costs pesos per cubic meter (20 pesos/tarea)*
Soft soil (<i>blando</i>)	20-25	7-9	2.85-2.25
Moderately compacted (<i>duro</i>)	10-15	2 1/5-5 1/2	5.70-3.65
Temperate	5-10	2-3 1/3	10.00-5.70
Rock (<i>rocoso</i>)	1-5	1/2-2	40.00-10.00

* 1 peso= \$ U.S. 0.80

On the basis of these parameters, it can be estimated that the cost in person-days per hectare of contour terracing on moderate slopes (5 to 10 percent) will range from 44 person-days (U.S. \$ 70.40) on soft soils to 100 person-days (U.S. \$ 160.00) on hard *tepetate*. These costs are low indeed when one considers the efficiency of contour terracing in capturing available runoff, enhancing soil mixture for agriculture, and controlling erosion. *Tepetate* is a hardpan that is exposed to soil surface after erosion has taken place.

Contour agriculture lends itself to the use of local labor and is suitable for adoption where the mean annual rainfall is 400 mm or more. In such areas it will definitely help to prevent soil erosion.

In the areas where rainfall exceeds 500 mm (especially if 1,000 + mm) a water-catchment terrace technique has been developed to allow for the conservation of excess water.

4.2.2. Silt traps (*Trincheras*). Two important types of storm water catchment technologies are now described: a) silt traps designed to trap both alluvium and runoff; b) check dams designed to impound water for subsequent agricultural or domestic use.

Silt traps (*trincheras*) are built of stone across the bed or intermittent streams, often in narrow valleys or gullies. As the alluvium deposits build up, level fields are created behind the check dam walls. As the dam continues to collect alluvium, runoff is stored in the field in the form of soil moisture. An important principle operates in this technique: by capturing runoff from a broad catchment area and concentrating in a reduced area, silt traps transform scarce quantities of rainfall (which otherwise would be lost to the production system) into utilizable soil moisture.

Trinchera walls were built so that they were buttressed against the valley walls and bedrock, thereby providing maximum strength. Larger, more complex silt traps are now in common use in Mexico. These areas are called *atajadizo* and, like smaller *trincheras*, they can be constructed out of rock. However, sometimes other materials such as earth, gravel or logs are used. The runoff and alluvium behind silt trap walls create, flood-irrigated agricultural fields.

On the basis of extensive interviews with Otomi farmers in Hidalgo, Mexico, Johnson (1977), was able to document the principles involved in successful silt trap (*atajadizo*) construction.

Well constructed *atajadizos* incorporate one or more of the following features:

- 1) double or triple stone walls separated by gravel rubble;
- 2) walls that extend beneath the surface of stream bed;
- 3) an outer wall that is pitched up-slope;
- 4) a floodgate to release excess water; and
- 5) curved walls allowing storm water to be distributed eventually throughout the field.

One important principle of silt trap construction in Hidalgo, Mexico, concerns the relative heights of the dam wall and the field behind it. Otomi farmers always advise that *atajadizo* should be kept 0.25 to 0.50 m higher than the field in order to impound storm runoff successfully and to allow it to infiltrate the soil.

Johnson (1977), documented structures in one Mexican community ranging from 0.15 to 7 m in height; 1.5 to 19 m in length; and 0.1 to 2.5 m thick. The size of silt trap fields varies from less than two square meters to approximately four hectares. The shape of individual fields depends on gully configuration. Like contour terraces, silt traps require investment in human labor rather than capital.

4.2.3. Check dams. Many contemporary check dams probably have been in continuous use since ancient times. In most fundamental ways, the structure and function of modern check dams are the same as their ancient counterparts. Thousands of modern check dam reservoirs serve as catchment seasonal runoff to meet (partially or entirely) the domestic and agricultural needs of peasant communities throughout sub humid Mexico.

Frequently, the labor required to construct and maintain these reservoirs is organized under traditional labor-sharing arrangements, thus building up the ancient collectivist heritage of Mexico's rural communities.

These massive structures were built to provide the water supply for haciendas, and thus are different in many ways from the smaller scale community check dams. Hacienda reservoirs owe much to design principles of European origin. Their masonry walls are extremely broad at the base (6 to 7 meters is not uncommon) and are provided with additional supporting buttresses. Lateral spillways are usually provided, and siltation problems are taken care of by sluice gates at the base of the structure.

4.2.4. Water catchment *in situ*. Anaya, et al (1998) developed an equation to calculate the optimum size of microcatchments for agriculture production under rain-fed conditions. The equation is:

$$D = D_R + \frac{(C - P)D_R}{KP} \quad (1)$$

D = micro-basin area (viewed as a unit cross-sectional area) equals the distance between rows, in cm, for crops like corn and soybean; or the width between planting areas (strips), in m, for field crops like barley, grasses, and wheat; or the surface area of tree wells, in m², for such trees as fruit trees;

D_R = root area (viewed as a unit cross-sectional area) corresponds to the diameter in cm of the planting zone for row crops; or the width in m between strips for fields crops; or to the land area in m² that tree roots occupy.

Maximum vegetative development for the plants should be considered;

K = soil runoff coefficient;

C = consumptive use (in mm); and

P = precipitation based on a 50% probability during the vegetative cycle (in mm).

Another advantage of water catchment systems *in situ* is related with diminishing effects of drought through periods of 5 to 10 years, which is helpful to ensure basic crops, vegetables, forage and fruits production.

The most popular systems of water catchment in Mexico are the following:

- Micro-catchments, (micro watersheds),
- Semi-circular bunds,
- Contour bunds for trees,
- Contour ridges for crops,
- Trapezoidal bunds,
- Contour stone bunds,
- Permeable rock dams, and
- Water spreading bunds.

5. Basic principles on water catchment systems

The selection and application of technologies on water catchment systems will depend upon the education and motivation of the people, availability of well-trained staff, government policies, the size of areas to be considered and the level of investment. Each situation must be considered individually and appropriate adjustments made in general rain-fed agriculture systems (FAO, 1991). Water catchment systems reduce drought effects, improve crop production and induce social benefits.

Water catchment systems can be used under rain-fed conditions (agriculture, rangeland, and forestry). Depending on rainfall patterns, an optimum use of this natural resource must be achieved; otherwise, uncontrolled run-off may cause erosion, desertification, misery and migration.

Four steps may be taken to improve the productivity of rain-fed lands: a) control erosion, b) optimize rainfall by water catchment techniques, c) improve soil fertility and, d) select the appropriate plant species adapted to local conditions.

6. Conclusion

Water catchment systems are essential to solve crucial social problems mainly in rural areas with scarcity of water, lack of basic crops and forage, thus provoking poverty, misery and migration. It is urgent to prepare a comprehensive inventory of technologies available in Mexico for augmenting and maximizing the use of water catchment systems in order to assist water resource planners and managers, in both governmental and non-governmental organizations.

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The Prospects of Rainwater Utilization in the Taihang Mountain, China

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Abstract

Based on the experiments carried out in a typical watershed, I will summarize the main rainwater utilization techniques in the area of the Taihang Mountain. I am also discussing the impact of rainwater utilization on the hydrological cycle. In addition, I am analyzing the potential and prospect of rainwater utilization in the Taihang Mountain.

1. Background Information

1.1 Location

The experimental area is located at 114°15'50"E and 37°52'44"N in the Taihang Mountain in North China.

1.2 Topography

Located at the juncture of the North China Plain and Loess Plateau, the experimental area has various geomorphic types, containing river valley, terrace, slope land and bare rock, etc. The altitude ranges from 247 to 1014 m above sea level.

1.3 Climate

The climate in the area can be classified in two types, namely the semiarid and semi-humid continental monsoon climate. It is characterized by little snow in the winter and much rain in summer. The annual temperature is 13°C and the accumulated daily temperature above 10°C is 4384.8°C·day and the frost-free period is 150 to 210 days. The total solar radiation varies from 116 to 136 kJ/cm² and the annual sunshine hour amounts to 1600 to 2800 hrs. The annual precipitation ranges from 400 to 600 mm, 67.8% of which falls in the period from June to September. The yearly potential evaporation reaches 1934 mm.

1.4 Hydrogeology

The geological stratum is mainly composed of granite-gneiss of Archaen group and Proterozoic era with limestone of Cambrian period and Ordovician period and sand-shale of Permian and Carboniferous period discordantly covering on it. The thickness of the layer is 0.5 to 20 m for sand-shale and 5 to 40 m for limestone. There is a regolith with thickness of 0.5 to 10m on top of the granite-gneiss. The aquifer is mainly in the crevice of the igneous rock and metamorphic rock and in the tectono-clastic zone between the granite-gneiss and limestone stratum with abundant groundwater. The specific capacity can reach 10 m³/m·s. However, little water exits in the weathering belt

of granite-gneiss rock.

1.5 Soil

In the hilly region, the soil type is mainly drab soil. Because the granite-gneiss rock is very rich in nutrient element and easy to be weathered, even the topsoil has been eroded, the underlying thick partly weathered rock can still act as usable soil. The soil structure is very stony, and easy to be eroded. Soil thickness ranges from 20 to 50 cm and averages 34.1 cm. The water holding capability of the soil is low while its conductivity is high.

1.6 Vegetation

The major vegetation types are xerophyte and semi-xerophyte shrubs, artificially planted trees, shrubs and grasses. In the sunny slope of the mountain, the dominant populations are *Ziziphus Jujuba* var., *Spinosa Hu* and *Vitex L .negundo* var. and *heterophylla Rehd.* The cover ratio of the plant averages 20% and the height of the population ranges between 0.3 and 0.6 m. In the shaded slope of the mountain, the dominant population is *Leptodermis Wall oblonga Bunge* with a height of 0.3 to 0.6m and 20% of cover ratio. The species of artificial plants are mainly composed of economical ones such as *Juglans regia L*, *Diospyros kaki L.*, *Ziziphus jujiba Mill* and *Prunus armeniaca L.* They are scattered over the valley and riverbed. Low plant and small cover ratio are the main features of the vegetation in this area.

To sum it all up, the area where the experiment took place lies in the semi-arid and semi-humid area in North China. Due to the typical continental monsoon climate and the serious soil erosion, water shortage has become the main constrains for the development of agricultural production and improvement of peoples' living condition. It is estimated that the rain-fed agriculture land amounts to 0.44 million ha, 79.8% of the total cultivated, and has low yield owing to frequent droughts. Besides, there are 1.05 million people and 4.00 million animals lacking drinking water supplies. Rainwater is the only potential water source in the area. Development of the rainwater resources plays a very important role in the agriculture production.

2.Rainwater utilization techniques

Rainwater harvesting is a traditional technology in the area of Taihang Mountain. Along with the increasing water requirement due to rapid population growth and social and economic development and the increasingly serious environmental pollution, rainwater utilization techniques have been further updated and developed. Measures in the treatment of catchment field and control of rainwater have been adopted to develop runoff agriculture and runoff reforestation. Based on the experimental results in a typical watershed, the fish scale pit, contour ditch, terrace in the gully, rainwater concentration and slope treatment by hardening, chemical agent spraying, field covering with plastic film as well as mulching, micro sprinkler, drip and seepage irrigation were developed. The rainwater utilization techniques are summarized in the following section.

2.1 Types of rainwater harvesting system according to the rainwater collection field

2.1.1 Rainwater harvesting using roof and courtyard

In this system, the roof and courtyard are used to collect rainwater for domestic use. The roof area of a normal household is about 150 m^2 . The average runoff coefficient is about 0.75. In a normal year, it can collect 80 m^3 rainwater to meet the water demand of 4-6 people and 1~2 big animals. The rainwater harvesting system is composed of 4 parts, namely, the roof, collecting ditch, water deliver pipe and cistern. Cistern is underground water storage. The local people also call it "dry well". It consists of bottom, wall and top cover. It has the size of 1.5 to 3.0m in diameter and 4 ~6 m in depth. Usually, the cistern is made of concrete with a thickness of 0.2-0.3 m to prevent leakage. There is a hole on the upper part of the wall for water intake and an outlet at the bottom.

2.1.2 Rainwater harvesting using natural slope

The natural slope is used to collect rainwater for irrigation of crop and cash plants. The system is composed of natural slope for rainwater catchment, ditches for water collecting and the cistern for storage. Sometimes, the slope is treated by compacting the surface, chemical agent spraying or by covering it with plastic film. The runoff coefficient for treated surface can be increased from 0.3 on the natural slope to 0.48, 0.65 or 0.67, respectively. Slope with treated area of 100 m^2 can collect 27 m^3 , 36 m^3 and 39 m^3 of rainwater to meet the water requirement of 300 m^2 grain field or 400 m^2 cash crops using drip and other water saving technique. The cistern is 3 m in length, 3 m in width and 2 m in depth.

2.1.3 Rainwater harvesting on bare rocks

This type of rainwater harvesting system is mainly distributed in area of calcareous sandstone and slate. Large bare rock is used as rainwater catchment field. Rainwater flows through the rock surface and collector ditches into pools or ponds for irrigation use. The pool is cylinder or cubic in shape with depth of 3m and storage capacity of 10 to 1000 m^3 . The bottom and sides of the structure are lined with cement mortar in hilly area and with soil, cement and lime mixture in the plain. The inlet and outlet are built on the side of the pool.

2.1.4 Rainwater harvesting using road as catchment

The road surface is used to collect rainwater for irrigation of crops and cash plants. It is composed of collecting ditch and storage pool or cistern. Roughly speaking, 100 m^2 of asphalt paved road can collect 40 m^3 of rainwater, while the same area of sand-gravel road can collect 30 m^3 of rainwater.

2.1.5 Harvesting of spring and submerged flow

These projects are mainly in the area of granite and genesis stratum where many springs and subsurface flow are widely distributed. Pipelines divert the scattered springs and the submerged flow is retained by concrete underground dams and then directly used for irrigation or stored in pools for irrigation and drinking purpose. Although there is little spring water, averaging a daily output of only 3 m^3 , it can be stored for irrigation of 0.4-

1.2 ha of farmland.

2.2 The other rainwater harvesting techniques

2.2.1 Weir pit and pond for rainwater harvesting

In these systems, runoff produced by rainfall is stored for irrigation of farmland by weir, pit or pond in a valley or gully with appropriate topographical and geological condition. The weir is built in a gully and composed of dam and water relief outlet with very simple technique. Usually, no complicated seepage control measures are needed. The normal storage capacity is less than 10,000 m³, enough for agriculture, husbandry and drinking purpose.

Pits are usually constructed in the granite-gneiss area where the soil as well as the alluvial and deluvial deposits have a strong penetrating capability and the rich submerged and basic flow are available. Pits in the main gully with round or cubic shape, 3~10m in diameter, 10 m in depth are excavated and lined with cement mortar. They are mainly for storing runoff and submerged flow for irrigation and domestic use.

The pond is for retaining flood flow with a capacity from 10 ~100, 000 m³ for agricultural irrigation water supply. In seasonal rivers with a large flood, both in total amount and peak discharge, the diversion dams and channel systems are constructed to distribute the runoff into many connected cisterns or convey water directly for irrigation.

2.2.2 Rainwater harvesting system in a micro watershed

The water collection field with relatively large area is used to produce water, which is stored in a reservoir or cisterns and then delivered by channels, pipes to supply irrigation and domestic water use. The water collection field is treated according to the economic condition. The respective rainwater harvesting system can also be connected to form a large runoff agriculture system.

2.2.3 Micro runoff reforestation

The micro runoff reforestation, also called on-the-spot irrigation system, includes the terrace with slope in between and terrace with an inverted slope, contour planting, fish scale pit and contour ditch. The water collection field is built for a single tree or a tree group without water storage and conveyance facilities in common. Rainwater is stored in the soil by increasing infiltration and improving soil properties. The economic trees are planted along contour line and their water requirement can basically be met by concentrating rainwater from a slope with 6-10 m in width.

3. Impact of regional rainwater harvesting on the hydrological cycle

The Taihang Mountain, located in the upper reach of the North China Plain is an important water source, which should guarantee the water supply for Beijing, Tianjin, Shijiazhuang and other big cities as well as fulfill the agriculture requirements in the Plain. Implementing water harvesting in the Taihang Mountain has to follow this principle.

3.1 The impact of seepage control of the slope on the hydrological cycle in the river basin

Rainwater utilization for the agriculture and forestry development has produced great social and economic benefits. Experiment on the reforestation on the sunny slope of Taihang Mountain by the Shijiazhuang Agriculture Modernization Institute, CAS showed that the production value for each hectare could reach US \$3600. Large-scale rainwater harvesting, especially the seepage control on a large slope does not reduce the water flow downstream. Artificial rainwater harvesting is indeed to deprive rainwater from evaporation. Evaporation is very intense in North China due to the dry climate. According to the rainwater catchment experiments we conducted in Taihang Mountain, natural slope usually does not produce runoff for the rain with common intensity. Runoff can only be formed in the southern slope when rainfall reaches more than 40 mm and has certain intensity. For example, rainfall of 20 mm can only moisten 4~6 cm of the upper soil layer, while the daily potential evaporation usually can be 6~8 mm even to 10 mm. It takes only 3-4 days to exhaust the moisture. It is apparent that the small and medium rain will be consumed by evaporation if it is not collected. Secondly, the rainwater catchment area accounts for 20% of the total watershed and the anti-seepage treatment only occupies about 10% of the slope area. So the rainwater catchment would not have a significant influence on the river runoff. Furthermore, most treated slopes collect water for the above mentioned runoff reforestation, which will in turn, improve the soil moisture and benefit the groundwater recharge. Thus the river runoff in the lower reach will not decrease.

3. 2 Impact of reforestation on watershed hydrological cycle

Generally speaking, evapo-transpiration of a forest is 22% and 30~40% higher than that in the cultivated field and in barren land. The recent experiment with runoff reforestation showed that although the evapo-transpiration of the tree increases, the soil evaporation decreases. In an experiment area of *Robina pseudoacacia* L. forest with 416 mm of precipitation, the ten-year test showed that evapo-transpiration by trees increased to 60% after slope treatment as compared to 30-40% in tradition case, while soil evaporation and other loss reduced it to 40%. It is also apparent that the increase of tree consumption comes from the inefficient evaporation.

According to the runoff reforestation experiment in Taihang Mountain, the forest density is determined by the following equation:

$$(D-d)/d=(CM+M-m)/m$$

where, D: distance between tree belts (m)
d: width of rainwater catchment area
C: test parameter
m: annual rainfall (mm)
s: runoff coefficient
M: forest water requirement (mm)

Based on the above equation, forest density is determined by water requirement of

vegetation community in a natural distribution. Therefore, evapo-transpiration of vegetation would not have negative influence on downstream water flow.

Rational distance between forest belts is 6~7 m according to the above equation. This means that even a dense planting within the belt can only be a scarce forest, for which evapo-transpiration would be small. Besides, the tree belt with high water consumption is in a small area, only 1/6 of the area between the belts. The soil evaporation on the 5/6 area will be reduced with evapo-transpiration increase in the other 1/6 area. So it can be seen that even though the entire slope is used for reforestation, the total water consumption would not increase. The reduction of water flow in the lower reach is out of the question.

4.Problems and prospect of rainwater harvesting in Taihang Mountains

With the rapid increase of population and economy and progress of technology, more and more people will start rainwater harvesting, which means a further control of the hydrological process by human beings. In the area of Taihang Mountain, rainwater harvesting was mainly concentrated in the area of calcareous sandstone where the water shortage is more serious. However it will be necessary to develop runoff agriculture and runoff forestation suitable for the whole Taihang Mountain area given the dry climate and water scarcity in agriculture production and forestation as well as in drinking water supply. In addition, to enable the low annual rainfall of 500~600 mm in the area with uneven distribution to meet the water need during the whole year further developments of rainwater harvesting systems are required. The problem in popularization of rainwater utilization techniques is the relatively high cost of the construction obstructs the development of rainwater utilization in some regions. It is very critical to have a cost-effective design for the system.

People still pay more attention to the water resources of rivers, lakes and groundwater and less attention to the widely distributed rainwater. In order to meet the increasing water demands of agriculture in the plain region and industrial and domestic use in the big cities such as Beijing, Tianjing and Shijiazhuang, 22 big and middle reservoirs with a total capacity of 7.85 billion m³ and more than 400 small reservoirs and 8000 ponds with a total capacity of 1 billion m³ were built in the area of Taihang Mountain. These reservoirs and dams collected most surface runoff in a normal year and little potential of water resources in the river exists. Moreover, the river project can only supply a certain area and the groundwater is not available everywhere, while the rainwater falls on the whole area. Therefore, rainwater utilization is very important for the development of mountainous regions. It is the only way to deal with water scarcity and has a great potential and wide prospect in the area of Taihang Mountain.

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Experiences gained in the development of rainwater catchment in Tanzania

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Abstract

As is the case in many African countries, rainwater catchment technologies have been used on a rudimentary level in Tanzania for a long time. Until recently, however, they have not made a significant impact in solving rural and urban water supply problems. Currently, various stakeholders are paying more attention to rainwater catchment as a means of supplementing the conventional water supply options such as piped water schemes, deep and shallow wells and springs. The shift in attitude among the decision-makers has been influenced by the realisation of the high potential of rainwater harvesting.

Over the past few years, efforts have been stepped up by the government as well as other organisations in developing rainwater-harvesting systems throughout the country. The whole process started with awareness creation and sensitisation on the importance and potential of rainwater harvesting technologies. Low cost demonstration rainwater harvesting cisterns are being constructed at strategic locations across country and people are being trained in the construction of low cost rainwater storage systems. Experience has shown that the demonstration tanks and other cisterns are playing a key role in sensitising the people, who have responded by constructing rainwater catchment systems with their own resources.

1. Introduction

Experience with rainwater catchment has a long history in Tanzania but most ancient systems have fallen into disuse. Individual communities have long practised rainwater catchment on a small scale as a traditional method to improve the availability of water.

Rainwater harvesting (RWH) has been applied as a source of water supply for a very long time. However it has not been developed to such a level that it can be a significant part of the country's water resources. Water authorities, including international donors involved in water development, have not favoured this technology but have, instead, mostly applied sophisticated technologies to develop both surface and ground water. Lately, however, the application of RWH techniques has been considered one of the ways to solve water supply problems for domestic, livestock, crop production and for industrial purposes. These techniques have regained importance and some organisations are now looking at their potential applications. Most attention has been focused to roof top catchment.

Over the last twenty years or so various external support agencies (ESA) have funded RWH projects in the country. These include CIDA, Sida, UNICEF, UNDP, African Medical Research Foundation (AMREF), Tanganyika Christian Refugee Services (TCRS), Water Aid (a British support agency), DANIDA, FINNIDA, NORAD and International Development Research Centre (IDRC) of Canada.

2. Need for rainwater catchment in Tanzania

Rainwater harvesting is a feasible option for improving the living conditions of millions of Tanzanians currently facing serious water supply problems. It is a very attractive supplement to traditional or improved water sources because it relieves the burden of water collection by bringing it closer to the homes and lowers the pressure on finite groundwater sources (Lee and Visscher, 1992). As much as 63% of the rural population is currently relying on unimproved traditional water points, which include shallow water holes, ponds, lakes, permanent or seasonal rivers, springs and shallow groundwater accessed by hand-dug wells.

Over the years water authorities, including international donors involved in water development, have mostly favoured application of sophisticated machineries in the development of both surface and groundwater. Unfortunately, these conventional techniques of water supply have proved to be too expensive to operate and maintain, in view of the poor economic standing of the country. The cost of developing new water sources through such technologies is often not affordable by the government. Also, there is commonly a shortage of technically trained personnel of various cadres needed to plan, design, construct, operate and maintain water schemes. Further, there are areas where people have to go a long way to fetch water. It is evident therefore that simple, cheap, appropriate and affordable technologies are necessary when developing new water sources, in order to provide people with sustainable water supplies. One of such technologies is rainwater catchment.

A lot of valuable time, particularly in rural areas, is spent on walking long distances to fetch water. If runoff water were collected efficiently, millions of Tanzanian women, who are the ones who collect water, would be saved the burden of trekking to far away water sources. The time saved through walking shorter distances would be devoted to activities designed to improving the living conditions of the rural dwellers. There is often sufficient water available to supply drinking and agricultural needs through the dry season if only rainfall and runoff are captured and stored for later use.

Rainwater harvesting may be a supplement, an alternative supply or the only feasible supply in many parts of Tanzania, especially in the arid and semiarid areas.

3. Strategies undertaken

3.1 Awareness creation

Efforts are being made to sensitise and create awareness among relevant people at national, district and village levels on the importance and potential of the rainwater harvesting technology. To achieve this a number of approaches are being used.

It was conceived that not all decision-makers are well sensitised on the importance of RWH. In order to raise the level of understanding and appreciation of the RWH technology among decision-makers, top government officials have been visiting countries where RWH has been practised for a long time. Other officers in the middle and lower cadres have also been exposed to such practices for a similar purpose. Alongside this strategy, posters, brochures and other audio-visuals carrying educational messages on RWH are being produced and

disseminated to different parts of the country. It is expected that these materials will serve to instil a positive view among various stakeholders towards the RWH technology.

3.2 Training

Training geared at building capacity to construct rainwater catchment cisterns in the districts and villages was considered essential. This activity has been carried out in order to create teams of people capable of constructing low cost tanks for rainwater storage. UNICEF and UNDP have been in the forefront in supporting this initiative.

Training sessions are usually practical-oriented whereby participants, apart from being given a brief theoretical background on rainwater catchment, are shown how to construct low cost rainwater storage tanks of various types and capacities. They then construct the tanks themselves. Figure 1 shows a training session conducted at Lulumba Secondary School in Iramba district, during which a 20,000 litre ferrocement standing tank was constructed. Figure 2 shows another training session for a 52,000 litre sub-surface tank conducted at Nzega town.



Figure 1: Construction of a 20,000 litre ferrocement tank at Lulumba Secondary School, Iramba district



Figure 2: Construction of 52,000 litre sub-surface tank at Nzega town

Trainees are usually drawn from some of the semiarid districts of Tanzania, which stand to benefit most from RWH. Venues where training sessions are conducted as well as participants of the training are normally selected by the district authorities. Participants are mostly drawn from the water, health and community development offices in each of the participating districts. Further, selected village artisans do participate in the training.

3.1 Demonstration rainwater catchment systems

Rooftop catchment systems

Tanks of different sizes have been constructed in different locations, with concentration in the semiarid areas. The tanks are part of the rooftop harvesting systems that are located mostly in public places like schools, hospitals and health centres.

Construction has been carried out by those who underwent training as explained under 3.2 above. Whereas the majority of these systems consist of tanks ranging in size between 1 m^3 and 50 m^3 there are systems of much larger capacity. An example is a roof catchment system built at Mkonze Primary school, in suburban Dodoma town through funding by UNDP in Tanzania. The system involves a 1250 m^2 catchment surface, which collects rainwater into a 675 m^3 underground trapezoidal tank of poultry mesh reinforced cement-coated asphalt lining. The tank is covered by galvanised iron roofing. Seepage is controlled by the asphalt lining and evaporation is controlled by galvanised iron roofing which also collects rainwater into the tank. A hand pump draws the water through a sand filter in a 1000 litre plastic tank where it is biologically purified. Experience has shown that this system is too costly and too labour intensive to be replicated by the rural communities (Kifua, 1997).

The strategic location of the rainwater catchment systems is to ensure that as many people as possible, see them. It is hoped that these demonstration systems will help to popularise the RWH technology in those areas through replication by individuals, communities and

institutions. There has been great interest in the rainwater tanks has been shown during construction and a number of individuals and institutions in the pilot areas have requested the construction of tanks at their own costs. Figure 3 is a demonstration RWH system with a 23,000 litre ferrocement tank at Mburahati dispensary, in Tanzania's capital Dar es Salaam.



Figure 3: Demonstration rooftop catchment system at Mburahati dispensary, Dar es Salaam

3.3.2 Ground catchment systems

Such systems have been constructed in large numbers particularly for stock and crop watering in the dry areas of the country. They include “charco” dams, earth dams and excavated reservoirs.

Some ground catchment systems are utilised for domestic water supply like rock catchments and paved surfaces. An example of the latter is the system constructed at Iyumbu village in Dodoma. It involves a 60m x 30m artificial catchment surface of poultry mesh reinforced cement-coated plastic sheeting. The rainwater is collected into a 760 m³ circular reinforced cement-block underground tank. The tank is covered by a galvanised iron roofing which also collects rainwater into the tank. The water is drawn by a *Nira 6* hand pump through a sand filter in a 1,000 liter plastic tank where it is biologically purified.

The system has proved to be oversized, too labour intensive and too costly to be replicated by the rural communities.

3.3.3 Sand storage dams

Sand storage dams (also called sand dams) are watertight weirs keyed into the floor and banks of sand rivers, with their heights extended to several metres above the level of sandbeds.

In Tanzania sand storage dams, built of stone masonry, concrete blocks or concrete, have been constructed on different locations in sand rivers. Three such dams were constructed, one at Mkonze village on Bwenzeru stream and two at Iyumbu village on Chimwaga and Magwilo. Water is drawn by gravity fed tap on the Chimwaga and by *Nira AF 85* hand pumps through sumps constructed in the riverbanks on the Bwenzeru and Magwilo. Gravel-packed perforated 10cm PVC pipes draw the water by gravity from the sand reservoirs into the cement-block masonry sumps. Being the only improved source of water and having been fitted with mechanised extraction, the water of these schemes is being used for 8-9 months, which is 3-4 months into the dry season.

3.3.4 Sub-surface dams

Sub-surface dams have been constructed in a few locations in river channels in the country. Recently, one sub-surface dam of concrete-block masonry has been constructed at Mkonze village on Mkonze stream. This scheme holds water 10-11 months, which is 6 months into the dry season.

In Mkoyo village, one clay-core and one stone-masonry sub-surface dams have been constructed at Nhundulu on Nkhole stream and Nyamwanji on Nkambala stream respectively.

The Nhundulu scheme supplies water till October while the Nyamwanji one supplies water throughout the year.

4.0 Experiences

4.1 Successes recorded

In Tanzania, rainwater harvesting is now receiving serious attention from the government and ESAs. It is now being recognised as one of the potential sources to help meet the national objective to provide clean and safe water within 400 metres of every home by the year 2002.

Many rooftop catchment systems have commonly been constructed by missionaries and ESAs around the country in churches, schools, hospitals and community centres (Rutashobya, 1992). Ground catchment and rock catchment systems have been constructed in many locations, especially in the southern part of Tanzania.

As already mentioned, in the last couple of years, the national RWH programme has been actively supported by UNICEF and UNDP through which many RWH systems have been built. The results are that many people are now relying on rainwater. Also, more people are increasingly recognising the importance and benefits of the RWH technology and are now building rainwater catchment systems with their own resources.

In order to accelerate the RHW initiatives a 5-year National Rainwater Harvesting Action Plan is currently under preparation. The plan will indicate activities requiring immediate, short-term and long-term action in the promotion and development of RWH in Tanzania (Rutashobya, 1998).

4.2 Problems and Obstacles encountered

A number of problems are usually encountered in the course of implementation of the efforts to spread the RWH technology. Some of these are mentioned below.

In some areas a good number of rural houses are thatch-roofed, making rooftop catchment unsuitable

A large percentage of the population, especially in rural areas, cannot meet the cost of construction of RWH systems

Surface water dams are subjected to high sedimentation and evaporation. Overstocking, which is common in the semiarid areas where these dams are mostly located, promotes soil erosion which aggravates sedimentation of the dams.

There is a problem of scouring downstream of the sand-storage dams. This problem persists even with measures like construction of stone-masonry aprons on the downstream side of the dam walls.

5.0 Conclusions

The rainwater catchment technology has a high potential of success in Tanzania. This is based on the experiences recorded in those areas where it has been applied. The technology is simple, relatively cheap and appropriate to the national socio-economic setting. Since many people have shown eagerness to apply rainwater harvesting the technology must be spread in the country as much as possible. It is therefore important that RWH forms part of the national strategic objectives for solving the current water supply problems of the country.

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Affordable Roofwater Harvesting in the Humid Tropics

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Abstract

The relatively high cost per household of installing full domestic roofwater harvesting (DRWH) has resulted in its take-up being largely limited to areas of especially high water stress or where DRWH is subsidised. The paper discusses various ways of attaining satisfactory benefit:cost ratios in areas where DRWH is not the only water supply option, for example by adopting partial or seasonal supply and by minimising ‘first cost’ (generally construction cost) at the expense of raising subsequent costs. As water storage accounts for the bulk of expenditure on most systems, the paper then focuses on means of minimising the construction cost of storage tanks in the size range 1000 to 10000 litres. Best cost-cutting practices with respect to both surface and underground tanks are reviewed. An approach of separating the ‘structural’ and the ‘water-proofing’ roles of construction materials is proposed and applications of this approach to both sorts of tank are examined. The paper will particularly reflect experiences in South Asia and East Africa which are the geographical focus of an ongoing 4-country DRWH research programme funded by the European Union.

1 Introduction

All participants at this conference will be familiar with the general properties of harvested roofwater - its generally high but not excellent quality, its seasonality and uncertainty, its convenience in being available very close to dwellings and its often high cost. This paper is mainly concerned with a particular scenario, the ‘humid tropics’, rather arbitrarily defined as a climatic zone for which annual rainfall exceeds 1000mm and where any dry season does not normally exceed 5 months in duration. In comparison with the scenarios commonly addressed by rainwater harvesting specialists, the humid tropics are comparatively easy. Even so the cost of any system capable of meeting all of a household’s water needs throughout the year is likely to exceed \$400 - unacceptably high for most low-income households in tropical countries. This cost is dominated by the cost of providing adequate storage. To achieve 95% reliability of roofwater supply where household water consumption is (only) 100 litres per day requires 10 to 15 cubic meters of storage: higher consumption rates require proportionally more storage.

It is therefore arguable that ‘total’ (complete, all-year) roofwater harvesting (RWH) is an inappropriate objective for most households or communities and that ‘partial, seasonal’ RWH should be the norm. Moreover even where total RWH is an ultimate objective, it makes much sense to reach it in stages by the stepwise extension of an initially partial and seasonal system. In the humid tropics there are generally alternative sources of water to roofwater. These sources commonly have defects such as high cost, low quality, unreliability or inconvenience; (indeed if they did not, we would hardly be considering RWH at all). However they are usable and indeed are being used now. In designing a RWH system we therefore need to take these rival sources into account, acknowledging of course that their characteristics vary with the

seasons and that they are under greatest stress precisely in those dry months when we need to fall back on them.

2 Combinations of RWH with other water sources

Roofwater is usually premium water, almost certainly more convenient than water from any alternative source and often cleaner. It may be softer and have a better taste (although not if stored in new cement-lined tanks). Whether it is cheaper will depend heavily upon the design of the harvesting system and in particular upon the ‘availability’ standard chosen.

One common pattern of combination - we will call it Scenario A - is rural RWH backed by haulage of water from a distant spring or well. The quality of the roofwater is likely to be similar to that of the other sources. The primary benefit of installing RWH is the reduction in haulage effort it offers. This benefit is more or less proportional to the water consumed whereas the cost of delivering roofwater is a rapidly rising function of quantity so supplied. The economically optimum size of the water store in a RWH system is likely to be between 7 and 30 day’s consumption, with the larger figure applying where the water haul is particularly onerous. A number of water plans (e.g. Indian norms ^{Teeka Ram, 1996}) appear to use 1500 meters horizontal distance or 100 meters height difference as the threshold of “unacceptably onerous” although these distances are commonly exceeded in developing countries. An economic RWH system may reduce the labour of water fetching by 80%. An interesting side effect is that the possession of say 7 days storage often assists water haulage itself, allowing a household to replace daily water-collection trips on foot by weekly trips by animal cart or even by motor vehicle.

Example of Scenario A : A rural RWH system in a bimodal rainfall region of Uganda
Daily household demand = 120 litres, daily roofwater runoff = 150 litres (averaged over several years)

IOSC denotes ‘Internally Optimised Storage Capacity’ to give minimum unit water cost.

Water storage as a multiple of daily demand (and as m ³)	S/D m ³	1 0.12	2 0.24	4 = ‘IOSC’, 0.48	8 0.96	16 1.92	32 3.84	64 7.68	128 15.36
Benefit (% reliability of RWH supply) *	B	31	46	60	70	78	89	97	99
Notional system Cost in \$ **	C	28	31	37	49	65	105	185	345
Cost/benefit ratio normalised to its minimum value	$\frac{C/B}{C/B_M}$ IN	1.46	1.09	1.00	1.14	1.35	1.91	3.09	5.65

*Fraction of days on which full demand can be met with roofwater. ** Storage capacity costs \$25/m³ and we assume no economies of scale in tank construction; other system components cost \$20.

Assuming negligible running costs, the normalised cost/benefit measure will also stand for the normalised cost per litre of roofwater supplied. In this example the internal optimum storage capacity (IOSC) is only 4 days' consumption; it is shown in bold in the table. Were the calculations to be repeated for a unimodal (Monsoon) rainfall region, the 'reliability of supply' figures would be lower and the tank size for minimum unit cost, IOSC, would be a little higher.

Another common pattern - Scenario B - is to combine urban or village RWH with an unreliable piped supply. The harvested roofwater directly reduces the consumption of piped water and gives the household a much higher level of water security. The storage facilities are of use with both roofwater and piped water sources. Holding low-quality piped water (any intermittent piped supply is likely to be seriously contaminated) in a darkened store is likely to improve its quality, especially if the internal flow-paths in the store have been designed to prevent 'short-circuiting' from inlet to outlet.

A further Scenario C is where roofwater is much superior in quality to any alternative source. In this case it is prudent for a household to reserve roofwater for premium uses (drinking and cooking) and use other sources for laundry, bathing etc. During any dry season the stored water is used only for the premium uses (for which as little as 8 lcd may be sufficient) and the storage is sized to give a high reliability against this low demand. However even here it is uneconomic to aim at over say 97% reliability, since employing expensive water treatment (like boiling) for a few days a year would be cheaper than constructing a larger tank. During any wet months, once the 'premium water' store is largely refilled, roofwater can also be applied to non-premium uses.

A final Scenario D ^{Appan, 1997}, rather uncommon in the tropics, is where there is a piped supply of excellent quality but high cost. Sometimes the piped supply is facing problems of rising demand that can only be met by a major and high-cost investment which the water company is eager to delay. Here roofwater may be deemed of inadequate quality for general use, but may be acceptable as a substitute for piped water for specific 'non-premium' uses such as toilet flushing. Optimum storage capacity will generally be small.

With all these scenarios, RWH is ruled out if its *minimum* cost per litre (corresponding to the *internally* optimum storage capacity - IOSC) is higher than that of any acceptable alternative. However normally it is economic for a RWH system to be built and indeed for a storage higher than IOSC to be used. Once storage exceeds about four times IOSC, the cost per litre rises rapidly and soon becomes economically unacceptable. There will exist some *externally* optimum storage capacity, EOSC, at which the cost of the combination of RWH and other water sources is minimised. This EOSC will always be higher than the IOSC.

As dry season water is more costly to supply than wet season water, it is prudent with RWH to vary consumption with the season. Most owners of RWH systems do this to a modest extent and thereby effectively reduce the mean cost per litre.

3 Strategies for reducing the cost of RWH systems

In the preceding section the emphasis was put upon economically optimum *sizing* of the storage capacity built into a RWH system. Clearly costs are reduced if tank sizes can be reduced, guttering can be made smaller or even roof area can be reduced.

We now look at ways of reducing the cost of a given volume of water storage. The general strategies we could follow, whether in researching cheaper tanks or in specifying them for a specific RWH project, are mostly covered by the following list:-

- a) *reduce the quantity of materials used*
- b) *reduce the quality (and hence unit cost) of the materials used*
- c) share tank materials with other functions (such as house structure)
- d) reduce labour costs of tank construction
- e) reduce transport costs
- f) *remove the need for special shuttering etc.*

Within this list we will concentrate here upon the italicised items (a), (b) and (f).

Materials incorporated in a rainwater storage device have two primary roles, namely to provide structural support and water retention. The same material may perform both roles or alternatively one material may be used for ‘strength’ and another for ‘waterproofing’. As we shall see, there is considerable interaction between the two.

Strength is the ability to contain the forces applied to a structure so that it operates satisfactorily (e.g. does not yield and leak) and does not collapse. This strength needs to be maintained for a number of years in the face of deterioration processes like rusting. Even if performance is eventually degraded, there should be little chance of a dangerous collapse. The forces of interest are gravity forces, water-pressure forces and external loading.

Gravity forces are quite large (each cubic meter of water weighs one tonne) but easily resisted provided the tank is not elevated. Because even slight movements may induce cracking in brittle materials, tanks - like house walls - require foundations that spread their weight over a sufficiently large area of ground that sinking or tilting do not occur over time. It is not uncommon to see jar type tanks leaning like the Tower of Pisa some years after their construction. The gravity forces of most difficulty to resist are those acting on horizontal members - in the case of tanks this means covers. Constructing covers of more than two meters diameter requires greater skill and more equipment than does constructing walls. Possibilities for simplifying cover construction are discussed in Section 6 below.

Pressure forces give rise to lateral tensions in walls - so-called ‘hoop’ tensions in cylindrical walls. This is problematic because most cheap durable building materials have a low tensile strength. Equally troublesome, their tensile stiffness is low and they may respond to tension by developing small vertical cracks that compromise water tightness. In the absence of any flexible waterproof lining, we should seek to minimise the tensile *strain* due to pressure forces to as little as .01% (100 microstrain) for cementitious materials or masonry. Better still we should strive to keep such materials in permanent compression and hence negative strain.

The need to resist external loads arises because of safety (covers should not collapse when climbed on) and because it is often socially impossible to prohibit such loading as a lorry driving over an underground tank. In this sense surface tanks are often less vulnerable to large external loads than underground tanks. In some countries earthquakes are another source of loading: a severe quake can generate temporary horizontal forces up to 10% of the weight of a tank plus the water in it.

Against this general background, the Development Technology Unit at Warwick University UK is researching ways of :-

- making the walls of cementitious or masonry surface tanks thinner (than current practice)
- substituting weak materials like stabilised soil for concrete/ferrocement
- simplifying tank-cover construction
- going underground and using the ground to resist pressure forces
- improving water quality by better tank design

of which only the first three are reported here. This research is part of a three-year four-country collaborative research programme funded by the European Union. The other components are studies of health aspects of RWH led by the Indian Institute of Technology, Delhi, India, studies of water security issues led by Lanka Rainwater Forum in Colombo, Sri Lanka and examination of institutional/professional constraints on the expansion of RWH led by FAKT, an NGO in Stuttgart, Germany. The programme also has a small E African component. As part of this programme, case studies of well-designed RWH system components are being documented. ^{RHRG, 1999}

4 Making tank walls thinner

The walls of above-ground tanks are usually built with zero initial strain (although the shrinkage of concrete during curing may generate tensile strains near the bottom of walls whose contraction is resisted by connection to a rigid base). Introduction of water therefore generates tensile stresses and strains. For a cylindrical tank of diameter D and wall thickness t , the hoop stress in the walls at depth h below the water surface will be up to $\sigma = \rho ghD/2t$ ($= 5hD/t$ kPa in MKS units) and in masonry or concrete this corresponds to about $\varepsilon = 0.15 hD/t$ microstrain.

Inserting exemplary values of $h = 2$ m, $D = 2.5$ m and $t = 0.04$ m gives tensile stress equal to $\sigma = 625$ kPa and tensile strain $\varepsilon = 20$ microstrain. For cementitious materials these figures are acceptably low, even in the absence of reinforcing, *provided* that the construction process has left no cracks. Unfortunately the shrinkage of mortar while setting, curing and drying may exceed 1000 microstrain and in the presence of constraints to movement may set up substantial cracks. Poor curing will make these even worse. Including steel reinforcement has little effect upon the loading strain in the mortar, but may help prevent the formation of a few large cracks by converting them into numerous micro-cracks. Ferrocement construction requires the steel mesh more as a ‘former’ against which the mortar is applied than as strength reinforcement.

In theory one should be able to go down to a wall mortar thickness of as little as .01 m (1 cm) in a ten cubic meter tank without exceeding the tensile strain limit of the walling material. Such a low value is however not used ^{Skinner, 1995} because there is a belief that the steel needs a mortar ‘cover’ of 1 cm or more on each side to protect it from rusting. Moreover the quality control and skill problems of applying such a thin layer are considerable. There are however moves to make ferro-cement thinner and one important aid would be a low-cost (electronic?) means of monitoring the mortar thickness as it is applied to a steel mesh.

If thinning the mortar requires better micro-crack control ^{Neville, 1995 p298-300, Chap 9 & p525-9}, then reinforcement of the mortar by a small amount of modern and cheap water-resistant fibre is an interesting option, as is the use of controlled permeability ‘formwork’ (backing the wire

mesh) to dry the surface layer^{Price,1990}, use of additives like micro-silica^{Parker,1985} to reduce permeability or plasticisers to allow lower water/cement ratios and of course higher quality curing.

Experiments are underway concerning the development of surface cracks and the use of reinforcing fibres and micro-silica.

5 Using weaker, cheaper walling materials

One would like to be able to move away from using cement mortar, as cement accounts for a high proportion of the cost of a surface tank made in a country where labour is cheap and cement is not. The main candidates for cheaper walling materials are brick (especially low-quality clamp-fired brick) and stabilised soil (whether in the form of blocks or of rammed earth). In some locations stone masonry may be an option. Plastics already have a significant share of the water tank market, but even using recycled plastics it seems unlikely that they represent a route to much lower costs. More promising is the combination of small quantities of plastics with bulkier but less water-resistant materials. Organic materials such as wood and fibre seem inherently unsuited to long term use in water tanks (where the water level varies so that materials may be cyclically wetted).

Cheap brick and stabilised soil are not widely used for surface tanks because of their low 'wet' compressive strength, their high permeability or their unreliability in tension. Clearly a material with *no* compressive strength when wet is difficult to use near water. Mud architecture has a long history showing it is possible to so protect the top and bottom of mud walls (even in moist climates) that they last for centuries. However a water tank's walls are so vulnerable to extensive wetting that it seems prudent to insist on any construction material in them to have some wet compressive strength - say 1MPa - a figure that can be reached fairly easily by the two materials under discussion.

Excessive permeability can be combated by incorporating special additives within the material itself but is most easily handled by the use of an internal waterproof lining such as a cement-water render, proprietary sealants or thin plastic membranes. (However membranes such as 250 micron polythene sheeting, are hard to attach and may be too easily punctured during construction or maintenance.) If the render is not flexible it may crack during the dimensional cycling that accompanies filling and emptying of the tank, so it becomes attractive to limit that cycling, or to prevent the opening up of any initial cracks, by keeping the render permanently in compression.

Unreliability in tension is probably the greatest barrier to using low-quality walling materials, but it may be overcome either by adequate internal reinforcing or more easily by external post-tensioning. In the latter case, wire or strapping can be wrapped round the outside of newly-built cylindrical tanks and then tensioned to say 30% of its yield strength (15% of UTS). Thus we might tension a 2 mm diameter steel wire to around 400 N. If this initial wire tension also corresponds to the hoop tension in the wall required to contain the internal water pressure of a full tank, one can guarantee that the walling material is permanently in compression. Since the required hoop tension varies from zero at the top of the tank to a maximum value at the bottom, the number of turns of wire can be varied in sympathy. Although the tension in the steel rises above its initial value as the tank is filled, it only does so by a small fraction. A ten cubic meter tank requires about 13 kg of such mild steel wire.

Post-tensioning raises many technical issues, such as protecting the exposed steel from rusting (is galvanising sufficient?), actually tensioning the wires, anchoring the wires to themselves or to the mortar, and accommodating any creep, shrinkage or swelling of the brick or mortar following tensioning (only about 100 microstrain change may be tolerable). The likely success of post-tensioning in closing micro-cracks in a tank's render is also hard to calculate. These are all research issues.

Three experimental tanks are under construction (February 1999) and their performance will be reported when this paper is presented.



6 Simpler covers for tanks

Tanks require covers to control evaporation, guard against contamination, maintain child safety, exclude insect vectors and impede algal growth. The covers can be built directly into position (before or after the walls) or built alongside the walls and later lifted onto them. The latter technique simplifies cover construction but raises its own problems of local over-stressing during lifting and the waterproofing of the cover-wall connection. Covers can be designed to be wholly in compression (arch and inverse catenary shapes) ^{McGeever, 1997} or partly in tension (flat discs and cones). The latter require use of materials capable of sustaining bending moments.

Following construction of two 'lift-on' ferrocement tank covers in UK using a thin shell 'reciprocal' structure and hence no formwork, similar covers will be tested in Uganda in June 1999 on both surface and underground tanks. Provided initial strength test results are confirmed, this structure looks a promising way of simplifying construction and perhaps also of reducing material content via simpler thickness control. For underground tanks, the interface between such a lift-on cover and the top of the underground bowl may be used to anchor a polythene sock liner hanging within the bowl.

7 Conclusions

The cost of high reliability RWH systems in low-rainfall areas is extremely high. In more humid areas there is considerable scope for reducing costs, firstly by using realistically small storage volumes (and relying to a small degree on alternative sources) and secondly by economising on the quality and quantity of construction materials. Simulations suggest that the economically optimum storage volume in the humid tropics lies in the range 4 to 20 day's consumption. Calculations suggest considerable scope for making tanks with thinner walls or using materials like low-quality brick or stabilised soil blocks, provided the construction technique can deal with the problem of surface cracking in mortars. Cover construction may also be considerably simplified.

This paper is based on new research started in late 1998 which has yet to yield much experimental data. The paper therefore reports mainly strategies to make RWH cheaper. By the time of the Conference however, more experimental data will be available for presentation.

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Abanbars as a Trustable Method of Water Harvesting

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Abstract

Uneven spatial and temporal distribution of precipitation, high rate of evaporation, arid and semi-arid climate, evaporative geological formations such as gypsum and salt domes in southern as well as desert areas of Iran make it impossible to maintain the surface and ground water supply. The only means to harvest water is century-old system called *abanbar*. The main objective of this paper is to investigate *abanbars* as a traditional method of water harvesting. I will discuss architectural, structural, geo-technical, hydrological, and hydraulic aspects of various types of *abanbars* and methods of constructing and maintaining them.

Introduction

By research and study on the environment of the present and past communities, one can define the significance and role of water in the development of the area. From the beginning of the history, human beings usually have chosen places for their habitation that had enough water.

The rate of water resources usage of an area is dependent on the climatic conditions, and also the condition of the science and technology in that area. For example, in some places one can obtain underground water by digging some wells and *qanats*. In the other places, the water supply is provided by using the surface waters such as rivers, and streams. But in some arid lands like Iran, about two-thirds of the country has an arid or semi-arid climate. Consequently, in the absence of enough precipitation, the level of water table is so deep that is not economical and feasible to obtain water by digging wells and *qanats*. Also the quality of groundwater due to evaporative geological formations are not suitable for drinking. The only system that can maintain the water supply for the community is the rainwater harvesting system which is called *abanbar*. *Abanbar* is a structure that can store the surface runoff resulting from precipitation. Unfortunately, due to population growth, increasing community water consuming demand, the modern technology, and some hygiene problems are the main reasons for *abanbar* deterioration during last several decades. This is unfortunate that these systems of water harvesting are being forgotten and that they are not considered effective as much as in the past. In this paper, besides the introduction of *abanbars*, an attempt has been made to have a more careful look at the system and its problems, and to present some solutions for existing problems. In other words, the objective is to find a solution to integrate these systems with modern technologies to save the most effective means of water harvesting in desert areas.

Geographical Scattering or Dispersion of *Abanbars* in Iran

Iran as a vast country with 1,648,000 square kilometers, has two mountain ranges: in the north stretching from west to east and in the west stretching from northwest to south. In the central part of the country, there are two big deserts (Lout and Dasht-e-kavir). The climatic condition of the country varies from fair to arid with average precipitation of around 2,000 mm/year in the north and about 25 mm/year in desert areas. The high amount of evaporation in desert areas and lack of surface waters such as rivers, streams and non-suitable quality of groundwater for municipality use due to evaporative geological formation are the main reasons for construction of *abanbars* in some part of Iran.

The geographical distribution of *abanbars*, are mostly in Persian Gulf, Fars and Hormozgan provinces and in desert areas mostly in Yazd, Kashan, and Semnan.

The followings are the main reasons why the *abanbars* are constructed and used in the past in those regions.

- Shortage of water and existence of a lot of problems in water supply;
 - Existence of underground water resources with undesirable quality and the need to provide water with a better quality;
 - Lack of surface water due to high temperature, a hot and warm climate and a high rate of evaporation;
 - Many limitations in water transferring, also the poor economy of the community and the necessity of having a cheap system for water harvesting;
 - Usage of *abanbar* as a system for improving water quality requirements.
- Various kinds of *abanbars*

Abanbars with regarding to their applications, are categorized in three groups which are as follows:

- a-Agricultural-desert *Abanbars*,
- b-Urban- rural *Abanbars*,
- c-Road *Abanbars*

Design Criteria

Several main parameters, which should be considered in design of *abanbars*, are as follows:

1- Population studies

Usually the volume and the number of *abanbars* are evaluated by the population, which is predicted in a design period. The capita per day water consumption can be calculated by using the statistical studies and other factors, which are discussed later.

2- Climatic conditions and the rate of precipitation.

3- Hydrologic and the hydraulic design criteria.

In order to perform the hydraulic design of *abanbars*, at first the hydrologic design factors should be defined. These factors are as follows:

- The duration of rainfall

- Intensity of rainfall
- Average annual temperatures and the rate of evaporation and transpiration.
- The area of the rainwater catchment (of the *abanbar*)
- Land coverage of the rainwater catchment.
- Air humidity content.

An *abanbar* is made of reservoir, faucet, stairs, vent, doorway, decorative parts, related structures around the *abanbars*, canals for collection of rainwater and directing to the *abanbars* and settling chambers.

- Reservoirs

The reservoir is the place where water will be stored and it is the most important part in construction of *abanbars*. Of course the shape and size of urban, desert and road *abanbars* are relatively different. For example in desert *abanbars*, the shape is circular and rectangular. The circular shapes have a diameter in the range of 2-6 meters and height the same as the diameter. But in rectangular shapes, the dimensions are 2×2×2 and 2×4×2 meters.

In urban-rural *abanbars*, the most popular shape of reservoirs is circular and also the size of these reservoirs is bigger than the desert *abanbars*. The diameter of these *abanbars* is in a range of 5-16 meters, and the height is the same as diameter. In some provinces like Yazd there are some *abanbars* with a volume of 3200 cubic meters. The biggest *abanbar* in Iran is located in Bander-e-Lengheh in Hormozgan province, which has 28 meters diameter with 15 meters height.

- Faucet

The faucet is a big brass one, which is connected to the reservoir. In two sides around the faucet there are some places for sitting and resting.

- Stairs

There are different methods to access the water in *abanbars*. The most popular way is to use stairs and faucet. But in desert-agricultural *abanbars*, the usage of a rope and bucket is more common.

- Vent

This part is used in *abanbars* as a way of ventilation and improving the water quality conditions. Since in arid lands, the hot climate has an adverse effect on water quality, the constructors were so clever to consider this matter and chose an effective way of air circulation.

- Doorway

The doorway not only is as a guide to the stairs and the access way but also shows some information about the constructors and the people who endow the *abanbars*.

- Decorative parts

Constructors of *abanbars* create decorations on the doorway cover for some different reasons. On one part, expressing their feelings and the other part, making a buffer to the wind, which by an abrasive action can decay the *abanbar's* walls.

- Related structures to the *abanbars*

Usually, beside the *abanbars*, there are some places which are used by people for friendly discoursing and some activities as well. For example in Yazd City, these places are used as a mosque for praying. In desert *abanbars*, these places are considered for resting and having a lunch or something like that.

- Canals for collection of rainwater and directing to the *abanbars*

These canals are usually constructed with a rectangular, trapezoidal or circular cross section. These canals should be constructed so that it will be able to convey the maximum probable runoff.

- Settling Chambers

Avoiding the transportation of a large volume of sediment (sand, silt, and so on), some settling chambers are constructed in the course of runoff flow that with a short retention time can settle a great deal of suspended solids.

- *Abanbars* damages and deterioration

There are many factors, which are responsible for *abanbar* damages and deterioration. These can be classified as, design aspects, structural aspects and social-cultural aspects.

1- Design aspects

There were some designers that were not qualified to construct *abanbar*. Design of the *abanbar* domes is the most important part; unfortunately inaccurate design has been the major cause of *abanbar* destruction. At the present time, the process of design, is the same as past, considering a positive and scientific look and integrating modern technology is evident.

2- Structural aspects

Construction of *abanbars* with some materials, like sarooj (fly ash and lime mortar) and stones is a popular method. But in some cases, usage of some materials such as soil and lime mortar, and so on, has caused damages to these structures.

3- Social - Cultural aspects

The problem of water-born diseases is the main reason of creating negative social-cultural attitudes about the *abanbars*. Namely, in evidence of dangerous water parasites such as, Guinea worm (*dracunculus mediensis*), intestinal infectious diseases and some aesthetic aspects have caused a lot of social- cultural negative trends to the *abanbars*, Nowadays, construction and maintenance of *abanbars* in big cities is abandoned.

Environmental aspects

Environmental problems related to *abanbars* are considered from different viewpoints.

- Health aspects
- Physical pollution [thermal, noise and radiation]
- Chemical pollution [pH, gases, dissolved solids, different elements,]
- Biological pollution [bacteria, viruses, parasites, protozoa]

- Aesthetically pollution [odor, test, color, turbidity, ...]

Physical pollution

The problem of physical pollutants such as thermal, noise and radioactive emission in the *abanbars* are not very serious, but it is logical that the catchment area of the *abanbars* site be surveyed completely. Thermal and noise pollution are not commonly seen in the *abanbars*.

Chemical pollution

Dissolving of different compounds such as sodium, calcium ferrous and manganese salts may cause some severe changes in the water quality. Some gases are mainly produced from the solution of these compounds in the water.

Biological pollution

Some well-known water-born diseases such as Vibrio, Typhoid, Paratyphoid, Dysentery, and different kinds of parasitic diseases such as Guinea worm, Amobiasis, Giardiasis and Shiglosis are a part of a large collection of water-born diseases which should be considered in an abandoned *abanbars*. The water from an *abanbars* should meet the water quality and health standards.

Among the different water-born diseases, which are considerable, Guinea worm disease, is the most incident one, and has been the main reason for not using the water as well as in the past. At the time of taking water from the *abanbars* by the buckets, and pouring water on the legs and hands of the people who are carrier of this parasite, the life cycle of the parasite can be completed and the possibility of affecting others is great. At the present time, the authorities of health centers have done some provisions to disinfect the water and isolate the direct contact between the water and the consumers.

Aesthetic pollution

Pollution of waters by different kind of pollutants can change the color, taste of water, and cause odors, which in fact, changes the aesthetic aspects of *abanbars*.

Social aspects

In Iran, *abanbars* are effective means of rainwater harvesting. This system of harvesting socially has the following advantages:

- Providing the water demand of society by a cheap and easy system.
- Decreasing the rate of immigration from the area.
- Creating positive effects on the psychological and physiological behaviors.
- Strengthening of the friendly relationships among the people, by forming a gathering around the *abanbars* and exchanging views.

Economical aspects

Abanbars also play an important role in the sustainable development of the economy of the area. The water that is obtained from the desert-agricultural *abanbars* can be used in watering the plants and trees and has made the market of agricultural products brisk. This matter, besides the direct profits has a great deal of indirect economical advantages.

On other hand, providing potable water for the community decreases the price of water. This system of water collection is much cheaper than other expensive systems such as dams and deep wells.

Religious-political aspects

As previously mentioned, construction of mosques and other public gathering places around the *abanbars* has instructive effects on the morality of the communities.

Cultural aspects

Every thing has its own specifications and these specifications are the criteria for the building of a societal culture. *Abanbars* as a vital necessity has its own culture and it is obvious that the culture makes an impression on the social-cultural behavior of the people.

Concluding remarks

Abanbars are the most effective way of rainwater harvesting in some places in Iran, especially in places with very low amount of precipitation, lack of stream and river flow and lack of suitable ground water resources. The social, cultural and economical feasibility of these systems proved its usefulness during last several decades. The only disadvantage with this system is the hygiene problems associated with its use. Integrating this system of water collection with modern technologies optimizes the proper use and that is one way to save *abanbar* systems as a sustainable water resources development.

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Sri Lanka's Experiences with Low Cost Extraction Hand Pump, Storage Cover, First Flush and Guttering in Domestic Rainwater Catchment Systems

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Abstract

In Sri Lanka rainwater catchment has been traditionally used in the wet as well as the dry zones. Owing to the high cost of storage tank covers, extraction pumps, first flush devices and guttering, most systems remain under-utilised. In 1995, I supervised an action research study on the feasibility of rainwater harvesting under the World Bank assisted Community Water Supply and Sanitation Project.

This study resulted in incorporating rainwater harvesting into official water supply schemes. Since then, thousands of rural domestic water supply systems have been using rainwater harvesting. Among the technologies that have resulted are the low cost reliable storage tank covers made of ferrocement and clay bricks, a low cost low head extraction pump, made of PVC parts used to extract water from underground tanks, simple semiautomatic first flush devices and simple guttering. This paper describes these technologies, which will improve the quality of rainwater harvesting while keeping the costs reasonable. This will allow low-income communities for whom rainwater harvesting seems the best option for domestic water supply to apply this system.

Introduction

Rainwater harvesting has been traditionally used in Sri Lanka both in the wet zone as well as in the dry zone of the country. However, owing to the high cost of storage tank covers, extraction pumps, first flush devices and guttering, most systems remain under-utilised. In 1995 for the first time in Sri Lanka, an action research study of the feasibility on rainwater harvesting for domestic use was conducted under the World Bank assisted, Community Water Supply and Sanitation Project, implemented by the Ministry of Housing and Construction and the author of this paper co-ordinated the study. This study incorporated rainwater harvesting into official water supply schemes in the country. Thousands of rural domestic water supply systems have since been using rainwater harvesting.

Among the technologies that have resulted are the low cost tank covers, made of ordinary clay bricks and ferrocement; a low cost extraction pump made of PVC pipes and fittings; a semiautomatic first flush device; and simple guttering. This paper describes these technologies which will be able to improve the quality of rainwater harvesting, within reasonable costs, which in turn will enable it to be applied to low income communities where rainwater harvesting makes the best option in domestic water supply.

Low cost tank covers

Brick Dome Type:

The objective is to build a tank cover in the shape of a dome using ordinary clay bricks, without the use of steel. In spite of the low cost of this material, this age-old method of construction is not widely used due to lack of appropriate construction techniques.

A very practical construction technique to construct a brick dome type tank roof is discussed as follows

Construction Steps

The brick dome is built on a circular base, which in this case can be the top of a circular tank. If the tank is built below ground, this circular base need not be reinforced. As tools, normal masons tools are adequate. In addition, there is need to prepare two wooden sticks. Each should have a 'L' notch on one side and a 'V' shape on the other side. The diameter of the tank can range up to nine feet (2.75 meters) comfortably.

Step 1:

Prepare two wooden sticks each with a length equal to $\frac{2}{3}$ the length of the tank internal diameter. (One end to have a 'L' shape and the other end to have a 'V' shape)

Step2:

Plant an iron crowbar vertically in the centre of the tank (there should be provision for this).

Step 3:

Keep the 'L' shape end of the stick to the mouth of the tank and the 'V' shape on the crowbar and mark the point.

Step4:

Tie a rope knot on the marked point so that the end of the stick can rest on it.

Step. 5:

Place the first brick on the mouth of the tank and support it with one of the sticks and rest the 'V' end of the stick on the rope knot on the crowbar. A rich cement sand mortar is used to join the brick to the tank mouth.

Step6:

Place a second brick next to the first brick using the second stick. A rich mortar is used to join the brick to the tank mouth and the first brick.

Step 7:

Place the third brick next to the second brick the same way. Here, while supporting the second brick with the left hand the second stick is removed from the second brick and is used to support the third brick. The brick mortar is used to join the third brick to the tank mouth and the second brick.

Step8:

Remaining bricks are laid the same way as the second brick, and once the full round is done, a key is placed between the first and last bricks to lock the brick round and the two sticks are removed.

Step9:

The second and the remaining rounds are done the same way as the first round, till the roof is complete. It is possible to leave an opening for service use at the centre of the tank.

Step 10:

The bricks lying over the outside and inside of the brick dome are plastered once, giving it very good strength.

The end product is a very aesthetic tank cover.

Ferrocement Type Tank Cover

This type of tank cover is mainly used for tanks built out of ferrocement. It is also possible to build the cover of the tank only using this technique with some adaptations.

As a special tool a re-usable iron skeleton made of $\frac{3}{4}$ inch flat iron is necessary. In Sri Lanka village workshops are able to fabricate these. A full set consisting of eight or ten vertical legs and a top ring costs less than US \$100 and can be used very many times, making the cost per tank very small.

Construction steps

- Step 1. Fabricate the legs of the skeleton mould set.
- Step 2. Put the base foundation of the tank
- Step 3. Plant the vertical legs on the foundation base, using the hole in the foot of the leg to fit into a pre-cast protruding bolt found in the base. The flat iron ring made to the size of the required tank opening is placed into the notches found on the top of the legs to make the skeleton stable.
- Step 4. Place 6mm. diameter steel wire around the outside of the legs horizontally, and tie with binding wire to obtain the curved shape of the tank cover. (and tank).
- Step 5. Tie two layers of half-inch chicken wire net around the skeleton.
- Step 6. Plaster the outside of the net with cement sand mortar.
- Step 7. Remove the skeleton and the 6mm. diameter steel wire from inside the tank, through the tank opening.
- Step 8. Plaster the inside of the tank.

The result is a tank and a cover made of 40mm. thick cement sand mortar and two layers of half inch chicken wire mesh.

In Sri Lanka, tanks of capacity up to 7.5 cubic meters with covers are made this way and has been in use since 1995.

Hand Pump

This pump can be made with little effort using materials found in most village hardware shops in Sri Lanka.

The suction head of the pump is limited but works well to extract water from underground rainwater harvesting collection tanks. The cost is only about a third that of similar types of pumps.

The pump is made of PVC pipes and fittings. In the suction pipe line a foot valve is fixed to the end placed inside the tank. At the other end a reducer is used to fix a larger diameter pipe which works as the cylinder of the pump. A plunger is prepared separately out of a smaller diameter pipe. To one end of this pipe an end cup is fixed. The size of the end cap needs to be slightly smaller than the cylinder.

To pump water first the suction pipe is filled with water and the plunger with its end cap end is put into the cylinder and by simply moving the plunger up and down water can be pumped. This pump is long lasting as it needs no replaceable parts. There are hundreds of these types of tanks now in use in rural Sri Lanka.

Semiautomatic first-flush

It is possible to fabricate a semiautomatic noiseless, first-flush by simply adding an extra downpipe with a cap to its bottom end. The cap should have a small hole. Water from the gutter is made to enter this downpipe first and its bottom end should be capped with the cap with the hole. Once this downpipe is full, its overflow is collected in the rainwater collection tank. If it takes long period of time for it to rain again, the water in the first downpipe will leak out of the small hole in the cap, making it ready to flush the first rain again.

Any leaves etc., should be screened from entering the downpipe, or the lid of the downpipe can be opened to clean out any matter collected in it. By increasing the length of the downpipe or including an additional chamber, the quantity of the first-flush can be increased as needed.

Simple guttering

For small roof catchments, very simple guttering can be produced by

- simply cutting a downpipe in two
- sending two nylon ropes through, for example an 8 inch wide polythene tube.

It is possible to buy UV resistant polythene tube or very low cost ordinary polythene tubes for this. To install the gutter, all what needs to be done is to tie the four ends of the nylon ropes at the edge of the roof eaves, so that the rainwater from the roof is led to the downpipe sprout.

Construction of Circular Rainwater Cisterns using Metal Forms

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Abstract

Technical volunteers of the Mennonite Central Committee (MCC), a Non-Governmental Organisation sponsored by the Mennonite churches of North America, have worked in the semiarid region of Northeast Brazil since 1968. In the late 1970's, they developed forms and a process for the construction of concrete cisterns as an appropriate technology for the catchment and storage of rainwater. The easy to use technology has been used to construct over 2,000 cisterns and line many hand-dug wells. There is no need for a professional mason or engineer to oversee the work; thus it is perfect for communities to use on their own.

The capacity of a 6 tube (ring) circular cistern is 15.000 L of potable rainwater, collected from rural buildings using eavestroughing. This amount is enough to supply a family of 8 for 250 days using 7.5 L per person per day. The advantage of this technology is that the force of the water is equal on the wall, unlike that of a rectangular cistern, where the water force is greater on the corners, often causing leaks. The construction of these cisterns uses a set of dismountable metal moulds which have a height of 50 cm, a diameter of 2.5 m and leave a wall spacing of 8 cm. The construction time period is seven days. The material costs are approximately US\$ 250.00, which may be entirely supplied by the family, or partly subsidised. The labour for the cisterns is supplied by the families, using the *work bee* method where 2 to 3 families construct one family's cistern, and then together construct the next family's cistern using the same form, which is passed from house to house. This results in the family feeling a higher degree of ownership and responsibility for the cistern.

Introduction

Origin:

In 1980 an alternative technology for the construction of rainwater cisterns was developed by technical workers of the Mennonite Central Committee (MCC), a Non-Governmental Organisation sponsored by the Mennonite churches of North America. Over the years this easy-to-use technology has been used to construct over 2,000 cisterns and line many hand-dug wells.

Description:

The family-size cisterns are cylindrical. With the use of a metal form, concrete tubes are constructed on top of each other. Two or three families form a *workbee* to construct a cistern. It takes one week to construct a cistern. The same form is then passed on to the home where the next cistern will be constructed. The form may also be used to construct rings to line hand-dug wells. The following materials are used: cement, sand, gravel and reinforcing steel, as well as eavestroughing.

Experiences:

This experience has been used successfully to construct several thousand cisterns in many counties in Pernambuco and Paraíba states, both located in the Brazilian Northeast region.

Advantages of the circular cistern technology over the traditional rectangular cistern technology

1. Circular cisterns are more secure, never bursting. Rectangular cisterns crack, if not well constructed.
2. With the same funds, more families are benefited. Normally conventional cisterns are quite large (50 m^3) which cost in the range of US\$ 570.00. The round cisterns, being smaller (15 m^3) are more economical: material costs are approximately US\$ 174.00 (including eavestroughing).
3. It is not necessary to construct a 50 m^3 cistern (conventional rectangular size). To fill a 50 m^3 cistern an 83 m^2 ($8 \text{ m} \times 10.4 \text{ m}$) catchment area is necessary – a very large building – assuming annual precipitation of 0.6 m (600 mm). If the cistern's purpose is to store water that is trucked in during a drought, 7 loads ($\times 7,000 \text{ L}$) never arrive at once. A 15 m^3 cistern is sufficient for two to three families. ($15,000 \text{ L} \div 180 \text{ day dry season} = 83 \text{ L/day}$. $83 \text{ L/day} \div 5 \text{ L/person/day} = 16 \text{ persons}$).
4. Easy-to-use technology. There is no need for a professional mason or engineer to oversee the work; thus it is perfect for communities to use on their own. A conventional rectangular cistern requires a mason.
5. Rapid construction. One cistern is constructed in a week's time. A conventional cistern takes from three to four weeks to be constructed.
6. This technology permits the construction of cisterns in large scale. One form may construct 36 cisterns in one year. With the acquisition of many forms hundreds of cisterns may be constructed in a short period of time.

Cistern Capacity

The volume of each tube having a 2.5 m diameter and 0.5 m height is the following:

$$V = \pi r^2 h = (3.14)(1.25)^2(0.5) = 2.5 \text{ m}^3$$

The capacity of a cistern with 4 tubes is 10,000 litres; of 5 tubes is 12,500 litres; and of 6 tubes is 15,000 litres.

A cistern with six tubes holds two water truck loads (of $7,000 \text{ L}$ each). Eight tube cisterns have already been constructed ($20,000 \text{ L}$ capacity).

House roof as the rain catchment area

An average size house tile roof has a 50 m^2 catchment area, if water is caught on both sides of the house. In a semiarid region where the average annual precipitation is 600 mm (0.6 m), 50 m^2 of catchment area will store 30 m^3 of rainwater ($50 \text{ m}^2 \times 0.6 \text{ m} = 30 \text{ m}^3$). Being that rainwater will be used gradually, 15 m^3 of volume is sufficient.

Water consumed by one family

In the rainy season there is plenty of water available. Thus the stored water will be reserved for the six months of dry season = 180 days. $15,000 \text{ L} \div 180 \text{ days} = 83 \text{ L/day} = 4.6 \text{ buckets/day}$. $83 \text{ L/day} \div 5 \text{ persons/household} = 16 \text{ L/person/day}$. This volume of water is sufficient for drinking and cooking purposes, being that water for livestock, bathing, laundry, etc., is supplied from ponds and dams.

The Metal Forms

The forms are fabricated in welding shops. A good welding shop is able to fabricate a new form, using an existing form as a model. A 2.5 m form costs in the range of US\$570.00, which includes the cost of the beam form.

The forms are dismountable. They are transported from one location to another on ox carts. A pick-up truck can transport up to three sets of forms at once.

The inner part of the form has three segments, as does the outer part of the form. The form is mounted using vertical metal pins (inner part) and bolts (outer part). The thickness of the cistern wall (determined by the space between the inner and outer forms) is 8 cm. A beam form (2.6 m long) is used for the construction of two beams used to support the lid. A set of forms, if well cared for (bathed with motor oil after the construction of each cistern) lasts an indefinite period of time. If used constantly going immediately from one cistern to the next, one form can construct three cisterns per month, or 36 cisterns per year.

Material necessary

Tools: level, hacksaw, pliers, ruler, trowel, etc.

Sand: clean, taken from a stream bed, without organic or clay particles and sieved.

Gravel (N.º 25): The rock can be crushed locally or purchased from a com. crusher.

Portland Cement: should be fresh and powdery.

Reinforcing steel: a 3/16" or 5.0 mm thickness is best. Make sure it is not rusty.

Black wire (N.º 18): is used to wire the reinforcing steel of the base and lid.

Motor oil: to oil the form so the concrete does not stick; helps prevent rusting of form.

Tap of ¾": A PVC threaded sleeve and pipe is placed in the wall of the first tube of the cistern for posterior screwing in of the tap for the removal of water from the cistern. Normally aluminium and piping is supplied for the eavestroughing and downspouting.

Aluminium – purchased in 60 cm width rolls and divided into two 30 cm rolls. Each household receives the necessary length (15 m) to make their own eavestroughing. 15 m weighs approximately 7 kg.

PVC Piping – 100 mm diameter. Used as downspouting to connect the eavestroughing from both sides of the house to the cistern. The quantity necessary depends on the distance of the cistern from the house, usually no more than 12 m.

Budget – Materials necessary for the construction of a 15 m³ capacity cistern.

Material	Quantity	Unit Price	Total Price
Portland Cement 50 kg	16 sacks	US\$ 3.70	US\$ 59.00
Reinforcing steel 5.0	50 kg	US\$ 0.50	US\$ 25.00
Gravel N.º 25	2 m ³	US\$ 7.15	US\$ 34.30
Black wire N.º 18	0.5 kg	US\$ 0.60	US\$ 0,30
Aluminium	7 kg	US\$ 4.00	US\$ 28.00
PVC piping 100 mm	12 m	US\$ 1.20	US\$ 14.40
Motor oil	5 litres	US\$ 1.20	US\$ 6.00
Tap with union	1	US\$ 1.00	US\$ 1.00
Freight*			US\$ 6.00
* material for five cisterns carried in one load			US\$ 174.00

Construction schedule

1. Excavation - takes from two to eight days, depending on the terrain.
2. Placing of materials on the location – the form, sand, gravel, cement, reinforcing steel, water, etc.
3. Construction: First day – the lid (in the morning), the floor (in the afternoon). Then one tube per day = 6 days for 6 tubes. It takes from two to three hours to fill one tube form; the rest of the day is free for other tasks.
4. Finishing – plastering, placing of the beams, lid and eavestroughing .

Excavation

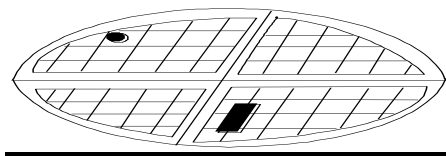
Diameter: Dig a round hole, 3.5 m in diameter (1.75 m radius). This diameter is 1,0m wider than the finished cistern, and allows working room during the construction. After the construction is completed, this space is filled in.

Depth: until soft rock is reached:

- a) Shallow soil: Only one tube (0,5 m) will fit in the hole. The majority of the cistern will be above ground level, until almost the height of the eaves. Thus water will be removed from the lower part of the cistern, with a sleeve/tap placed in the first tube.
- b) Deep soil: Four or more tubes will fit in the hole (two metres). The majority of the cistern will be below ground level, with only two tubes (one metre) above ground. In this case the water will be removed from the top of the cistern, via the hole in the lid.

Lid Construction

1. Line a flat area with empty paper sacks.
2. Place the outer part of the form on top of the paper sacks.
3. Oil the forms, both inside and outside, so that the concrete does not stick.
4. Divide the lid area in four quarters with wooden slats.
5. Cut the reinforcing steel, leaving a 25 cm space from one rod to the next.
6. Straighten the rods. Wire the rods together to form a grid.
7. Place a rectangular box of slats (40 cm × 55 cm) as a spacer for the bucket hole.
8. Place a empty can of 15 cm diameter as the spacer of the downspouting pipe.
9. Mix the concrete mortar, fill the form and smoothen with a trowel. The lid thickness will be 4 cm. One hour after filling, remove the form.
10. Moisten the lid two to three times per day during the first two days so that it cures better.

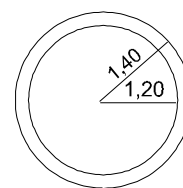


Concrete mortar mixture

7 buckets of sand
1 sack of cement
7 buckets of gravel
2 buckets of water

Floor Construction

2. Excavate a circular hole of 3.5 m diameter and depth of 1-2 metres, depending on the type of soil (shallow or deep). Level the base. If clay based, line the base with a 2.5 cm layer of sand, as clay contracts and expands as moisture changes; the sand serves as a cushion between the soil and floor.
3. Mark the footing. Scratch one radius of 1.20 m and a wider radius of 1.40 m.
4. Dig a 5 cm deep trench between the two marks (20 cm width).
5. Place the outer part of the form (in one piece, leaving the doorway open), within the footing, touching the exterior part of the footing. Do not close



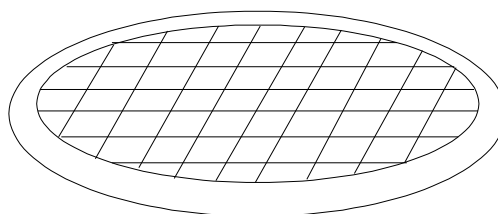
the form; leave a 30-40 cm opening at the doorway – close this opening with the door piece of the inner part of the form. Oil the form well.

6. Cut the 3/16" reinforcing steel rods, leaving 25 cm from one rod to the next. Straighten the rods. Wire the rods together with fine black wire. Cut 2 ring pieces – one to fit in the footing, and the other to wire to the outside edge of the grid.
7. Prepare the concrete mortar mixture, making it neither too dry or too wet.

Concrete mortar mixture - 2 mixes of:

- 7 buckets of sand
- 1 sack of cement
- 7 buckets of gravel
- 2 buckets of water

8. Place the concrete mortar first in the footing trench. Next, place the mixture on the floor, raising the steel grid 4 cm above the ground, so that it remains in the middle; the floor will have a thickness of 8 cm. Trowel it smooth using a level to ensure the floor is level.



10. Prepare 10 staples of 9.  3/16" steel, and place on the edge of the floor, in a radius of 1.29 m. The vertical steel of the first tube will connect to these staples.

Tube Construction

One tube is constructed each day. Oil the forms daily, after they are removed from the finished tube. Take care so that the oil does not drip; a leak may develop.

1. With the assistance of four to six persons mount the form, taking care to not hit the tube beneath (still not cured) with the form movement. Mount first the inner part of the form, and secure with the vertical pins. Next mount the outer part of the form, and secure with the horizontal pins and swivelling horizontal angle iron brackets located at the top of the form.
2. Cut the rings of 3/16" steel: 4 rings for the lower tubes, 3 rings for the middle tube, and 2 rings for the 2 upper tubes. The length of the ring is the circumference with an extra 20 cm.

Table: Number of rings of reinforcing steel (r)

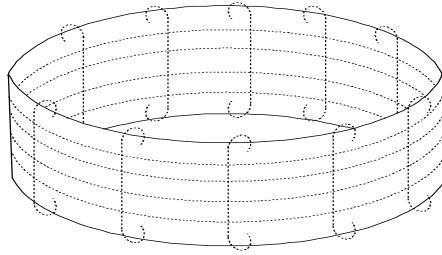
Cistern of	1° t	2° t	3° t	4° t	5° t	6° t	Total
4 tubes (t)	4 r	3 r	2 r	2 r			11 r
5 tubes	4 r	4 r	3 r	2 r	2 r		15 r
6 tubes	4 r	4 r	4 r	3 r	2 r	2 r	19 r

3. Cut 20 vertical rods, 70 cm in length, with the ends bent. 10 of these rods will catch on the staples at the base of the 1° tube; place 5 vertical rods in the 2° tube as well as in the third 3° tube. It is not necessary to place vertical rods in the superior tubes.
4. The horizontal wire rounds will pass on the outside of the vertical rods.

5. Prepare the concrete mortar

2 mixes of:

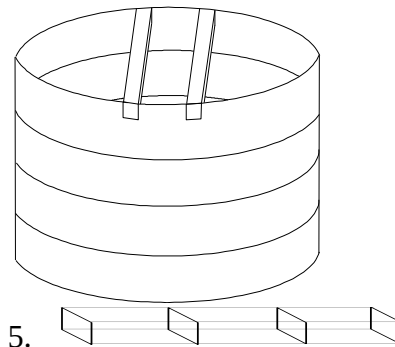
- 6-7 buckets of sand
- 1 sack of cement
- 6-7 buckets of gravel
- 2 buckets of water



6. Place the mortar in the form with the assistance of 2 persons packing with sticks. Place the horizontal steel rings, taking care that they remain in the middle of the tube wall. Wire the ends.
7. When the tube is $\frac{1}{3}$ full, remove the 6 horizontal pins; pack the concrete to fill in the holes left by the pins.
8. To remove the form from the tube constructed the previous day, dismount first the inner part of the form, removing the vertical pins, first of the door, then one by one each of the 3 segments, as well as the swivel horizontal angle iron brackets. To remove the outer part of the form, loosen the turn buckle on the door – the form easily comes off. Take care so that the form does not fall on someone's feet.
9. During construction of the last tube, leave 4 spacers (bricks in a vertical position) at the top (12 cm high, 10 cm wide) for the placing of the two beams. The spacers are located 25 cm away from the centre (50 cm from one beam to the next).

Construction of the two beams (supports)

1. The two beams are placed parallel to support the lid which is made in four quarters.
2. Oil the beam form well.
3. Cut four lengths of $\frac{3}{16}$ " steel 2.58 m in length (2 cm shorter than the form). Straighten them.
4. Cut steel to make the 4 $\square$ (squares).
6. Bend them on the brackets of the inner form.
7. Wire the 4 lengths inside the 4 squares.
8. Place the grid inside the form.
9. Fill the form with concrete mixture: leftovers from the filling of one tube, (or 1 bucket sand, 1 bucket gravel, $\frac{1}{3}$ bucket cement).
10. Pack the concrete well. Let the beam cure two days before removing from the form. Then make the second beam in the same manner.



Finishing

1. Plaster the cistern on all parts of the inside, esp. at the tube seams and pin holes.
2. Plaster the cistern on the outside, at the tube seams and any irregular areas.
3. Set and plaster the beams and lid in place, after curing them at least one week.
4. Clean the cistern. Install the eavestroughing and the cistern is ready to be used.

Usando Formas de Metal: Tecnologia para a Construção de Cisternas Redondas para Captação d'água da Chuva

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Resumo

Técnicos da Comissão Central Menonita (CCM), uma Organização Não Governamental (ONG) das Igrejas Menonitas da América do Norte, têm atuados na região semi-árida do nordeste brasileiro desde 1968. No final da década de 70, desenvolveram formas e um processo para a construção de cisternas de concreto como uma tecnologia apropriada para a captação e armazenamento d'água da chuva. Esta tecnologia, de fácil manuseio, tem sido utilizada para a construção de mais de 2.000 cisternas e o revestimento de muitos poços amazonas. Não há necessidade de um pedreiro ou engenheiro para supervisionar a obra; assim é perfeito para comunidades utilizarem independentemente.

A capacidade de uma cisterna de 6 tubos (anéis) é de 15.000 L d'água potável, captada das telhadas de construções rurais, usando uma calha. Essa quantidade é suficiente para fornecer uma família de 8 pessoas para 250 dias, usando 7,5 L d'água por pessoa por dia. A vantagem dessa tecnologia é que a força d'água é igual na parede, ao contrário de uma cisterna retangular, onde a força d'água é maior nas costas das paredes, muitas vezes causando rachaduras na cisterna. A construção de uma cisterna utiliza um jogo de formas de metal desmontáveis, com uma altura de 50 cm, diâmetro de 2,5 m e deixa uma espessura para a parede de 8 cm. O período de construção é de sete dias. O custo de material é de aproximadamente R\$ 300,00, que pode ser fornecido inteiramente pela família ou ser parcialmente subsidiado. A mão de obra é da própria família usando o sistema de mutirão onde 2 ou 3 famílias constroem a cisterna de uma família, e posteriormente a da próxima família, utilizando a mesma forma, que é passada de residência a residência. O resultado é que a família sente um maior grau de posse e responsabilidade pela cisterna.

Prefácio

Na zona rural no interior do Nordeste, milhares de famílias passam sede durante o verão e as longas secas que atingem a região. Desde pequena, as crianças começam a carregar uma lata pequena d'água andando diariamente quilômetros para qualquer fonte seja um barreiro ou olho d'água. Mas durante o inverno, especialmente das chamadas trovoadas, chove na média 500 mm, bem em cima da própria casa do agricultor. Esta água é quase toda perdida. Como um homem falou, “no Nordeste não falta água, falta a onde armazenar a água.” Segundo os preceitos de Pe. Cícero ele aconselhou, “Construir uma cisterna no oitão da sua casa para receber a água da chuva.”

Este trabalho descreve uma tecnologia alternativa para construção de cisternas que foi usada com muito sucesso em vários locais no nordeste brasileiro. Com materiais financiados por eles mesmos ou de projetos de organizações governamentais ou não governamentais, os próprios agricultores, em mutirão, construíram milhares de cisternas nos oitões das casas

deles. Os agricultores dizem que o financiamento para construção de cisternas foi o melhor aspecto deste projeto; agora eles têm água na porta da casa o ano inteiro.

Os agricultores se tornam sujeitos na solução do problema d'água, sendo que eles mesmo constroem as cisternas. Nos mutirões da construção cresce a confiança no outro. Estes aspectos sociais são tão importante quanto as vantagens meramente técnicas; dão-lhes ânimo para enfrentar outros problemas da vida deles. São alternativas importantes para combater o clientelismo onde o agricultor é somente objeto dos desejos dos grandes – para conseguir qualquer benefício o agricultor é obrigado a se humilhar, a vender o voto dele, vender a dignidade dele.

Introdução

Origem:

Uma tecnologia alternativa para construção de cisternas foi desenvolvida pelos técnicos da AMAS (entidade filantrópica das Igrejas Menonitas da América do Norte) em 1980. Essa tecnologia é simples de usar – qualquer pessoa aprende depois de fazer uma cisterna.

Descrição:

Faz-se cisternas familiares redondas. Com o uso de uma forma de metal faz-se tubos de concreto um em cima do outro. Duas a três famílias formam uma mutirão para construí-la. Leva uma semana para fazer uma cisterna. Depois, a forma que foi utilizada é passada para o local onde a próxima cisterna será construída.

Também, a forma pode ser usada para fazer tubos para poços amazonas.

Use-se como materiais: cimento, areia, pedra britada e ferro.

Experiências:

Esta tecnologia foi usada com êxito em mais de doze municípios pernambucanas, além de vários municípios no agreste e sertão paraibana. Total construídas: ≈ 2.500 . Destas, 700 foram construídas no município de Tacaimbó com financiamento pelo Programa São Vicente da SUDENE.

Vantagem da Tecnologia Alternativa (Cisterna Redonda) sobre Tecnologia Convencional (Cisterna Retangular)

Cisternas redondas são mais seguras, nunca estouram. Cisternas retangulares racham se não bem feitas.

Com os mesmos recursos, mais famílias beneficiadas.

Normalmente, cisternas convencionais são enormes (50 m^3). Orçamento médio: R\$1.000. As cisternas redondas, sendo menores (15 m^3) são mais econômicas: o material necessário custa R\$304,50 (incluindo calha, cano.)

Daí dá para construir quatro a seis cisternas de 15 m^3 , espalhada pela uma região. Com uma só cisterna de 50 m^3 , as outras 5 famílias tem a obrigação de buscar água naquela cisterna.

Não necessário construir uma cisterna de 50 m^3 .

Precisa área de captação de 83 m^2 ($8 \text{ m} \times 10,4 \text{ m}$) – um prédio enorme – supondo precipitação anual de 0,6 m (600 mm), para encher 50 m^3 volume.

Se for para receber água de um carro pipa durante uma seca – nunca chega 7 carros ($\times 7.000 \text{ L}$) de uma só vez.

Cisterna de 15 m^3 é suficiente para 2-3 famílias. ($15.000 \text{ L} \div 180 \text{ dias verão} = 83 \text{ L/dia}$. $83 \text{ L/dia} \div 5 \text{ L/pessoa/dia} = 16 \text{ pessoas}$).

Tecnologia simples. Dispensa uso de mão de obra especializada. As famílias mesmas constroem as cisternas. Cisterna convencional requer pedreiro.

Construção rápida. A cisterna é construída em uma semana. Uma cisterna convencional leva 3-4 semanas para ser construída.

A tecnologia permite a construção de cisternas em massa. Uma forma pode construir 36 cisternas por ano. Com a aquisição de muitas formas centenas de cisternas podem ser construídas em pouco tempo.

Capacidade da Cisterna

Volume de cada tubo de 2,5 m diâmetro e 0,5 m de altura é o seguinte:

$$V = \pi r^2 h = (3,14)(1,25)^2(0,5) = 2,5\text{m}^3$$

A capacidade de uma cisterna de 4 tubos é 10.000 litros; de 5 tubos é 12.500 litros; e a de 6 tubos cabe 15.000 litros.

Uma cisterna com seis tubos cabe dois carros pipas (de 7.000 L). Já foram construídas cisternas com até oito tubos (20.000 L capacidade).

Telhado da casa com área de captação

Uma casa residencial média tem 50 m² de área de captação. Numa região como a semi-árida onde a precipitação pluviométrica anual é 600 mm (0,6 m), 50 m² de área de captação vai juntar 30 m³. Sendo que água vai ser retirada, 15 m³ de volume é suficiente.

Volume d'água usado por família

No inverno tem água a vontade. Daí a água captada vai ser reservada para os 6 meses de verão = 180 dias. 15.000 L ÷ 180 dias = 83 L/dia = 4,6 latas/dia. 83 L/dia ÷ 5 pessoas/casa = 16 L/pessoa/dia. Esta quantidade d'água é suficiente para beber e cozinhar, sendo que a água de gasto para animais, banho, lavar pano, etc., vem de barreiros, açudes, etc.

As Formas de Metal

As formas são fabricadas em oficinas de solda elétrica.

Qualquer oficina boa pode fabricá-las tendo uma forma para servir de modelo.

Preço: R\$1.000,00. Este preço inclui a forma da estaca.

As formas são desmontáveis. Os agricultores costumam usar um carro de boi para carregar as formas de um local para outro. Uma camioneta tipo pick-up pode transportar até três jogos de formas.

A parte de dentro tem três segmentos, como também a parte de fora. A forma é montada com pinos verticais. A espessura da parede da cisterna (o espaço entre a parte da forma de dentro e da fora) é de 8 cm. Uma forma de estaca (2,6 m) de comprimento, é usada para construir as duas estacas usadas para apoiar a tampa. Uma forma, bem conservada (banhada com óleo após a construção de cada cisterna) dura para sempre. Sendo usada sem parar – logo de uma cisterna para a próxima – uma forma dá para construir três cisternas por mês, ou 36 cisternas por ano.

Materiais Necessários

Ferramentas: nível, serra de aço, alicate, régua, metro, colher de pedreiro, etc.

Areia: Deve ser lavada, tirada de um riacho, (sem goma) e peneirada.

Pedra britada (N.º 25): pode ser quebrada no local ou comprada de uma pedreira.

Cimento: Deve ser novo.

Ferro (arame entalhada) espessura de 3/16" ou 5,0 mm.

Arame preto (N.º 18) É usado para amarrar a grade de ferro da base e da tampa.

Óleo lubrificante, para passar nas formas para que o concreto não pegue.

Torneira de ¾": Uma luva de PVC com rosca e cano é colocada no primeiro tubo da cisterna para retirada d'água.

Normalmente é fornecido alumínio e cano para captação d'água do telhado.

Alumínio – comprado em rolos de 60 cm de largura e depois dividido para 2 rolos de 30 cm. Daí cada família tira quanto for necessário (15 m) e mesmo faz a calha (bica). 15 m pesa aproximadamente 7 kg.

Cano de esgoto – 75 ou 100 mm de diâmetro. Usado para encanar a água da bica até a cisterna. Quantidade necessária: conforme distância da cisterna da casa -12 m.

Orçamento – Materiais para uma cisterna de 15 m³ capacidade.

Material	Quantidade	Preço Unit.	Preço Total
Cimento	16 sacos	R\$ 6,50	R\$ 104,00
Ferro 5.0	50 kg	R\$ 0,90	R\$ 45,00
Pedra britada N.º 25	2 m ³	R\$ 30,00	R\$ 60,00
Arame preto N.º 18	0,5 kg	R\$ 1,00	R\$ 0,50
Alumínio	7 kg	R\$ 7,00	R\$ 49,00
Cano 100 mm	12 m	R\$ 2,00	R\$ 24,00
Óleo lubrificante	5 litros	R\$ 2,00	R\$ 10,00
Torneira com luva	1	R\$ 2,00	R\$ 2,00
Frete*			R\$ 10,00
* carrega-se material para cinco cisternas por viagem			R\$ 304,50

Programação da Construção

Escavação do buraco – leva de dois a oito dias, dependendo do terreno.

Colocação dos materiais no local – forma, areia, pedra, cimento, ferro, etc.

Construção: Primeiro dia – a tampa (pela manhã), a base (pela tarde). Daí um tubo por dia = 6 dias para 6 tubos. Leva de duas a três horas para fazer um tubo; o resto do dia fica livre para outras tarefas.

Acabamento – reboque, colocação das estacas, tampa, e da bica do telhado para a cisterna.

Escavação do Buraco

Diâmetro: Cavar um buraco redondo, 3,5 m de diâmetro (1,75 m de raio). Este diâmetro é 1,0 m a mais do que o diâmetro da cisterna pronta, e dá espaço para trabalhar ao redor da cisterna durante a construção. Depois da construção enche as frestas com terra.

Profundidade: até chegar na pedra:

Solo raso: Só vai caber um tubo dentro do chão (0,5 m) A maior parte da cisterna vai ficar por fora do chão, até quase a altura do telhado da casa. Daí a água será tirada de baixo da cisterna, com uma luva / torneira colocada no primeiro tubo.

Solo profundo: Vai caber quatro tubos ou mais (dois metros). A maior parte da cisterna vai ficar dentro do buraco com só dois tubos (um metro) por fora do chão. Neste caso a água será tirada por cima da cisterna, da tampa.

Construção da Tampa

Forrar uma área plana do terreiro com papelão – sacos de cimento desocupados.

Colocar a parte da forma de fora

Passar óleo na forma, por dentro e fora.

Dividir a área da tampa em quatro partes com ripas de madeira.

Cortar as varas de ferro, deixando 25 cm de uma para outra.

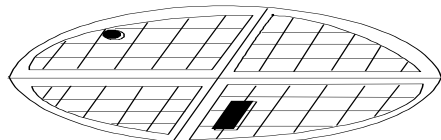
Aprumar as varas. Amarrar as varas com arame fino para formar uma grade.

Colocar uma forma de ripas para deixar o buraco da entrada (40 cm × 55 cm).

Colocar uma lata desocupada de 15 cm diâmetro para deixar o buraco para entrada da água da bica.

Fazer a massa, colocar e alisar. A tampa ficará com 4 cm de espessura. Uma hora após de feita, retire a forma.

Molhar a tampa duas a três vezes por dia nos primeiros dois dias para que ela fique mais forte.



Receita da Massa

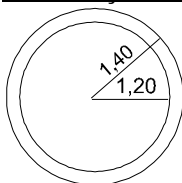
7 latas areia

1 saco cimento

7 latas pedra

2 latas água

Construção da Base



Cavar um buraco redondo de 3,5 m diâmetro e profundidade de 1-2 metros, dependendo do tipo de solo (raso ou fundo). Nivelar bem o chão. Se for de barro, forrar com uma camada de 2,5 cm de areia.

Cavar o alicerce. Marcar um raio menor de 1,20 m e um raio maior de 1,40 m.

Cavar 5 cm de profundidade entre as duas marcações (20 cm de largura).

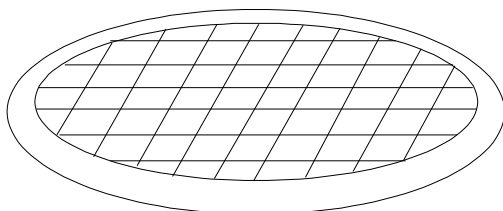
Colocar a parte da forma de fora (em um pedaço só, só abrir a porta), dentro do alicerce, encostando na parte exterior do alicerce. Não feche a forma; ficará uma brecha de 30-40 cm na porta – tampar com uma tábua, ou janela da forma de dentro. Passar óleo na forma.

Cortar as varas de ferro, deixando 25 cm de uma para a outra. Aprumar as varras. Amarrar as varas com arame fino para formar uma grade. Cortar 2 rodas de ferro – uma para ficar dentro do alicerce, e a outra para amarrar na beirada da grade.

Fazer a massa.

Receita da massa - 2 traços de:

7 latas areia



1 saco cimento

1 latas pedra

2 latas água

Colocar a massa primeiro dentro do alicerce. Depois colocar a massa para a base. Levantar a grade de ferro 4 cm do chão, para que ela fique no meio – a base vai ficar com 8 cm de espessura. Usar o nível para fazer a base, é muito importante que a base seja no nível.



Preparar 10 grampos de ferro, e colocar na beirada da base, num raio de 1,29 m. O ferros verticais do primeiro tubo pegarão nos grampos.

Construção dos Tubos

Faz-se um tubo por dia.

Todos os dias passar óleo bem na forma. Tome cuidado para que o óleo não pingue no concreto já feito; essa pode causar vazamento na cisterna.

Com a participação de quatro a seis pessoas montar a forma, tomando cuidado de não quebrar o tubo inferior (ainda verde) como o movimento da forma. Montar primeiro a parte de dentro e colocar os pinos verticais. Em seguida montar a parte de fora e colocar os pinos horizontais e as cantoneiras montada em cima da forma.

Cortar as rodas de ferro: 4 rodas nos tubos inferiores, 3 rodas no tubo no meio, e 2 rodas nos 2 tubos superiores. O comprimento da roda é a circunferência mais 20 cm passando.

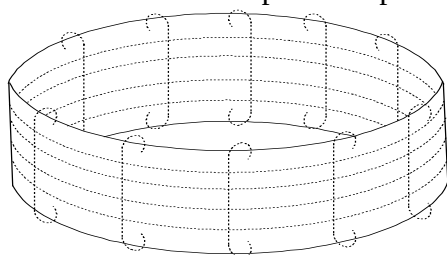
Tabela: Número de rodas de ferro (r)

Cisterna de	1º t	2º t	3º t	4º t	5º t	6º t	Total
4 tubos (t)	4 r	3 r	2 r	2 r			11 r
5 tubos	4 r	4 r	3 r	2 r	2 r		15 r
6 tubos	4 r	4 r	4 r	3 r	2 r	2 r	19 r



3. Cortar 20 ferros verticais, 70 cm comprimento, com as pontas dobradas. 10 destes ferros vão se pegar nos grampos da base no 1º tubo; colocar 5 ferros verticais no 2º tubo; também no 3º tubo colocar 5 ferros verticais. Não é necessário colocar ferros verticais nos tubos superiores.

4. As rodas de ferro passarão por fora dos ferros verticais.



5. Fazer a massa:

Receita da massa – 2 traços de:

6-7 latas areia

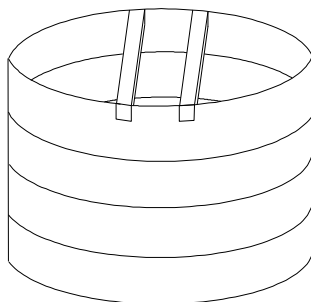
1 saco cimento

6-7 latas pedra

2 latas água

6. Colocar a massa, com a ajuda de duas pessoas socando com paus. Colocar as rodas de ferro, para que fique no meio do tubo. Amarrar as pontas da roda com arame.

7. Quando o tubo estiver $\frac{1}{3}$ cheio retirar os seis pinos horizontais e socar bem a massa para fechar os buracos deixados pelos pinos.
8. Quando for retirar a forma do tubo feito no dia anterior retirar primeiro a parte de dentro; retirar a janela, depois um por um, cada um dos três segmentos. Para retirar a forma de fora, desatar os parafusos da porta – a forma solta com facilidade. Cuidado para que a forma não cai nos pés de alguém.
9. Na construção do último tubo, deixe quatro buracos (12 cm altura, 10 cm largura) para a colocação das duas estacas. Em cada lado os buracos ficam 25 cm afastados do centro (50 cm de um buraco para o outro). É fácil deixar este buraco com 4 tijolos colocados no sentido vertical.



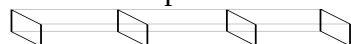
Construção das Duas Estacas (vigas)

As duas estacas são para apoiar a tampa, que é feita em quatro partes.

Passar óleo bem na forma da estaca.

Cortar quatro varas 2,58 m (2 cm mais curtas do que a forma). Aprumá-las.

Cortar ferro para fazer 4 □ (esqueletos).



Dobrá-las nos cantoneiros na parte superior da forma de dentro.

Amarrar as 4 varas dentro dos 4 esqueletos.

Colocar esta grade dentro da forma.

Encher a forma com massa: a sobra de um tubo, (ou 1 lata areia, 1 lata pedra, $\frac{1}{3}$ lata cimento).

Socar bem a massa. Deixar a estaca dois dias antes de tirá-la da forma. Daí se faz a segunda estaca.

Acabamento

Rebocar a cisterna por dentro.

Passar massa nas emendas da parte de fora da cisterna.

Colocar e chumbar as estacas e a tampa, após pelo menos oito dias para curar.

Limpar bem a cisterna. Colocar a bica, e a cisterna está pronta para ser usada.

Rain Collection as Water Source For Small Rural Communities in Chiapas, Mexico (A case study: technical and social aspects for transferring of rural technology in Mexico)

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Abstract

In Mexico there are many small rural communities with serious water supply deficiencies. The introduction of alternative, low-cost technologies represents means of supplying water such as through fog and rain catchment. In the state of Chiapas, in southern Mexico, research is under way on rain water collection for human consumption. This research can then be applied in communities in the states of Chiapas, Oaxaca, Guerrero, Veracruz, Puebla and throughout Baja California. In Chiapas, there are 19,972 poor rural communities, 15,712 of which have fewer than 100 inhabitants. The lack of a constant water supply is most severe in the highlands of Chiapas where the population is made up mainly of indigenous groups. The communities are on mountainous terrain with a widely dispersed population. These characteristics combine to make the provision of public utilities, such as water, electricity and sewerage, difficult with conventional means.

The combination of potability and low cost makes rain collection a viable alternative for rural areas, weather permitting. The Mexican Institute of Water Technology and Chiapas University constructed a rain water collector (RWC) in Yalentay Chiapas. The rain water collector constructed in Yalentay consists of four parts: 1. Roof of aluminum, for collecting rain water, 2. Underground-cistern, divided in two tanks, 3. Filters, to improve the water quality and 4. Regulator tank.

Background

In Mexico there are 198,311 rural communities (INEGI, 1998), with 24.154,775 inhabitants. In all the states of the Mexican Republic there is a serious problem of water supply for small rural communities. For technical or economical reasons conventional water supply technologies are not feasible. In order solve this problem, the Mexican Institute of Water Technology (IMTA) elaborated a handbook (for more information, call Martín Mundo-Molina. Phone and fax: (73) 19 40 12. Email: mmundo@tlaloc.imta.mx) about alternatives technologies for rural communities. The first topic in the handbook deals with rainwater collection in small rural communities.

In this paper I show the most important characteristics of a rain water tank. The RWC was designed by IMTA to supply potable water to small rural communities with fewer than 500 inhabitants. A rain water collector was constructed in Yalentay, in the state of Chiapas, Mexico. Yalentay is an Indigenous Totzil community located 70 km from Tuxtla Gutierrez, in Chiapas, South Mexico.

With the financial support of the Agencia Española de Cooperación Internacional (AECI), IMTA and Chiapas State University constructed a rainwater tank and brought it to Yalentay.

Yalentay is located at 1700 meters above sea level. The climate of the region is tempered with rains in summer, the annual average rain is 1200 millimeters and the annual average temperature is 16° C.

In the highland of Chiapas the geographic characteristics and economic circumstances do not permit a water supply with conventional technologies. The majority of the indigenous people are lacking an adequate water supply system. For this reason there are many cases of "poverty diseases" such as cholera. Many of these small rural communities are far removed from the municipal administration or larger cities. They are located in the highland zones, they are quite dispersed or some don't even have a water fountain.

In Chiapas there are a total of 19,972 rural communities. Of these, 15,712 rural communities have less than 100 inhabitants. 41% of the state's population doesn't have potable water and 55,7% doesn't have sewer system.

In Yalentay, people say that the altitude and the dispersed population are the principal reasons why no water system has been introduced. The municipal government water supplied Yalentay with water trucks. Each family paid US\$1,5 for each water truck that came to Yalentay.

During the last dry season, Yalentay was supplied with 29 water trucks. Each of these water trucks holds 6,000 liters. A total of 174,000 liters was supplied to Yalentay. This volume was consumed in 24 days considering that Yalentay has 400 inhabitants and each inhabitant consumed 18 liters per day. Rainwater collection could be an alternative for water supply for the rural communities in Mexico.

Rain water collector

Rainwater is collected from one's own thin roof. The underground cistern is an inverted and truncated pyramid with the minor base on the bottom (figure 1).

DETALLE DE CISTERNA Y FILTRO INTERNO

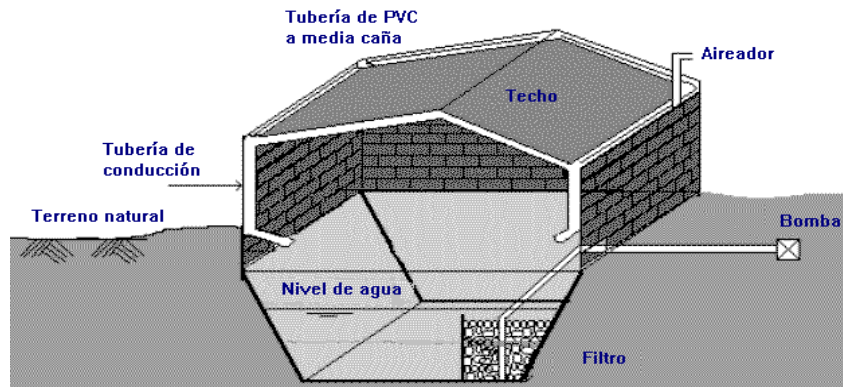


Fig. 1 Roof, walls, underground-cistern, filter of the rain water collector (Mundo et al, 1997).

CISTERNA SUBTERRÁNEA

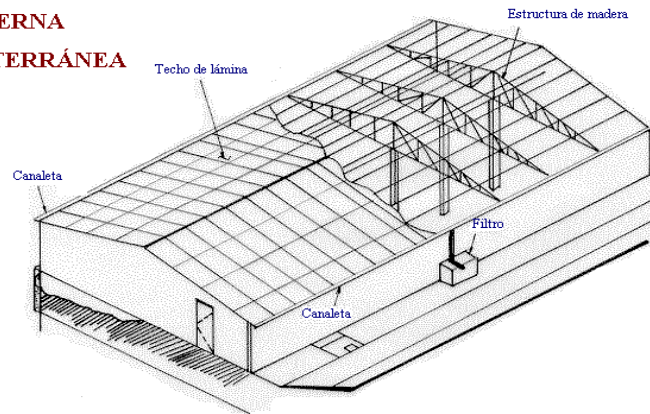


Fig. 2 Rain water collector constructed in Yalentay, Chiapas Mexico (Mundo et al, 1997).

The walls of the underground cistern have a slope of 1:1.5. The RWC walls were constructed and reinforced with chicken wire mesh.

Rainwater collection is made through lateral canals connected to PVC pipes, which take the rainwater to the underground cistern. The RWC has two filters (figure 1), compounded of sand and gravel layers. The water supply from RWC to Yalentay is by force of gravity, because the RWC was located in a highland zone. Inside the cistern, it is absolute dark in order to avoid water pollution by algae or insects (figure 2). The underground cistern has 12 ventilation pipes to maintain water quality. The RWC was constructed with region materials.

Maintenance

The RWC has two access doors for internal cleaning, which should be done at least once a year. About every 12 months the roof and the canals should be cleaned. In order to maintain the water quality the filter should be checked every 12 months.

Technology transfer

Children's diseases in Yalentay are caused by the absence of water. In Yalentay there is no water for washing, drinking or any other uses. If women need water for their daily activities they have to walk a long distance to fetch it. It was due to the women that the RWC was immediately accepted in Yalentay.

To bring the RWC to Yalentay four activities were developed:

1. Meetings for women, children and men
2. Meetings with the local authorities
3. Permanent communication among social and technical heads of the projects
4. Interviews and permanent communication with the community in the survey process.

The meetings were held to clarify the social problems in relation to water. These meetings started with questions about the water supply in the community. For example: Which are the principal problems of the community? What do we do in order to confront this problem? The answers gave the researchers a good idea about social problems in Yalentay. The meetings with the local authorities had two objectives: first, to get information about the water problem in Yalentay and second, to inform the local authorities about the possibilities of passing on ideas about the project to the people. The local authorities received information about the internal community organization, and this was fundamental in the water patronage organization.

The social researchers were working permanently with the people in Yalentay. They established the communication between technical researchers and the community.

Conclusions

The RWC constructed for Yalentay is low-cost and sustainable. The rainwater tank is an alternative for drinking water in rural communities in Mexico. Especially in places, where other water supply systems are not viable.

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Determination of the Optimum Volume of a Cistern Applied to San Andrés Island, Colombia

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Abstract

In rural areas far away from urban centers and on the very small islands (less than 100 km²), where underground water is very limited and the geologic conditions for storing surface water are not favorable, rainwater harvesting is the only available alternative to supply drinking water. In my paper I will present a methodology to find the best storage capacity of a rainwater cistern taking into account the hydrological, harvesting and consumption variables. While small cisterns help to save water, big cisterns are cheaper.

Introduction

San Andrés Island (West Indies, Colombia) has about 70.000 inhabitants including certain, significant number of so-called “illegals.” Water is one of the most important resources of the island. This situation generates a strong pressure on the underground water supply creating problems of bacteriological contamination due to wrong management and saline intrusion due to aquifer overexploitation. While the island natives are used to collect rainwater, immigrants, especially the poorer ones, have to spend up to half of their income to buy drinking water.

General information

San Andrés has an area of 27 km² and is located 187 km from Nicaragua’s Atlantic coast. It is 12 km long and has an average width of 2.5 km. The center of the island is hilly, and the hills reach a height of 85 m. The geology is almost exclusively limestone and conforming two units of different age. The San Andrés geologic unit that rises in the center of the Island, and the San Luis geologic unit that constitute the plane part of the Island, overlying and surrounding the San Andrés unit.

The climate is influenced by the Trade winds, with a rainy season from June to December and a dry season from January to May. The average temperature is 27 ° C and the mean annual rainfall 1950 mm.

Methodology

To find the optimum storage capacity of a cistern a mass balance is carried out adjusting the demand for water to avoid unnecessary overflows.

Water supply

Due to the rainfall stochastic characteristic, it is necessary to apply statistical techniques in order to estimate it. Although the rainfall for the same month through the years is not always the same, it has a “tendency”, a value which is reached on the average "x" times in a very long period - Return Period -. To estimate the rainfall probability, we use the Weibull distribution (1):

$$P(x) = \frac{m}{N+1} \quad (1)$$

In which m is the ordered sequence of “x” values -in this case the historical precipitation-, m = 1, 2, 3,... ..., N and N is the sample size of the ungrouped data. The result of the statistical analysis for San Andrés Island is shown in table 1.

Table 1. Monthly precipitation values in mm. for different probabilities.

P(x)	0.50	0.70	0.75	0.80	0.90	Average
Return Period	<u>2.00</u>	<u>1.43</u>	<u>1.33</u>	<u>1.25</u>	<u>1.11</u>	
Jan	72	55	54	45	36	89
Feb	35	21	21	14	10	37
Mar	20	14	12	10	4	22
Apr	20	10	9	6	5	30
May	120	65	64	58	38	125
Jun	207	120	114	95	68	226
Jul	176	141	139	124	75	200
Aug	169	121	120	118	92	194
Sep	210	168	167	152	129	236
Oct	310	223	202	181	118	303
Nov	225	157	150	137	97	287
Dec	148	106	101	96	75	161

Where 72 mm will be the predicted precipitation in January with 50% probability - Return Period 2 years - this means that on the average in the long run, every two years the rainfall value in January will be at least 72 mm.

However, the quantity of harvested rainwater is subject to the collector system efficiency and the roof area. Table 2 shows the water available in m³/month for different gathering areas on San Andrés Island, if the efficiency of the collection system is 80 % (roof, channels, etc.), and a 75% rainfall probability.

Table 2. Water available in m³/month on San Andrés Island

roof area in m ²										
	<u>1</u>	<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>	<u>30</u>	<u>35</u>	<u>40</u>	<u>50</u>
Jan	0.0432	0.216	0.432	0.648	0.864	1.08	1.296	1.512	1.728	2.16
Feb	0.0168	0.084	0.168	0.252	0.336	0.42	0.504	0.588	0.672	0.84
Mar	0.0096	0.048	0.096	0.144	0.192	0.24	0.288	0.336	0.384	0.48
Apr	0.0072	0.036	0.072	0.108	0.144	0.18	0.216	0.252	0.288	0.36
May	0.0512	0.256	0.512	0.768	1.024	1.28	1.536	1.792	2.048	2.56
Jun	0.0912	0.456	0.912	1.368	1.824	2.28	2.736	3.192	3.648	4.56
Jul	0.1112	0.556	1.112	1.668	2.224	2.78	3.336	3.892	4.448	5.56
Ago	0.096	0.48	0.96	1.44	1.92	2.4	2.88	3.36	3.84	4.8
Sep	0.1336	0.668	1.336	2.004	2.672	3.34	4.008	4.676	5.344	6.68
Oct	0.1616	0.808	1.616	2.424	3.232	4.04	4.848	5.656	6.464	8.08
Nov	0.12	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	6.0
Dec	0.0808	0.404	0.808	1.212	1.616	2.02	2.424	2.828	3.232	4.04
Total	0.9224	4.612	9.224	13.83	18.44	23.06	27.67	32.28	36.89	46.12

To find the net available water volume it is necessary to multiply the precipitation in mm. by the efficiency of the collection system in fraction and for the gathering area in m², then it is divided by 1000, a factor to make the equation dimensionally correct.

Estimate of the demand

The available water supply is calculated based on the net volume available per square meter or yield of the system (0.9224 m³/m²-year) and the number of inhabitants per housing.

The following example shows how to calculate the available daily water supply per inhabitant on San Andrés Island using the data from Table 2, taking a gathering area of 100 m² and 5 inhabitants per house.

$$\frac{0.9224\text{m}^3}{\text{m}^2 - \text{year}} \times \frac{1000\text{liters}}{1\text{m}^3} \times \frac{1\text{year}}{365\text{days}} \times \frac{100\text{m}^2}{\text{house}} \times \frac{1\text{house}}{5\text{habitants}} = 50.54 \frac{\text{liter}}{\text{habitant} - \text{day}}$$

It is important to score that the variables above are only the available water volume, the gathering area and the number of inhabitants; the others are just factors to make the equation dimensionally correct.

Table 3. Rainwater supply in l/person-day on San Andrés Island for different gathering areas

Average Value	San Andrés		
Area average of the housing (m ²)	<u>75</u>	<u>125</u>	<u>100</u>
Inhabitants	5	5	5
Gathering capacity $P(x) = 0.75$ and $e_f = 0.8$ (m ³ /year)	69.18	115.30	92.24
Available supply (l/person-day)	37.91	63.178	50.542

To give an idea how much water is supplied, we suppose that with 50 l/person/day (more or less 5 buckets), it is possible to have drinking water, cook one's meals and take a little shower.

Determination of the optimum storage capacity

A mass balance is carried out, where the demand given by the available rainwater supply found in table 3, is multiplied by the number of inhabitants and the number of days per/month; the offer will be given by the monthly precipitation multiplied by the efficiency of the collector system and by the gathering area, found in the table 2. Then, different cisterns volumes are tried out, in a way that the value at the end of the harvesting period -December -, is the same as the value at the beginning of the harvesting period -January - and that the volume stored in the cistern never has negative values. Once the value is found, the biggest volume stored in the cistern during the year is found out, and this will be the volume in m³ that the cistern should have.

Table 4. Balance between the offer and demand of water for the different months and different gathering areas on San Andrés Island. The cistern volume in m³ is in black.

Roof area (m ²)		Initial Vol.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
In	75		3.24	1.26	0.72	0.54	3.84	6.84	8.34	7.20	10.0	12.1	9.00	6.06
Out			5.87	5.31	5.87	5.69	5.87	5.69	5.87	5.87	5.69	5.87	5.69	5.87
Net			-2.63	-4.05	-5.15	-5.15	-2.03	1.16	2.47	1.33	4.34	6.25	3.32	0.19
Storage		19	16.3	12.3	7.17	2.02	-0.01	1.14	3.61	4.93	9.27	15.5	18.8	19.0
In	125		5.40	2.10	1.20	0.90	6.40	11.4	13.9	12.0	16.7	20.2	15.0	10.1
out			9.79	8.85	9.79	9.48	9.79	9.48	9.79	9.79	9.48	9.79	9.48	9.79
net			-4.39	-6.75	-8.59	-8.58	-3.39	1.92	4.11	2.21	7.22	10.4	5.52	0.31
Storage		32	27.6	20.8	12.2	3.69	0.30	2.22	6.33	8.54	15.7	26.1	31.6	32.0
in	100		4.32	1.68	0.96	0.72	5.12	9.12	11.1	9.60	13.3	16.1	12.0	8.08
out			7.83	7.07	7.83	7.58	7.83	7.58	7.83	7.83	7.58	7.83	7.58	7.83
net			-3.51	-5.39	-6.87	-6.86	-2.71	1.55	3.29	1.77	5.79	8.33	4.43	0.25
Storage		26	22.4	17.1	10.2	3.38	0.67	2.22	5.51	7.28	13.0	21.4	25.8	26.0

The last step should be carried out with the help of a spreadsheet in order to speed up the mathematical operations, since these, although simple, would take too much time without the help of a simple computer.

Conclusions

Following the previous instructions there will be a constant supply of rainwater as well as the best plan for the use of the resource.

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Technical Presentation of Various Types of Cisterns Built in the Rural Communities of the Semiarid Region of Brazil

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Abstract

In this paper I will give a brief description of the technical aspects of some types of cisterns which are currently being built successfully in the rural communities of the Northeast. I will describe the advantages and disadvantages of the construction of certain types of cisterns. I will also mention my own observations collected during the building and the use over several years.

The types of cisterns are the following:

1. Concrete plate cistern
2. Wire Mesh Concrete Cistern
3. Brick cistern
4. Reinforced concrete cistern
5. Lime cistern
6. Plastic cistern

1. Introduction

In this paper I will give a brief description of the technical aspects of some types of cisterns which are currently being built successfully in the rural communities of the Northeast of Brazil. I will describe the advantages and disadvantages of the construction of certain types of cisterns. I will also mention my own observations collected during the building and the use over several years. A list of necessary materials and costs for the various types of cisterns are attached.

The types of cisterns are the following:

1. Concrete plate cistern
2. Wire mesh concrete Cistern
3. Brick cistern
4. Reinforced concrete cistern
5. Lime cistern

2.1. Concrete plate cistern

Concrete plate cisterns can be found throughout the Northeast of Brazil where they have been built with success. These cisterns were originally used in small farming communities and today small businesses and local governments are also building them.

The concrete plate cistern is buried in the ground at up to more or less two thirds of its total height. It consists of concrete plates (mixture cement: sand 1:4) of at least 50 to 60 cm, 3 cm thickness, curved in accordance with the projected radius of the cistern's wall and depending on the anticipated capacity. There are versions where, for example, the concrete plates are smaller and thicker and made of a weaker cement mortar. These plates are made on site in simple wood forms. The wall of the cistern is erected with these fine plates based on the cemented ground. To prevent the wall from carving in during construction, it is sustained with rods until the mortar has dried.

After this a galvanized steel wire (2,77 mm) is wound around the outside of the wall and then plastered. (see illustration 1).

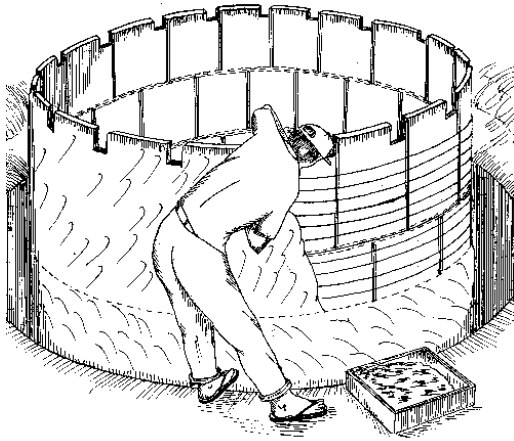


Illustration 1: *Fitting of the wall and outside plastering of cement plate cistern*



Illustration 2: *Process of covering the cistern (inside view)*

Following, the inside wall and the floor are plastered and covered with a fine layer of strong cement.

The cover of the cistern, conic and plain, is also made of concrete plates which are supported by narrow concrete rafters (see illustration 2). One external coat is enough to tighten it.

The empty space around the cistern is carefully filled up with earth. In this way the earth supports the cistern.

Advantages:

- the necessary tools, including the wood to make the forms, are available in all rural communities.
- the drawing of water happens easily from above, there is no need for a faucet;
- it is very adequate for small projects of cistern building, allowing the construction of a limited number of cisterns in a short time;
- low construction costs;
- the water is cool, since most of the cistern is underground.

Disadvantages:

- the construction requires qualified masons. For regular people it is difficult to trace a circle with the right radius for the fine wall on the foundation plates. The outline can only be off by 2 cm. To build the wall presents the same difficulty.
- the adherence between the concrete plates is insufficient, mainly in the horizontal direction. Tensions can cause cracks through which the water can leak;
- the underground part cannot be examined to detect leaks;
- the hole for the cistern has to be dug in a diameter 0,6 m larger than the diameter of the cistern itself in order to allow work on the outside wall. This means that for a cistern of 10 m³ an amount of 12 m³ has to be dug up (digging to a depth of 1,60 m).
- between the fabrication of the plates and the beginning of the building of the walls it is necessary to wait about three weeks in order for the concrete to dry sufficiently;
- the fixing of leaks is often impossible.

2.2. Wire Mesh Concrete Cistern

This type of cistern is normally built above ground (see illustration 3). It has a height of two meters. Before setting the concrete floor it is only necessary to remove the soft earth. The ground is leveled to a depth of about 20 cm and a layer of gravel and coarse sand are put underneath a layer of concrete.

For the construction of this cistern a steel sheet form is needed. This consists of sheets of thin (0,9 mm) plain steel (1m x 2m) screwed together in a cylindrical fashion (see illustration 4).

The upright form is primarily wrapped with wire mesh, followed by galvanized steel wiring in a thickness of 2 or 4 mm, for cisterns with a capacity of 10 or 20 m³ respectively (see illustration 5).

The wire mesh has to go underneath the form and has to cover a length of approximately 50 cm at the bottom of the cistern.

After putting on two layers of plaster on the outside (see illustration 6), the steel form is pulled out. The inside is plastered twice and afterwards covered with a fine layer of cement.

The cover of the cistern can also be made with the help of a steel form, but it is easier and quicker to use the same technologies as for the cement plate cistern.

In the intervals of the various stages of work and during the night the cistern has to be covered with a canvas to avoid a premature drying of the fine concrete wall which can cause a loss of resistance.

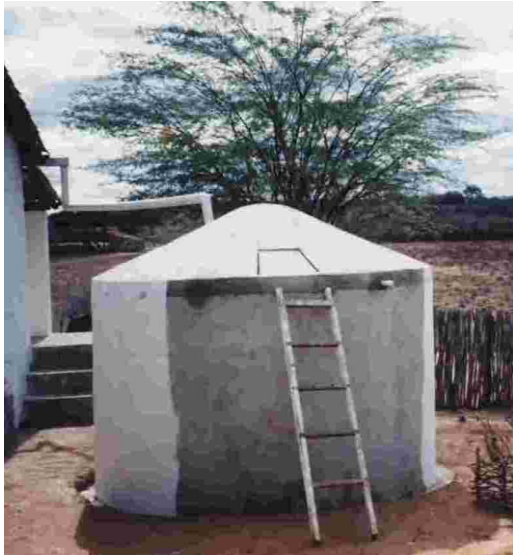


Illustration 3: 10 000 l wire-mesh concrete cistern

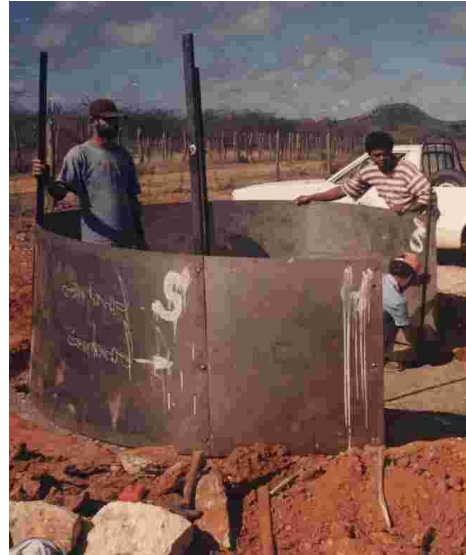


Illustration 4: Screwing of the steel sheet form

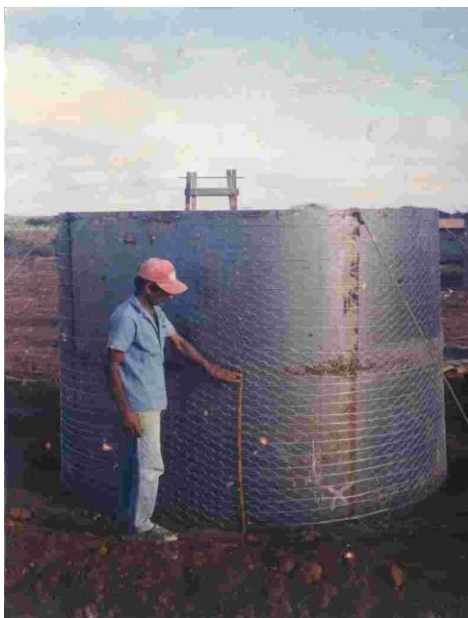


Illustration 5: Steel sheet form, wrapped by wire mesh and galvanized wire



Illustration 6: Application of the first layer of mortar on top of the wiring

Advantages:

-this way of constructing is similar to the way of building a mud house (something people know well and where the woven together wood structure is plastered together with mud on both sides);

- thus the technology is easily understood by the population;
- appropriate for small as well as big cistern construction projects -with little modifications in the structure of the cistern, this type can be adapted to be transported even over long distances, while the cisterns can be built at a central located site;
- the construction goes quickly;
- little use of prime materials;
- after having been used for the cylindrical forms the steel sheets can be used again and are easily transported in small pick-ups or even in carts;
- doesn't require heavy digging work because the cistern is above ground;
- leaks can be easily discovered;
- possible leaks can be easily fixed.

Disadvantages:

- the use of steel sheets which are not always available everywhere in the countryside;
- the proportion between cement, water and sand has to be applied correctly;
- the walls may not dry during work and for the two following weeks;
- the water can heat up easily with the sun; for this reason the cistern has to be painted in white;
- the drawing of water is more complicated, it has to be done from above with the help of a small ladder or with the help of a faucet, increasing the risk of an accidental emptying;
- the construction work cannot be interrupted, otherwise the different layers of plaster don't stick together sufficiently.

Dimensions of wire mesh concrete cisterns of 10 000, 20 000 and 40 000 liters

Volume	10 000 liters	20 000liters	40 000 liters
Diameter	2,5 m	3,6 m	5,2 m
Radius	1,25 m	1,8 m	2,55 m
Height	2 m	2 m	2 m
Circumference	7,85 m	11,3 m	16 m
Thickness of wall	4 cm	5 cm	6 cm
Foundation	remove the soft earth, 10 cm of pebbles and sand, 7,5 cm of concrete		

2.3. Brick cistern

This cistern is also two thirds underground like the cement plate cistern. It also requires a major digging out in order to work on the outside wall of the cistern.

The circular brick wall is put up on a concrete base. The thickness of the wall is about >20 cm. The wall is plastered on the inside as well as on the outside and covered with a fine layer of cement.

To assure greater elasticity, the mortar has to be made with cement and lime.

The cover of the cistern is level and made of concrete or even of wood beams topped with a fine layer of concrete.

Advantages:

- optimal for individual construction or for a neighborhood work party in rural communities;
- besides cement and a bit of iron, all the materials are locally available;
- the cistern turns out to be very cheap if local resources and work parties are used;
- the water remains fresh.

Disadvantages:

- if all the materials have to be bought, the cistern turns out to be expensive;
- takes long to be built;
- the risk of leaks between the cement floor and the wall are big;
- additional digging out work;
- for a bigger cistern the concrete cover is quite expensive because of the large diameter.

Observations:

In order to avoid leaks between the floor and the wall, one has to put wire mesh of one meter length in such a way that 50 cm cover the floor and 50 cm cover the wall before putting on the plaster. The cover can be replaced with barbed wire put on in regular intervals. The outside wall has to be wrapped with galvanized wire (or barbed wire). An additional need of material includes 8 meters of mesh and 135 meters of barbed wire for a cistern of 16 m³.

2.4. Reinforced concrete cistern

The reinforced concrete cistern is particularly adequate for individual construction. On top of a concrete floor one builds a structure of steel wire (diameter of wire up to 5 mm). This structure is then wrapped up several times with wire mesh.

Two workers apply a first layer of mortar, one filling the structure while the other one secures a board or something similar against the other side of the wall being made.

It's very important to use the right proportions of cement, water and sand, as well as the right use of canvas in order to avoid an early drying of the walls, which could cause a loss of stability.

Advantages:

- adequate for individual construction

Disadvantages:

- despite being the most solid one because of the use of steel which exceeds in many ways the quantity really needed, this type of construction is no longer advisable because it demands large quantities of industrial materials such as cement and steel and takes a long time.

- demands lots of skills from the masons, as much to build the wire structure as well as for the application of plaster.

2.5. Lime cistern

The lime cistern is almost totally underground, in most cases only a small part of the upper part appears on the surface (see illustration 7). The earth is dug out in the exact size of the cistern. The floor of the cistern is concave. Inside the cistern looks like the inside of the broader half of an enormous eggshell (see illustration 8). One starts to build the cistern from the center of the bottom with bricks standing upright (see illustration 9). The walls are made with 20 cm thick bricks lined directly against the earth.



Illustration 7: Underground lime and bricks cistern

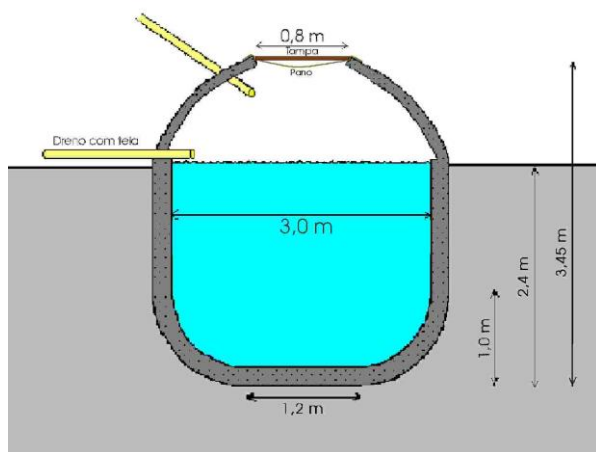


Illustration 8: Cross-cut of lime and bricks cistern (10 000 l)

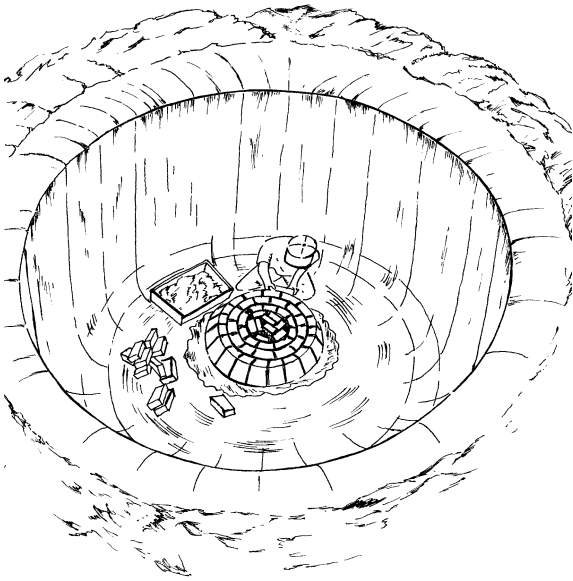


Illustration 9: *Beginning of building of a cistern of bricks and lime*

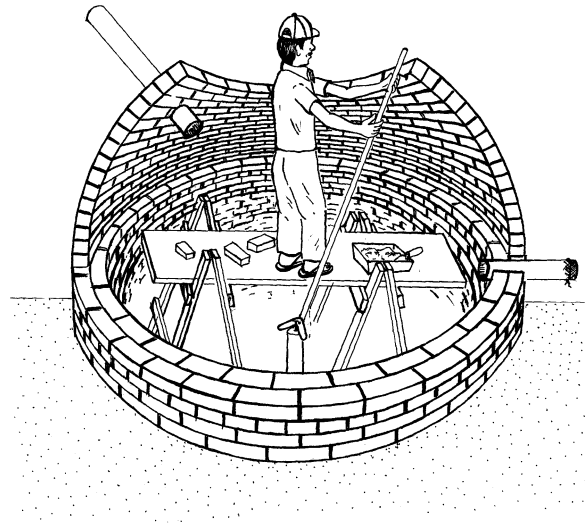


Illustration 10: *Covering the cistern with a brick dome*

For the building one uses a plaster of pure lime. The internal plastering is applied twice or three times with a lime plaster to which is added a bit of cement and finally covered with a fine layer of cement water render.

The cover of the cistern can be made with planks, it could be a regular cover, but it has to be properly closed of to protect against the entry of small animals, or simply, it can be a brick dome (See illustration 10).

Advantages:

- except for some kilos of cement, all the construction materials are available everywhere in the country and can be produced by the farmer or can be obtained in local farming supplies stores;
- the construction techniques are well known, coal and lime furnaces are built the same way;
- the building method complements the life rhythm of the small farmers because construction doesn't need to be done in one setting;
- the cistern can be built without any outside financial help;
- the walls built with lime are more resistant to pressure because lime is more elastic than cement.

Disadvantages:

- workers for digging are needed;
- the lime construction techniques are lost because of the widespread use of cement and very few masons still know how to work it;
- lime only becomes impermeable by using additives;
- lime needs more time to harden than cement.

3. Rainwater catchment from the roof:

The various types of rainwater catchment described here are usually talking about the rainwater running off houses' roofs. In the case of about 90% of houses the roof is big enough to guarantee an amount of drinkable water sufficient for all those living under its roof. But it is also possible to use a ground space for catchment if it has been cemented or covered with stones.

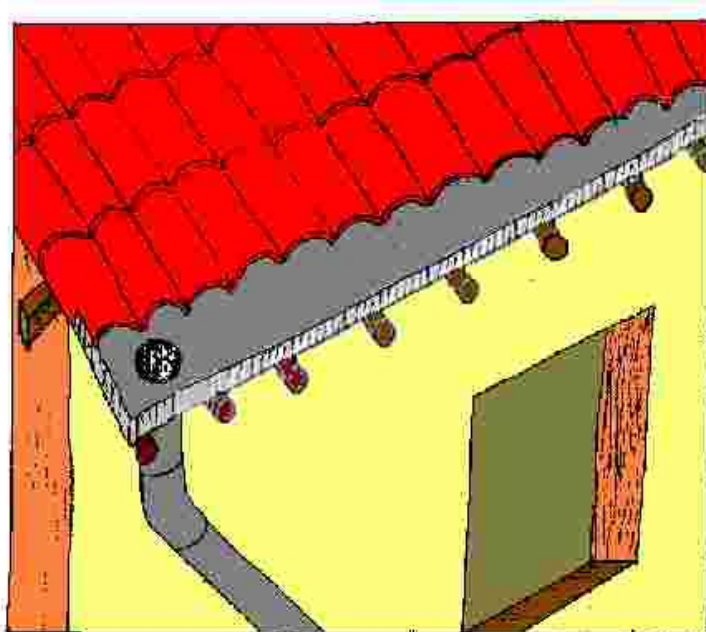


Illustration 11: *L-shaped zinc gutter*

The gutters and drop outlets to catch water from the roof can be of various materials: used PVC pipes cut in half, zinc sheets, even oil cans or wood. The gutters have to fit straight underneath the roof tiles in order to catch the heavy rainfall during thunderstorms. One way to catch water is to get a zinc sheet of 60 cm length, double it in L-shape and fit it straight under the last eaves of the roof rafters (see illustration 11).

4. The cistern resolves the water supply for the family

The water supply for a family always has to be established on an individual base. As each house has its own roof, each house has to have its own water supply.

Besides it is technically more difficult to have collective cisterns. The area to collect rainwater is limited and one has to think of the distances between the houses, normally a few hundred meters, but sometimes a few kilometers. The thing to do would be to have large areas for catchment on the ground and big collective cisterns meaning high costs for technical solutions.

We suggest to build cisterns holding a maximum of 20 000 liters, with little risk of cracking and using cheap construction material.

A collective cistern has to have a minimum volume of 160 000 liters in order to guarantee the water supply of ten houses during 8 months of dryness.

A cistern construction program is only advisable if all the houses in a community can have their cisterns built within a short time frame. If only one or a few houses build a cistern, the other people from the community will go there to fetch water during the next dry period and the cistern will be empty quickly.

5. Conclusion

To live with a cistern demands discipline: one has to learn to use water with parsimony; the areas of catchment have to be clean; the gutters have to be kept in good working condition; water cannot be retrieved with pails which had been put on the ground in order to avoid contamination. An installation for rainwater catchment can supply drinking water of good quality. It is a one time investment, doesn't bring about maintenance costs, is a fixed structure and maintenance is so simple children can even do it. On top of it, it is the ecologically most correct solution.

What makes installation difficult are organizational questions. Mostly people don't have the desire to actively participate in a water supply program. But to be efficient a program needs lots of community participation otherwise it is not possible to pay for the installations. The community has to be convinced that this is a good solution. This requires a well developed coordinating work over years.

But a house with a cistern means a decisive change in the traditional ways of the people in the Northeast. Until today, life in the Northeast means to be slowed down by nature, by the seasons, without active participation in what's happening, without interfering in anything in one's own favor. When people build cisterns to catch rain water and when they can take care of their families thirst during a drought with this water, it means a first step for the rural population to integrate itself actively into the life cycles of a semiarid region and to resolve a vital problem, that is, to have enough water for the survival of a family. But we know too: As long as survival is not guaranteed, cisterns only mean a temporary relief and people will wait for the moment when they can migrate to the big cities.

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- Watt, S B, *Ferrocement Water Tanks and their construction*, Intermediate Technology Publications, London, 1978

Illustrations 1, 6 e 7: José Ivomar Pereira de Sá

Illustrations 2, 3 e 4: Harald Schistek

Illustrations 5 e 8: Johann Gnadlinger

Attachment:

Budget for various types of cisterns Data of Juazeiro, Bahia State, of 1997 and 1998 1 R\$ = 0,6 US\$ (June 22,99)

1.a. List of materials and budget for the building of a CEMENT PLATE CISTERN of 10 000 liters:

radius: 1,15 m, diameter: 2,30 m, height: 2,40 m

quantity	material	price per unit	total price
11	cement/bag	7,00	77,00
70	cans of sand (transport)	0,10	7,00
7	cans of rock/pebbles	1,00	7,00
1.100	liters of water		0,00
4,5	kg of iron 1/4	1,00	4,50
10	kg of wire 12 galvanized	1,14	11,40
	total		106,90
5	days of mason work and mason's helper	22,5	112,50
	Total R\$		219,40

1. b. List of materials and budget for the building of a CEMENT PLATE CISTERN of 20.000 liters

radius: 1,63 m, diameter: 3,26 m, height, 2,4 m

quantity	material	price per unit	total price
18	cement/bag	7,00	126,00
114	cans of sand (transport)	0,10	11,40
10	cans of rock/pebbles	1,00	10,00
1.800	liters of water		0,00
7,5	kg of iron $\frac{1}{4}$	1,00	7,50
14	kg of wire 12 galvanized	1,14	15,96
		total	170,86
8	days of mason work and mason's helper	22,50	180,00
		Total R\$	350,86

2. a. List of materials and budget for the building of a WIRE MESH CEMENT CISTERN of 10 000 liters

quantity	material	price per unit	total price
13	cement/bag	7,00	91,00
1,5	sand m 3	11,00	16,50
0,8	rocks/pebbles m 3	16,00	12,80
9	m wire/chicken 2,5 m height	3,00	27,00
12,8	kg of wire 12 galvanized	1,14	14,59
	Total		161,89
3,5	days of mason work and mason's helper	22,50	78,75
	Total R\$		240,64

2. b. List of materials and budget for the building of a WIRE MESH CEMENT CISTERN of 20 000 liters

quantity	material	price per unit	total price
22	bags of cement	7,00	154,00
2,5	m 3 sand	11,00	27,50
1,3	m 3 rock/pebbles	16,00	20,80
11,5	m wire/chicken 2,5 m height	3,00	34,50
51	kg of wire 8 galvanized	1,14	58,14
	total		294,94
4,5	days of mason work and mason's helper	22,50	101,25
	Total R\$		396,19

2. c. Material and budget for the steel sheet form of a cistern of 10 000 liters

quantity	description	length	dimension	weight/unit	price/kg	value
5	steel stakes		2,4 1 1/2 x 3/16	2,67	0,88	28,20
10	steel ring parts		2,14 1 1/2 x 1/8	0,95	0,84	17,08
9	steel sheets 20 (0,9 mm)		2 x 1 m	14,40	1,14	147,74
25	carriage bolts				price/unit	
		1 1/2			0,20	5,00
20	machine bolts				0,20	4,00
	Total					202,02

3. List of materials and budget for the building of a BRICK CISTERN of 15 500 liters

quantity	material	price per unit.	Total price
4.000	bricks	0,025	100,00
15	cement bags	7,80	117,00
10	lime bags	2,20	22,00
0,5	m 3 rock/pebbles	70,00	35,00
48	kg iron of 1/4"	1,00	48,00
	total		322,00
6	days of mason work and mason's helper	15,00	90,00
	Total R\$		412,00

4. List of materials and budget for the building of a LIME CISTERN:

Cistern of 10.000 liters				Cistern of 20.000 liters	
	Price/ Unit	Quantity	Price R\$	Quantity	Price R\$
Digging Out	m ³	12		22	
Cans of quick lime	1.60/can	16	25.50	31	49.60
Cement	7.00/bag	1	7.00	2	14.00
Bricks	40.00/per thousand	3500	140.00	6000	240.00
Work (mason + helper)	days	10	150.00	16	240.00
	Total		322.50		543.60
	Total excluding work		172.50		303.60

Observation:

If the bricks and the lime are produced in the community and if no one is employed, the lime cistern can be built at no monetary costs.

5. Budget and estimated material use for roof water catchment for a cistern of 15 500 liters

quantity	material	price per unit	total price
10	m galvanized sheet, 50 cm width	2,80	28,00
4	m PVC pipe 4"	10,00	10,00
1	joints	2,50	2,50
	Total R\$		40,50

Apresentação Técnica de Diferentes Tipos de Cisternas, Construídas em Comunidades Rurais do Semi-árido Brasileiro

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Resumo

Nesta palestra vamos dar uma breve descrição dos aspectos técnicos de uns tipos de cisternas que atualmente estão sendo construídas sobretudo nas comunidades rurais pelo Nordeste com sucesso, nós vamos falar sobre vantagens e desvantagens de construir ou ter um certo tipo de cisterna. Ficam registradas sobretudo as observações feitas no acompanhamento da construção e no uso durante vários anos.

Os tipos de cisternas tratados são os seguintes:

1. Cisterna de placas de cimento
2. Cisterna de tela-cimento
3. Cisterna de tijolos
4. Cisterna de ferro cimento
5. Cisterna de cal
6. Cisterna de plástico

1. Introdução

Nesta palestra vamos dar uma breve descrição dos aspectos técnicos de uns tipos de cisternas que atualmente estão sendo construídas sobretudo nas comunidades rurais pelo Nordeste com sucesso, nós vamos falar sobre vantagens e desvantagens de construir ou ter um certo tipo de cisterna. Ficam registradas sobretudo as observações feitas no acompanhamento da construção e no uso durante vários anos. Uma lista de materiais e custos de vários tipos de cisternas está anexada.

Os tipos de cisternas tratados são os seguintes:

1. Cisterna de placas de cimento
2. Cisterna de tela e arame
3. Cisterna de tijolos
4. Cisterna de ferro cimento
5. Cisterna de cal

2. 1. Cisterna de placas de cimento:

O modelo de cisterna de placas de cimento é encontrado em todo Nordeste e continua sendo construído com êxito. Estas cisternas foram usadas originalmente em comunidades de pequenos agricultores e hoje estão sendo construídas também por pequenos empreiteiros e prefeituras.

A cisterna de placas de cimento fica enterrada no chão até mais ou menos dois terços da sua altura. Ela consiste em placas de concreto (mistura cimento : areia de 1 : 4), com tamanho de 50 por 60 cm e gcom 3 cm de espessura, que estão curvadas de acordo com o raio projetado da parede da cisterna, dependendo da capacidade prevista. Há variantes onde, por exemplo, as placas de concreto são menores e mais grossas, e feitas de um traço de cimento mais magro. Estas placas são fabricadas no lugar mesmo em simples moldes de madeira. A parede da cisterna é levantada com essas placas finas, à partir do chão já cimentado. Para evitar que a parede venha a cair durante a construção, ela é sustentada com varas até que a argamassa esteja seca.

Depois disso, um arame de aço galvanizado (Nº12 ou 2,77 mm) é enrolado no lado externo da parede e essa é rebocada (veja ilustração 1).

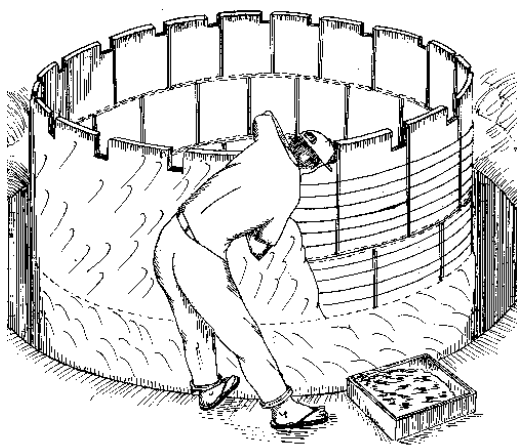


Ilustração 1: Armação da parede e reboco externo de cisterna de placa



Ilustração 2: Armação da cobertura (visto por dentro da cisterna)

Em seguida a parede interna e o chão são rebocados e cobertos com nata de cimento forte.

O telhado da cisterna, cônico e raso, também é feito de placas de concreto, que estão apoiados em estreitos caibros de concreto (veja ilustração 2). Um reboco somente externo é suficiente para dar firmeza.

O espaço vazio em volta da cisterna é cuidadosamente aterrado. Assim a terra apoia a cisterna.

Vantagens:

- as ferramentas necessárias, inclusive a madeira para fazer os moldes, estão disponíveis em todas as comunidades rurais;
- a retirada da água acontece com facilidade pelo lado de cima, não é preciso ter uma torneira;
- é muito adequada para projetos pequenos de construção de cisternas, que prevêm a construção de um número limitado de cisternas em um curto tempo;
- baixo custo de construção;
- a água é fresca, já que a maior parte da cisterna fica debaixo da terra.

Desvantagens:

- a construção exige pedreiros qualificados. Para a população é difícil riscar na placa de fundação o círculo perfeito com o raio correto para a parede fina. O contorno só pode ter uma margem de erro de 2 cm. Levantar a parede apresenta a mesma dificuldade;
- a aderência entre as placas de concreto pode ser insuficiente, principalmente no sentido horizontal. Tensões podem provocar fissuras por onde a água vaza;
- a parte subterrânea não pode ser examinada para detectar vazamentos;
- o buraco a ser cavado tem que ter um diâmetro em 0,6 m maior que o diâmetro da cisterna, para possibilitar os trabalhos na parede externa. Isso significa que para uma cisterna de 10 m³, que 12 m³ de terra tem que ser retirados (cavando até uma profundidade de 1,60 m);
- entre a fabricação das placas e o início do levantamento das paredes é preciso aguardar cerca de três semanas para que o concreto possa curar (endurecer) o suficiente;
- um conserto de vazamentos é impossível na maioria das vezes.

2. 2. Cisterna de tela e arame

Este tipo de cisterna normalmente é construído na superfície (veja ilustração 3). Ela tem uma altura de dois metros. Antes de concretar o fundo, só é preciso retirar a terra fofa. O chão é nivelado a uma profundidade de cerca de 20 cm e uma camada de cascalho e areia grossa é colocada debaixo da camada de concreto.

Para a construção dessa cisterna é preciso uma forma de chapa de aço (veja ilustração 4). Essa consiste de chapas de aço plano (1 m x 2 m), finas (0,9 mm) que são seguradas por cantoneiras e parafusadas uma nas outras em forma cilíndrica.

A forma levantada é primeiramente envolta com tela de arame e em seguida com arame de aço galvanizado com uma espessura de 2 ou 4 mm - para cisternas com capacidade de 10 ou 20 m³

respectivamente (veja ilustração 5). A tela de arame deve passar por debaixo da forma e cobrir uma largura de aproximadamente 50 cm no fundo da cisterna.

Depois de colocadas duas camadas de argamassa na parte exterior (veja ilustração 6), a forma de aço é retirada (e reusada para construir outras cisternas). O interior é rebocado duas vezes e depois coberto com nata de cimento.

O teto da cisterna pode ser fabricado também com a ajuda de uma forma de aço, porém é muito mais fácil e rápido utilizar a tecnologia usada na cisterna de placas.

No intervalo das diversas etapas de trabalho e durante a noite a cisterna tem que ser coberto com uma lona para evitar o ressecamento prematuro da parede de concreto fina, o que provocaria pequenas rachaduras.

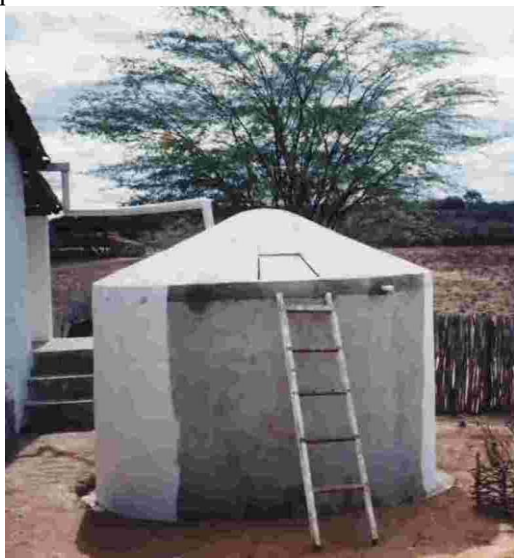


Ilustração 3: Cisterna de tela-cimento de 10 000 litros

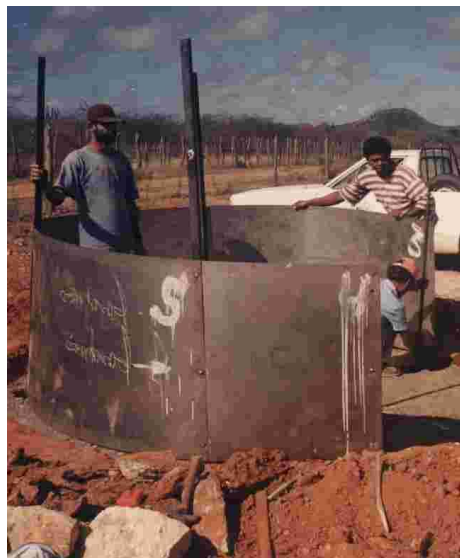


Ilustração 4: Levantamento da forma da cisterna

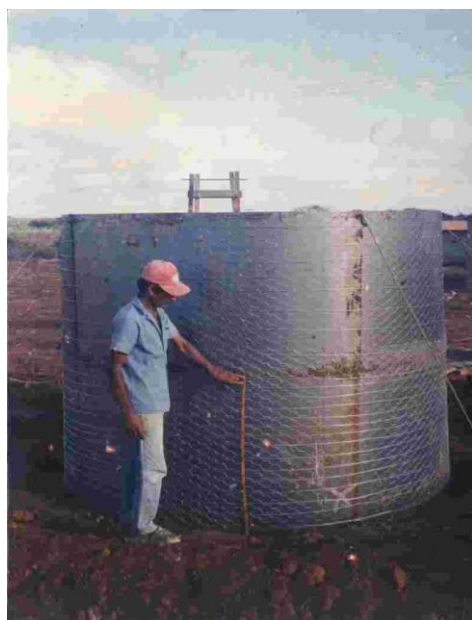


Ilustração 5: Colocação da forma, da tela tipo galinheiro e do arame



Ilustração 6: Colocação da primeira camada de argamassa acima da tela

Vantagens:

- esse modo de construir assemelha-se à maneira de construir uma casa de taipa (um processo muito conhecido pela população, onde as paredes de madeira entrelaçadas são preenchidas pelos dois lados com barro);

- portanto a tecnologia é facilmente assimilada pela população;
- apropriado tanto para pequenos como para grandes projetos de construção de cisternas;
- com pequenas modificações na estrutura da cisterna, este tipo pode ser adaptado para ser transportado até por grandes distâncias, portanto as cisternas poderiam ser construídas em um pátio central de fabricação;

- pouca demora na construção;
- necessidade de pouco matéria-prima;
- as chapas de aço, depois de desmontada a forma cilíndrica, ficam planas novamente e são facilmente transportadas em pick-up pequenos, do tipo Saveiro ou mesmo em carroças;
- não exigem trabalhos pesados de escavação, pois a cisterna fica acima da terra;
- são praticamente à prova de vazamentos;
- eventuais vazamentos são facilmente consertados.

Desvantagens:

- uso de chapas de aço, que não estão sempre disponíveis em todos os lugares do interior;
- a proporção entre cimento, água e areia tem que ser respeitada à risca;
- as paredes não devem ressecar durante as obras e pelas duas semanas seguintes;
- a água esquentar com facilidade ao calor do sol, por isso a cisterna sempre tem que ser pintada de branco;
- a retirada da água é mais complicada, ou por cima com a ajuda de uma pequena escada, ou por meio de uma torneira, o que porém aumenta o risco de um esvaziamento acidental;
- a obra não pode ser interrompida durante a construção, pois senão as subsequentes camadas de reboco não aderem suficientemente entre si.

Dimensões de CISTERNAS DE TELA-CIMENTO com aproximadamente 10.000, 20.000 e 40.000 litros

volume	10.000 litros	20.000 litros	40.000 litros
diâmetro	2,50 m	3,60 m	5,20 m
raio	1,25 m	1,80 m	2,55 m
altura	2 m	2 m	2 m
circunferência	7,85 m	11,3 m	16 m
espessura da parede	4 cm	5 cm	6 cm
fundação	retirar a terra solta 10 cm de seixo e areia 7,50 cm de concreto		

2. 3. Cisterna de tijolos

Esta cisterna fica também cerca de dois terços debaixo do chão como a cisterna de placas de cimento. Ele também exige uma escavação maior, para que se possa trabalhar na parte externa da parede.

A parede circular de tijolos é levantada em uma base concretada. A espessura da parede é de 20 cm. A parede é rebocada pelo lado de dentro e de fora e o lado de dentro é coberto com nata de cimento.

Para assegurar uma maior elasticidade, a argamassa deve ser feita com cimento e com cal.

O teto da cisterna é nivelado, de concreto de armação simples ou até de vigas de madeira com uma laje fina de concreto.

Vantagens:

- otimamente adequada para construções individuais ou em mutirão nas comunidades rurais;
- além do cimento e de um pouco de ferro, todos os materiais estão disponíveis no local;
- a cisterna se torna muito barata, se recursos locais e trabalho em mutirão são empregados;
- a água permanece fresca.

Desvantagens:

- se tudo tem que ser comprado, a cisterna torna-se cara;
- muita demora em ser construída;
- o risco de vazamentos entre o fundo cimentado e a parede é grande;
- exige trabalho de escavação adicional;

- em cisternas maiores, o teto de concreto fica relativamente caro por causa do grande diâmetro.

Observação:

Para prevenir vazamentos entre o fundo e a parede, deve ser colocado uma tela de arame de 1 metro de largura de modo que cubra 50 cm do chão e 50 cm da parede, antes de colocar o reboco. A tela pode ser substituída por pedaços de arame farpado colocados em intervalos regulares. A parede externa deve ser enrolada com arame galvanizado (ou arame farpado). A necessidade adicional de material é de 8 metros de tela de arame e 135 metros de arame farpado para uma cisterna de 16 m³.

2. 4. Cisterna de ferro cimento

A cisterna de ferro-cimento é adequada especialmente para a construção individual.

Em cima de um fundo cimentado é construído uma armação de arame de aço (diâmetro do arame até 5 mm). Esta armação é enrolada varias vezes com telas de arame.

Uma primeira camada de argamassa de cimento é aplicada por dois trabalhadores, sendo que um enche a armação enquanto o outro segura uma tábua ou algo parecido, contra o outro lado da parede a ser feita.

A observação da proporção exata entre cimento, água e areia é muito importante, como também o uso de lonas para evitar o ressecamento das paredes antes da hora, o que causaria perda de estabilidade.

Vantagens:

- adequada para construções individuais

Desvantagens:

- embora seja a mais sólida, por causa da quantidade de aço usada, que supera em muito a quantidade realmente necessária, essa maneira de construção hoje não é mais recomendável, pois demanda grandes quantidades de materiais industrializados, como cimento e aço, e a construção é muito demorada.

- exige bastante habilidade dos pedreiros, tanto para levantar o esqueleto de arame, quanto para a aplicação da argamassa.

2. 5. Cisterna de cal

A cisterna de cal fica praticamente na sua totalidade debaixo da terra, sendo que muitas vezes só uma pequena parte da cúpula superior aparece na superfície (Veja ilustração 7). A terra é escavada na medida exata do tamanho da cisterna. O fundo da cisterna é côncavo. Por dentro a cisterna tem a forma da metade grossa de uma enorme casca de ovo (veja ilustração 8). Começa-se levantar a cisterna no centro do fundo da cisterna com os tijolos em pé (Veja ilustração 9). As paredes de tijolos, com 20 cm espessura, estão diretamente encostadas na terra.

Para o levantamento usa-se em geral argamassa de cal pura. O reboco interno é aplicado em duas ou três camadas de argamassa de cal com pouco cimento e coberto com nata de cimento.



Ilustração 7: Cisterna de tijolos e argamassa de cal

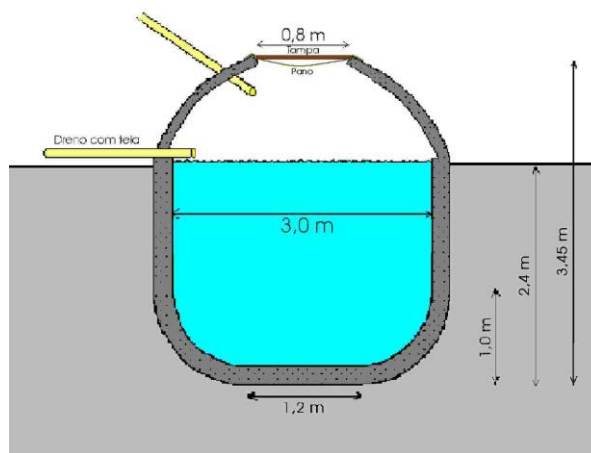


Ilustração 8: Corte da cisterna de tijolos e argamassa de cal

O teto da cisterna pode ser feito de tábuas, pode ser um telhado comum, porém bem vedado contra a entrada de pequenos animais, ou, mais simples, pode ser uma cúpula feita de tijolos (veja ilustração 10).

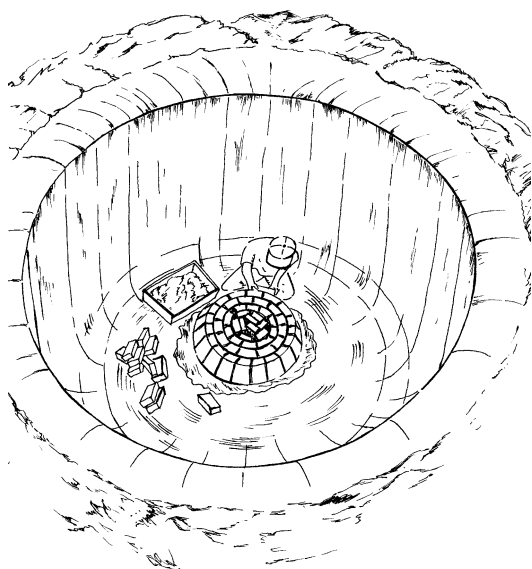


Ilustração 9: Início de levantamento de uma cisterna de tijolos e cal

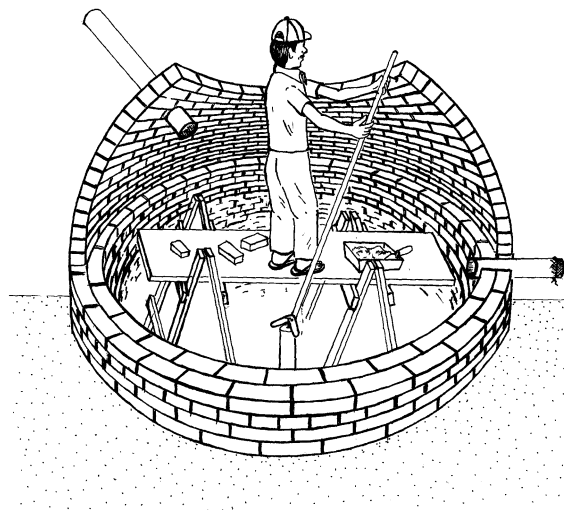


Ilustração 10: Cobrindo a cisterna com uma cúpula de tijolos.

Vantagens: .

- exceto alguns quilos de cimento, todo o material de construção é disponível em praticamente todo o interior e pode ser fabricado pelo próprio agricultor ou então ser obtido em troca de produtos da roça;
- a técnica de construção é muito conhecida, pois da mesma forma se constroem os fornos de carvão e de cal;
- a maneira de construir condiz mais com o ritmo de vida dos pequenos agricultores, pois a construção não precisa ser terminada de uma vez;
- a cisterna pode ser construída efetivamente sem ajuda financeira externa;
- as paredes levantadas com cal são mais resistentes a tensões, porque a argamassa de cal é mais elástica que a argamassa de cimento.

Desvantagens:

- são necessários trabalhos de escavação;
- a tecnologia da construção com cal caiu no esquecimento por causa da hegemonia do uso do cimento e praticamente nenhum pedreiro a conhece mais;
- a argamassa de cal só se torna impermeável com o uso de aditivos;
- a argamassa de cal precisa de muito mais tempo para endurecer que a de cimento.

3. A captação da água de chuva pelo telhado:

Os diversos tipos de instalações para captação de água da chuva até aqui descritos normalmente são abastecidos com a água que escorre do telhado da casa. Em cerca de 90% dos casos a área do telhado é grande o suficiente para garantir uma quantidade de água potável suficiente para todos que moram debaixo desse telhado.

Porém também é possível usar uma área no chão, que seja cimentada ou coberta com pedras, como área de captação.

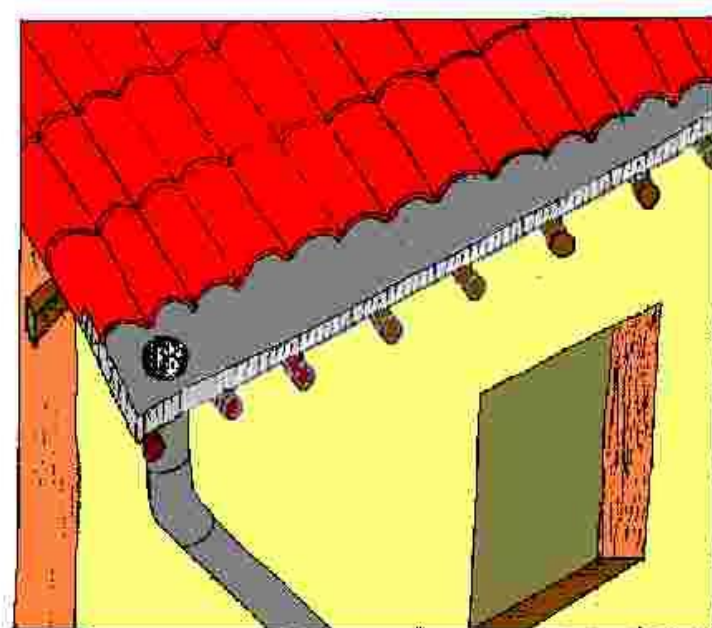


Ilustração 11: Calha de zinco em forma de "L"

As calhas e bicas para captar a água do telhado podem ser de vários tipos de material: são usados canos de PVC cortados no meio, folhas de zinco, até latas de óleo ou madeira. As calhas devem ficar imediatamente em baixo das telhas para não desperdiçar a chuva forte das trovoadas. Uma maneira de como captar a água é usar uma folha de zinco de 60 cm de largura, dobrar o zinco pelo comprimento em forma de um "L" e coloca-la diretamente embaixo da última fileira de caibros no telhado (veja ilustração 11).

4. A cisterna resolve o fornecimento de água para a família

O abastecimento de água para a família sempre deve acontecer em bases individuais. Assim como cada casa tem seu próprio telhado, deve ter também seu próprio sistema de abastecimento de água. Seja uma cisterna, um caxio ou uma cacimba. Isto é importante no processo de conscientização no que diz respeito à precaução quanto à água, tanto dos pais como dos filhos, que um dia devem assumir a propriedade.

Além do mais é até tecnicamente difícil pensar em cisternas coletivas, por exemplo, uma vez que a área de coleta da água da chuva é restrita, sem falar na distancia entre as casas, que normalmente varia entre algumas centenas de metros a alguns quilômetros. O jeito seria criar grandes áreas de captação no chão e grandes cisternas coletivas, o que acarretaria altos custos com as necessárias soluções técnicas.

Nós sugerimos cisternas com volume máximo de 20.000 litros, que não apresentam praticamente nenhum risco de rachaduras, mesmo utilizando material de construção barato.

Uma cisterna coletiva deveria ter um volume mínimo de 160.000 litros, para poder garantir o consumo de dez casas durante os oito meses de seca.

Um programa de construção de cisternas só é aconselhável, se todas as casas de uma comunidade podem receber sua cisterna dentro de um curto espaço de tempo. Se somente em uma ou algumas poucas casas uma cisterna será construída, os outros membros da comunidade irão buscar água lá durante o próximo período seco e logo a cisterna estará vazia. Além do risco de rachaduras, que isso acarretaria, deixaria os moradores com a impressão, que a cisterna não resolve o problema da falta de água, pois "depois de dois meses não tinha mais nenhuma gota d'água".

5. Conclusão

Viver com uma cisterna, exige disciplina: precisa-se aprender a usar a água com parcimônia; as áreas de captação têm que ser limpas; as calhas têm que ser mantidas em boas condições; a água não pode ser retirada com baldes, que foram colocados no chão, para evitar contaminação. Desta maneira, uma instalação de captação de água de chuva pode fornecer água potável de ótima qualidade, requer um investimento único, não apresenta custos de manutenção, não tem partes móveis, tanto que

a manutenção pode ser feito até por crianças, e ainda por cima é a solução ecologicamente mais correta.

Uma casa com uma cisterna significa também uma mudança incisiva nos hábitos tradicionais do povo nordestino. A vida do nordestino até hoje significa mais ser arrastado pela natureza, pelas estações do ano, sem ter participação ativa nos acontecimentos, sem interferir neles a seu próprio favor. Quando ele constrói uma cisterna para captar a água da chuva e consegue com esta água matar a sede de sua família durante os meses da seca, isso significa um primeiro passo para a população rural integrar-se ativamente no ciclo de vida do semi-árido e de resolver um problema vital que é a água para a família de maneira sustentável.

O que dificulta a instalação são em geral problemas de organização. Em grande parte, a população não tem o desejo, de participar ativamente de um programa de abastecimento de água. Mas um programa, para ser eficiente, precisa de muita colaboração por parte da comunidade, pois de outro modo não seria possível pagar as instalações. Os envolvidos precisam ter convicção que esta solução é a correta. Isso exige uma coordenação com bom funcionamento.

A água sozinha não vai resolver os problemas do Nordeste. Um programa de construção de cisternas não resolve nem de longe o problema da dependência da população rural da elite local. Se não resolvermos o problema da água junto com a questão da renda (criação de animais - agricultura - emprego, ou reforma agrária), a pobreza vai continuar a mesma de antes, e que a melhor solução é a migração para a cidade grande.

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Figuras 1, 9 e 10: José Ivomar Pereira de Sá

Figura 2: Dieter Bühne

Figuras 3, 4, 5 e 6: Haroldo Schistek

Figuras 7, 8 e 11: João Gnadlinger

ANEXO

Orçamento para vários tipos de cisternas (valores em R\$ de 1997 e 1998 de Juazeiro, BA)

1.a. Lista de materiais e orçamento para a construção de uma CISTERNA DE PLACAS de 10.000 litros com: Raio: 1,15 m - Diâmetro: 2,30m - Altura: 2,40 m

Quantidade	Material	Preço unitário	Preço total
11	cimento/saco	7,00	77,00
70	lata de areia (transporte)	0,10	7,00
7	lata de brita/seixo	1,00	7,00
1.100	litro de água	0,00	0,00
4,5	kg de ferro 1/4"	1,00	4,50
10	kg de arame 12 galvanizado	1,14	11,40
	Total		106,90

5	dia de pedreiro e servente 22,5	112,50
	Total	219,40

1.b. Lista de materiais e orçamento para a construção de uma CISTERNA DE PLACAS de 20.000 litros com: Raio: 1,63 m - Diâmetro: 3,26m - Altura: 2,40 m

Quantidade	Material	Preço unitário	Preço total
18	cimento/saco	7,00	126,00
114	lata de areia (transporte)	0,10	11,40
10	lata de brita/seixo	1,00	10,00
1.800	litro de água	0,00	0,00
7,5	kg de ferro 1/4"	1,00	7,50
14	kg de arame 12 galvanizado	1,14	15,96
	Total		170,86
8	dia de pedreiro e servente	22,5	180,00
	Total		350,86

2.a. Lista de materiais e orçamento para a construção de uma CISTERNA DE TELA-CIMENTO de 10.000 litros

Quantidade	Material	Preço unitário	Preço total
13	cimento/saco	7,00	91,00
1,5	m³ de areia	11,00	16,50
0,8	m³ de brita/seixo	16,00	12,80
9	m tela/galinheiro 2,5 m altura	3,00	27,00
12,8	kg de arame 12 galvanizado	1,14	14,59
	Total		161,89
3,5	dia de pedreiro e servente	22,5	78,75
	Total		240,64

2.b. Lista de materiais e orçamento para a construção de uma CISTERNA DE TELA-CIMENTO de 20.000 litros

Quantidade	Material	Preço unitário	Preço total
22	cimento/saco	7,00	154,00
2,5	m³ de areia	11,00	27,50
1,3	m³ de brita/seixo	16,00	20,80
11,50	m tela/galinheiro 2,5 m altura	3,00	34,50
51	kg de arame 8 galvanizado	1,14	58,14
	Total		294,94
4,5	dia de pedreiro e servente	22,5	101,25
	Total		396,19

2.c. Material e seu custo para a forma de uma cisterna de 10.000 litros

Quantidade	Descrição	Comprimento/ dimensão	Peso/unid.	Preço/kg	Valor
5	cantoneira	2,4 1 1/2 x 3/16	2,67	0,88	28,20
10	barra chata	2,14 1 1/2 x 1/8	0,95	0,84	17,08
9	chapa 20 (0,9 mm)	2x1 m	14,40	1,14	147,74
25	parafuso de carroceria	1 1/2		0,20 (unid.)	5,00
20	parafuso sextavado			0,20 (unid.)	4,00
				Total	202,02

3. Lista de materiais e orçamento para a construção de uma CISTERNA DE TIJOLO de 15.500 litros

Quantidade	Material	Preço unitário	Preço total
4.000	tijolo	0,025	100,00
15	saco de cimento	7,80	117,00
10	saco de cal	2,20	22,00
0,5	m ³ brita/seixo	70,00	35,00
48	kg de ferro 1/4"	1,00	48,00
		Total	322,00
6	dias de pedreiro e servente	15,00	90,00
		Total	412,00

4.a. Lista de materiais e orçamento para a construção de uma CISTERNA DE CAL de 10.000 litros

Quantidade	Material	Preço unitário	Preço total
12	escavação (m ³)	0,00	0,00
16	lata de cal virgem	1,60	25,50
1	saco de cimento	7,00	7,00
3.500	tijolo (milheiro)	40,00	140,00
10	dia de pedreiro e servente	15,00	150,00
		Total	322,50

Observação:

Se os tijolos e a cal são produzidos na comunidade e usa-se mão-de-obra própria, a cisterna de cal pode ser construída quase sem custo em dinheiro.

4.b. Lista de materiais e orçamento para a construção de uma CISTERNA DE CAL de 20.000 litros

Quantidade	Material	Preço unitário	Preço total
22	escavação (m ³)	0,00	0,00
31	lata de cal virgem	1,60	49,60
2	saco de cimento	7,00	14,00
6.000	tijolo (milheiro)	40,00	240,00
16	dia de pedreiro e servente	15,00	240,00
		Total	543,60

Observação:

Se os tijolos e a cal são produzidos na comunidade e usa-se mão-de-obra própria, a cisterna de cal pode ser construída quase sem custo em dinheiro.

5. Orçamento e estimativa do material necessário para captação de água do telhado para uma cisterna de 15.500 litros

Quantidade	Material	Preço unitário	Preço total
10	m chapa galvanizada, 50 cm	2,80	28,00
4	m cano de PVC 4"	10,00	10,00
1	joelho	2,50	2,50
		Total	40,50

Development of Rooftop Rainwater Catchment System Design Criteria for Pohnpei State, Federated States of Micronesia

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Abstract

This paper reports on the results of the University of Guam component of a three University cooperative research study funded by the US. Geological Survey Water Institute Program. The results of the University of the Virgin Islands and the University of Hawaii components will be reported in other papers contained in these proceedings. All three projects concentrated on problems encountered with rainwater catchment system (RWCS) implementation in each island region.

The purpose of the University of Guam project was to develop and disseminate criteria to be used in the design of new or refurbishing of existing individual water supply systems for various islands in Pohnpei State, Federated States of Micronesia. The end product was a set of design curves and tables for sizing RWCS so that these systems can provide a continuous water supply even during the harsh drought conditions that affect this part of the world.

Introduction

The severe droughts affecting the Federated States of Micronesia (FSM) in 1993 and 1998 brought an increased awareness of drought and its effects on island water supplies. One major source of water supply in the atoll islands and many rural areas of the high islands of the FSM is rainwater catchment systems (RWCS). In many cases, through poor design and use practices, these systems failed to meet the needs of the people they were designed to serve. The combination of poor design and drought conditions has lead to severe hardship for many of the island's inhabitants.

The purpose of the project, as reported in this paper, was to develop and disseminate criteria to be used in the design of new or refurbishing of existing RWCS. The paper will concentrate on the end product of the study which was to develop a set of design curves and design tables for sizing RWCS. These curves and tables were designed so that new or renovated existing RWCS can provide a continuous water supply even during the harsh drought conditions that affect this part of the world

Background

The islands of the FSM, while usually blessed with high rainfall, continue to suffer from water supply deficiencies due to many factors. These islands are very remote, and each island is dependent on locally available resources. They are also periodically struck by long periods of El-Niño induced drought. These droughts bring great hardships to those islanders living on the smaller atolls and rural areas of the high islands. They depend almost exclusively on RWCS as their primary source of water. Serious supply problems occur when the components of these systems are not sized appropriately.

The FSM lies in the Micronesia (Western Pacific) area of the Pacific Ocean. This area lies between the equator and the tropic of cancer and extends from longitude 130 E to 180 E. More than 2000 islands are spread across this area. Of this total, almost 100 are inhabited. The islands range in size from less than 100 ft² (9 m²) to 212 mi² (540 km²). Annual rainfall ranges from 80 to 400 in (2,032 to 10,160 mm) per year. The FSM consists of four states; Chuuk, Kosrae, Pohnpei, and Yap States, with a total population of approximately 88,000. Pohnpei State, which serves as the location of the capital of the Federated States of Micronesia, has a population of approximately 27,000. (State of Pohnpei, Office of Budget, Planning and Statistics, 1990) Pohnpei State is made up of one high island, the Island of Pohnpei, and several smaller atolls.

Water supply systems on the Island of Pohnpei consist of a centralized distribution system for the Kolonia island center area, several rural village supply systems, individual household rain catchment systems and small wells and seeps. The atoll island water supply systems consist of rain catchment systems that are supplemented with water from shallow hand-dug ground water wells.

Project objectives

The overall objectives of the Guam portions of the joint project were to: 1.) Update information on water consumption for rural populations in Pohnpei State, FSM, 2.) Develop design and use criteria for the components of RWCS for individual water supply systems, and 3.) Prepare a booklet containing the design criteria developed in objective 2 in a manner that is comprehensible to those who will be installing and maintaining the RWCS water supply systems. This paper will report on the second of these objectives.

Develop design and use criteria for the components of RWCS

Objective one of the project was accomplished through field visits to Pingelap atoll, a remote atoll in Pohnpei State. After this phase of the project was completed, we next explored various RWCS component sizes and water consumption rates in a computerized RWCS operational model. The operational model used was a Windows © based program called "ROOFRAIN". (Heitz, Leroy and Khosrowpanah, Shahram, 1998) This program uses information such as daily rainfall, family size, roof rain catchment configuration and desired use rates as inputs. The daily rainfall record at the Pohnpei Island Weather Service Office at the Airfield (Station # 4751) was used for the analysis. The record at this station was complete for the period 1953 to 1996.

Two water usage rates were adopted for all of the model runs. A use rate of 4 gallons (15.1 liters) per person per day was used for drinking, cooking, and washing dishes. A use rate of 11 gallons (41.6 liters) per person per day was used for bathing, washing clothes, and toilet flushing. These rates were developed by averaging present water usage rates throughout the FSM. (Heitz, Leroy et al., 1997)

The model uses a two level approach to use rates similar to the actual operation of the tanks by homeowners. The first use rate was called the normal use rate. This rate is applied when the tank is above a preset conservation level. This rate was set at 15 gallons (56.7 liters) per person per day. This use rate includes all of the uses normally supplied by the RWCS. The second rate was called the conservation use rate. This rate is applied when the tank level falls below a preset conservation level. The conservation use rate was set at 4 gallons (15.1 liters) per person per day. The conservation uses are those essential uses of drinking, cooking, and washing dishes. Four different operating schemes were explored. The first three schemes instituted the conservation use rates when the tank was below $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ full respectively. At all other times the use rates were set to the normal use values. The final scheme used the conservation use rate at all times no matter how much water was in the tank.

Next, we chose the design criteria for the proposed RWCS systems. The basis for the design criteria was to choose the minimum size components that would provide a reasonable level of protection against shortages of consumable water during drought times. A conservative value of 0 (zero) days without water is the minimum acceptable level of performance that was chosen. This conservative value was chosen because of the lack of backup water supplies in most of the areas where the design criteria will be applied. We operated the model over a range of RWCS component sizes, people served, and conservation practices.

Table 1. shows the results of the model runs that were made using conservation scheme 1 which assumes conservation use rates apply only when the tank is below $\frac{1}{4}$ full. The table shows the number of individuals that can be supplied from various combinations of tank sizes and usable roof areas. The usable roof area is the product of the total roof area contributing water to the system and a runoff factor that accounts for leakage in the guttering. A similar table was developed for each of the conservation schemes described earlier.

Next, a set of design monographs was developed from the model run data. A monograph was developed for each of the conservation schemes described earlier. A 2nd order polynomial function was fit to the model output data. The usable roof area was assumed to be the independent variable and the number of people served was assumed to be the dependent variable in the polynomial function. A plot of the data for the $\frac{1}{4}$ full conservation scheme is shown in Fig. 1. Note that the areas between the curves have been crosshatched to indicate four different required-volume sectors. These required-volume sectors correspond to the sizes of tanks that are typically being constructed in the study area. The areas between the curves are assigned to the larger of the two bounding tank sizes therefore assuring a conservative design.

Those using the monographs will compute the usable roof area of the structure and determine the number of people who will be served by the system. The intersection of a vertical line from the usable roof size value and a horizontal line drawn through the number of people served will reveal the correct tank volume sector and therefore the correct tank size to build.

Table 1. Results of rain catchment modeling runs where conservation use rates are adopted when the tank level falls below ¼ full.

	Tank Volume gallons (liters)			
	5,700 (21,577)	3,100 (11,735)	1,400 (5,300)	500 (1,893)
Usable Roof Area ft ² (m ²)	1800 (167)	1800 (167)	1800 (167)	1800 (167)
Number of People Served	17	13	8	4
Usable Roof Area ft ² (m ²)	1600 (149)	1600 (149)	1600 (167)	1600 (149)
Number of People Served	15	12	7	3
Usable Roof Area ft ² (m ²)	1400 (130)	1400 (130)	1400 (130)	1400 (130)
Number of People Served	14	12	6	3
Usable Roof Area ft ² (m ²)	1200 (111)	1200 (111)	1200 (111)	1200 (111)
Number of People Served	13	10	6	3
Usable Roof Area ft ² (m ²)	1000 (93)	1000 (93)	1000 (93)	1000 (93)
Number of People Served	11	9	6	3
Usable Roof Area ft ² (m ²)	800 (74)	800 (74)	800 (74)	800 (74)
Number of People Served	10	8	5	3
Usable Roof Area ft ² (m ²)	600 (56)	600 (56)	600 (56)	600 (56)
Number of People Served	8	6	5	2
Usable Roof Area ft ² (m ²)	400 (37)	400 (37)	400 (37)	400 (37)
Number of People Served	6	5	3	2
Usable Roof Area ft ² (m ²)	200 (19)	200 (19)	200 (19)	200 (19)
Number of People Served	4	3	2	1

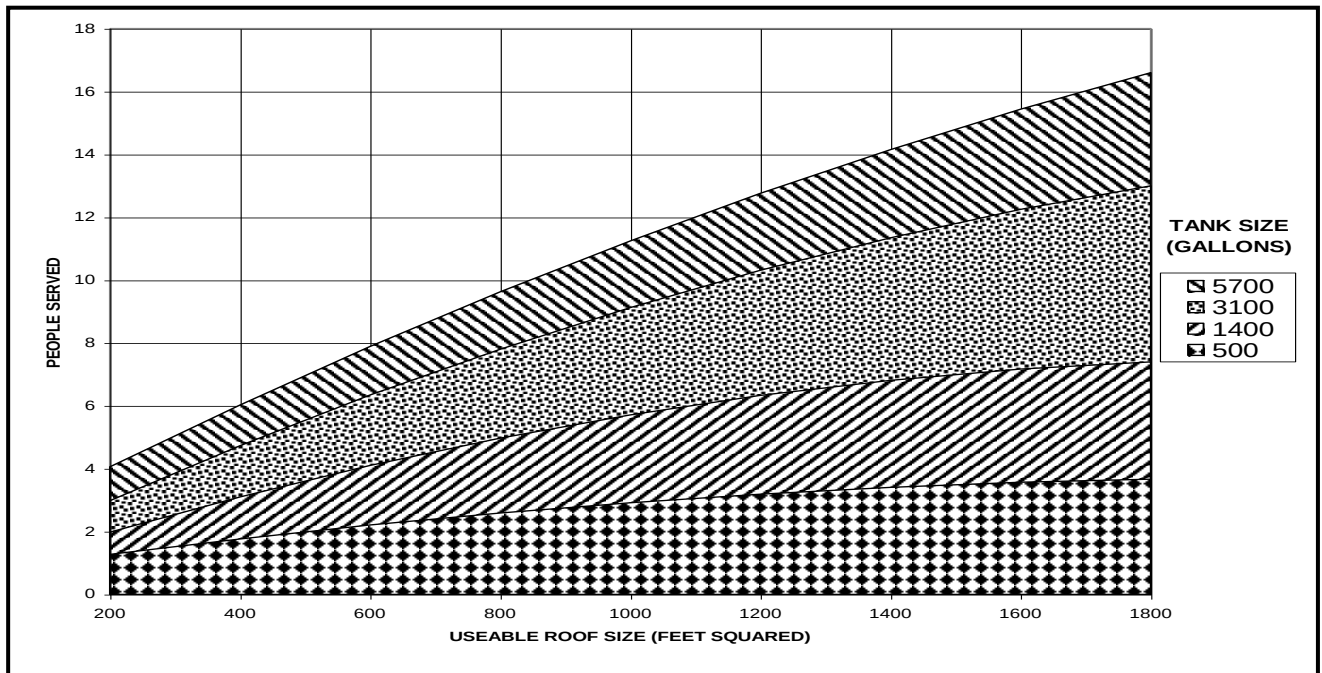


Figure 1. Rain Catchment System Design Monograph. Conservation scheme used assumes that tank use rate will be 4 gal (15.1 liters) per person per day when the tank is below ¼ full and 15 gal (56.7 liters) per person per day at all other times.

While the design monographs described earlier are a concise compact method of providing design information, it was felt that these monographs would not be understood by many of the local people who need information on RWCS sizing. To supplement the design monographs a series of tables was also produced using the data from the model runs. These tables contain the same information as the monographs but in tabular form. An example of these tables is shown in Table 2. The final design brochure will contain a set of tables for usable roof areas varying from 200 to 2000 square feet (9.3 to 185.6 square meters).

To use these tables, those designing new or renovating existing RWCS compute the usable roof area and select the appropriate table for that area. They will pick the correct size tank by choosing the intersection of the row corresponding to the number of people served and the column identifying the type of conservation scheme that will be practiced.

Table 2. Tank sizing tables for Pohnpei Island for Usable Roof Size of 400 to 600 square feet (37.2 to 55.7 square meter) roof area.

	STOP USING WATER FOR BATHING AND WASHING CLOTHES WHEN TANK IS BELOW:			
PEOPLE	FULL	¾ FULL	½ FULL	¼ FULL
9	5700	5700	No	No
8	3100	5700	5700	No
7	3100	3100	5700	No
6	1400	3100	3100	5700
5	1400	1400	3100	3100
4	500	1400	1400	3100
3	500	500	500	1400

TANK SIZES SHOWN ARE IN GALLONS

Conclusions

This study has shown that it is quite possible to design RWCS that can meet the needs of the people of Pohnpei State even during the worst drought conditions. What is important is that the components of RWCS be sized appropriately for the number of people being served by the system and for the kind of conservation practices that are being applied. In field investigations that evaluated RWCS configurations (Heitz, Leroy and Khosrowpanah, Shahram, 1998) we found that in many cases the tanks sizes were more than adequate and in other cases we found that the roof catchment areas were adequate. What was lacking was coordination between tank size, roof size and people being supplied by the systems. If those building new or renovating existing RWCS use the newly developed curves and tables there should be a vast improvement in water supplies and thus an elimination of the hardships of drought that have existed for years in Pohnpei State.

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Influence of Rainfall Amount and Distribution on Rainwater Catchment System Design

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Abstract

The analyses of rainfall characteristics form the core of the hydrological design of rainwater catchment system. Of importance are such aspects as rainfall amount, rainfall distribution, length of wet and dry spells, drought severity among others. The coefficient of variation, unlike the standard deviation, does not depend on the annual totals but only on the degree of variation between the monthly totals for each year. Rainfall amount and rainfall distribution are analysed by calculating the probability of exceedence for each value according to a plotting position formula devised by Weibull.

The results indicate that in the hydrological design of rainwater catchment system, two aspects of rainfall are of paramount importance. These are rainfall amount and rainfall distribution. The hydrological design leads to the determination of the major parameters of catchment area and tank size. This study therefore serves to demonstrate adequately that rainfall amount influence catchment size while rainfall distribution influences the storage capacity.

Rainwater Catchment System Design Methods

The major parameters involved in rainwater catchment system design are the collection area, water demand pattern, rainfall pattern, storage capacity and system reliability. Of the five, the major item of uncertainty is the rainfall regime, which must be analysed in order to determine both the minimum collection area and the size of the tank.

Ngigi (1996) has proposed an extensive investigation of rainfall characteristics such as rainfall amount, rainfall distribution, length of wet and dry spells and severity of drought among other factors for rainwater catchment system design purposes. However, in his development of rainwater catchment system design curves for Kitui area in Kenya, only the reliability of rainfall amounts is established. The reliability of rainfall distribution and its effect on rainwater catchment system design are only mentioned but not taken into account in the design method adopted. Scott, Mooers and Waller (1992) in their development of cistern sizing reference map have used rainfall amounts without any specific consideration of the rainfall distribution. Hai (1998) research in runoff harvesting potential for crop production in Kitui, Kenya uses a rainfall probability to determine design rainfall based on rainfall amounts only.

Schiller and Latham (1987) in their comparison of commonly used hydrologic design methods, notes that the major constraint in the design process is cost which is directly related to the size of the tank. The main part of rainwater catchment system design is in the estimation of tank size required, a quantity that depends on the demand level, the rainfall regime and the reliability of supply required. It is towards this end that a classification of rainfall distribution into various levels of reliability has been attempted using the coefficient of variation values to facilitate more accurate design of storage capacities.

Procedure

The procedure adopted in this study involves the establishment of the reliability of both rainfall amount and rainfall distribution. The combination of the two reliabilities gives the overall design reliability.

2.1 Rainfall amount probability

A preliminary analysis of the historical rainfall data was performed to ensure homogeneity. The 63 years of data were then arranged in descending order and the probability of a given amount was computed using the equation given below: -

$$P = \frac{r}{N + 1}$$

where; P= probability of this amount of rainfall being exceeded

r= rank of rainfall value (highest = 1; lowest = N)

N= total number of data in years

2.1.1 Rainfall distribution reliability

The variation of monthly distribution of rainfall in a year was computed using the coefficient of variation for each of the 63 years of data. The coefficient of variation unlike the standard deviation does not depend on the annual rainfall but only on the degree of variation between the monthly totals for each year. The probability of a given value of coefficient variation that represents that rainfall distribution reliability is obtained using the procedure and the equation given above.

2.1.2 Probability rainfall

Probability rainfall is derived from both rainfall amount and rainfall distribution probability. The distribution of an annual total within the twelve months of the year can be obtained by computing the proportion of the annual total that each month contributes. This leads us to a situation where any given probability of rainfall amount can be distributed in any of the computed probability of rainfall distribution that is desired. Using this approach, a 10% rainfall amount probability is distributed using the proportions obtained in a 10% rainfall distribution probability. The result is the 10% probability rainfall. This is repeated for other levels.

2.1.3 Factor experimentation

The first trial was performed using seven sets of rainfall amount probability, each of which was distributed using the proportions obtained in a single probability of rainfall distribution probability. The rainfall probabilities were then subjected to mass curve analysis to determine the catchment area and storage capacity requirements to serve given water demand. This is repeated for four more probabilities of rainfall amount.

In the second trial, five sets of rainfall distribution probabilities are applied to a single rainfall amount probability. The resultant probability rainfall is subjected to mass curve analysis to determine the catchment area and storage capacity requirements as in the first trial. This is repeated for six more rainfall amount probabilities.

3. Results and Discussion

Results in table 1 show that for each rainfall distribution probability, the tank size remains fairly constant even when rainfall amount probability is increased at that particular rainfall distribution probability. Each rainfall distribution probability level has its own unique storage capacity. This is illustrated in figure 1.

Table 1: Tank size designs (m^3) at various rainfall amount reliabilities and constant rainfall distribution reliability

Rainfall amount reliability	Catchment area (m^2)	Tank size (m^3) at various reliabilities of rainfall distribution				
		30%	50%	70%	90%	95%
10%	52	6.6	8.6	12.1	13.6	21.9
30%	64	6.3	8.3	11.7	13.2	21.4
50%	72	6.4	8.3	11.8	13.3	21.5
70%	88	6.3	8.2	11.7	13.2	21.3
80%	96	6.4	8.4	11.8	13.3	21.5
90%	122	6.4	8.3	11.8	13.3	21.5
95%	130	6.3	8.2	11.7	13.2	21.4
Average tank size (m^3)		6.4	8.3	11.8	13.3	21.5

Table 2: Roof catchment area design (m^3) at various rainfall distribution reliabilities at constant rainfall amount reliability.

Rainfall distribution reliability	Tank size (m^3)	Catchment area (m^2) at various reliabilities of rainfall amount						
		10%	30%	50%	70%	80%	90%	95%
30%	6.4	52	64	72	88	96	122	130
50%	8.3	52	64	72	88	96	122	130
70%	11.8	52	64	72	88	96	122	130
90%	13.3	52	64	72	88	96	122	130
95%	21.5	52	64	72	88	96	122	130

The results for trial two shown in table 2 on the other hand portray a different scenario. For each rainfall amount probability, the catchment area remains fairly constant even as rainfall distribution is varied to different levels, for that particular level of rainfall amount probability. Each level of probability of rainfall amount has a unique catchment area.

4. Conclusion

The results indicate that in a hydrological design of rainwater catchment systems, two rainfall characteristics are of great importance. These are the rainfall amount and the rainfall distribution. This study demonstrates adequately that rainfall amount influence catchment area while rainfall distribution influence storage capacities.

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Optimization of Rainwater Catchment Systems Design Parameters in the Arid and Semiarid Lands of Kenya

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Abstract

It is evident from experiences in Kenya that rainwater could be the long awaited answer to water scarcity in the next millennium. However, some technical and policy hindrances need to be addressed. Lack of appropriate technical designs, among other factors, has led to low adoption of rainwater harvesting technology, especially in Arid and Semiarid Lands (ASAL), where rainwater is one of the most viable water supply. This calls for optimisation of Rain Water Catchment Systems (RWCS) design parameters and formulation of comprehensive water policy. Therefore, to address this problem, the paper focus on the hydrological criteria for determining RWCS design parameters, especially storage capacity and catchment area, using historical rainfall records of Kibwezi rainfall station. Specifically, a design procedure for determining optimal design parameters and developing design curves is outlined. The mass curve analysis was adopted for the determination and optimisation of the design parameters due to outlined inadequacies of most empirical formulae. The strength of the design procedure is the determination of optimal design parameters at various reliability levels of rainfall amount and distribution. The analysis of design parameters revealed that the catchment area and the storage capacity are affected by variations in rainfall amount and distribution respectively.

In addition, the paper proposes a procedure for incorporating rainfall distribution, which has been consistently ignored in the designs of RWCS. The proposed procedure involves adjustment of monthly rainfall by using rainfall distribution indices such that the monthly rainfall totals correspond to annual rainfall at a given rainfall reliability level. The adjusted monthly rainfall is subjected to mass curve analysis to determine the design parameters at various reliability levels. The selection of optimal design parameters is simplified by the development of design tables and curves from which the catchment area and storage capacity for a specific water demand can be easily obtained at various reliability levels. The paper concludes by proposing some recommendations to promote utilisation of rainwater, and adoption of RWCS technology in Kenya. Therefore, the developed procedure could enormously contribute to the adoption and implementation of optimal RWCS designs, and hence supplement government efforts towards meeting ever increasing water demand. The procedure could also be used to evaluate the reliability of existing RWCS.

Introduction

Population pressure has led to substantial settlements in the ASAL, which covers over 80% of Kenya's land surface. These areas were predominantly used for livestock production. The ASAL currently carries more than 35% and 50% of human and livestock population respectively. The ASAL normally experiences low, erratic and unreliable rainfall, with frequent droughts even within the rainy seasons. Hence unreliable and poorly distributed rainfall patterns is the most limiting factor to settlement and agricultural production. In addition, drought occurrence in Kenya has preceded wet seasons or years when so much water is lost as runoff. This is a clear manifestation of the need to promote RWCS technologies both for domestic use and agriculture. There is need to improvise sustainable ways of dealing with the twin problem of lack of adequate water and food supply. The issue of food security is

currently in the development agenda of the ASAL. Therefore, sustainable technologies and supporting policies are necessary to augment water supply.

Thus the development of the ASAL poses a major challenge in the provision of water for economic activities. Provision of adequate domestic water supply and food security are a prerequisite for decent settlement in the ASAL which is compromised by water scarcity. The natural water scarcity is aggravated by alarming population growth rates, environmental degradation, competition over use of limited natural resources, and increasing water demand due to improving living standards, industrialisation and irrigation. In the ASAL, surface water is scarce and exploitation of groundwater is not economically feasible, especially for the rural poor. Therefore, sustainable RWCS remain predominantly one of the most attractive solution to water scarcity. It is unfortunate that such an important technology has not been fully developed despite its world-wide success. For example, in the Negev Desert of Israel, domestic and agricultural water supply is obtained from the meagre rainfall of less than 100mm per year. Ironically, most of the famine stricken ASAL of Kenya receive far much more rainfall.

RWCS technology is cheap, technically simple and environmentally friendly as a water supply system, especially in the ASAL. This notwithstanding, RWCS technology has, in the past, been overshadowed by conventional water supply systems. However, currently it is receiving substantial recognition as a viable and important water supply option (Wafua, 1995; MoWD, 1992, GoK, 1994). This could partly be attributed to failure of conventional water supply systems such as community water projects and multi-million irrigation projects compounded by lack of funding which has led to shift in water resources development and management policies. A number of examples in the ASAL (Ngigi, 1996 and Kiggundu, 1998) clearly indicate that the potential for RWCS as an excellent option to improve food security and water supply. The challenge now is to improve these existing systems to optimise water supply and crop production.

Notwithstanding this recognition, the current approaches have been daunting due to lack of design procedures and guidelines to assist the farmers in realising optimal benefits. Unfortunately, despite increasing adoption of RWCS technologies, according to Ngigi (1996) and Kiggundu (1998), its promotion has been hampered by lack of inadequate designs and water management systems. A field survey conducted by Ngigi (1996) in Machakos and Makueni districts revealed that most of the existing RWCS were inadequate in terms of storage capacity with 40-70% cases of overflow and, despite the long dry seasons of more than 6 months, storage period lasted only 1-2 months. Further, apart from NGOs assisted projects which, unfortunately seemed to have standardised storage tanks, the others did not show any signs of prior designing, and most of the existing roof catchments were not adequately guttered. Generally, there is a mismatch between catchment area and storage capacities (Ngigi, 1996 and Kiggundu, 1998).

Therefore, promotion and adoption of RWCS requires optimisation of the design parameters to reliably meet the anticipated water demand at least cost. Unless this is done, RWCS technologies will remain a partial solution, and not the ultimate answer to water scarcity in the next millennium. The problems of inadequate designs can be addressed through technical, economic and policy options. The most appropriate solution should be self-sustaining, socially acceptable and adaptable to the environment and local technology. In this paper, a technical option is addressed through promotion of a hydrological design criteria which determine the adequacy and reliability of RWCS to meet the anticipated water demand. However, although hydrological criteria supersede economic considerations, the design of RWCS is a compromise between these two design criteria. The compromise is normally reflected in the reliability level of RWCS.

Optimisation of Design Parameters

Optimisation of design parameters entails analysis of rainfall, water demand, catchment area and storage capacity. The following section briefly outlines the necessary analysis of the design parameters using Kibwezi rainfall data as an example.

Rainfall analysis

Rainfall is the main input parameter in the design of RWCS. Therefore, appropriate rainfall analysis is a prerequisite in the determination of design parameters, mainly storage capacity and catchment area. Rainfall analysis entails integration and determination of rainfall parametersC-amount, occurrence/reliability and distribution-Cwhich form the pillar for the selection of optimal design parameters. All the rainfall parameters are interrelated and equally important in the design of RWCS (Ngigi, 1995). More often than not, existing design procedures do not consider all the rainfall parameters and hence lead to inadequate RWCS.

The reliability of RWCS can be determined from the expected reliability of the rainfall amount obtained from frequency analysis of monthly and annual rainfall. Note that although shorter recording intervals are more predictive in the performance of RWCS, their application is not very practical because rainfall occurrence probabilities are normally very low, especially in the ASAL (Ngigi, 1997). Then the reliability is given by using the Weibull plotting positions formulae which compute the expected rainfall amount at various exceedance or non-exceedance probability levels. The higher the reliability the higher the cost of the RWCS, and therefore, the choice of reliability level should consider, not only hydrological criteria, but also the cost of alternative sources of water, and more importantly, the economic capability of beneficiaries. Therefore, the choice of the design rainfall is thus a compromise between hydrological and economic requirements This entails optimisation of the RWCS to supply water at an economically feasible reliability level which takes into account the risk of failure. For RWCS, failure is taken as the period with rainfall lower than the design amount leading to exhaustion of the storage capacity. Hence, the reliability is taken as the probability of non-exceedance of the certain amount of rainfall.

The frequency distribution of monthly rainfall totals does not correspond to annual totals at the same probability of rainfall occurrence due to variation in rainfall distribution among the years. Therefore, application of monthly rainfall to determine the design rainfall amount need to be adjusted to tally with the expected annual rainfall amounts (Ngigi, 1997). However, rainfall distribution has not been adequately considered in the design of RWCS. In particular, it has not been well incorporated thus adversely affecting the storage capacity.

To adjust the monthly rainfall, the distribution indices of annual rainfall were obtained from the proportion of each month's rainfall contributing to the annual totals. These proportionality indices were computed by dividing the monthly rainfall by the annual rainfall for all the years in record (Ngigi, 1996). The indices were then subjected to frequency analysis and standardised to give the expected annual rainfall. The monthly rainfalls, and hence the rainfall distribution, were obtained by multiplying distribution indices by annual rainfall at various reliability levels. This process yielded adjusted monthly rainfall that closely agree with the annual rainfall at any given reliability level (see Table 1 below). This facilitated the determination of the expected annual rainfall distribution at various probability levels which can then be used as the design rainfall for RWCS, in that particular locality.

Table 1: Actual rainfall amounts, distribution indices and adjusted rainfall amounts at 30% and 70% reliability levels.

Month	Actual rainfall amount (mm)		Distribution indices		Adjusted rainfall amount (mm)	
	30%	70%	30%	70%	30%	70%
Jan.	43	8	0.058	0.022	34	25
Feb.	29	1	0.041	0.002	22	16
Mar.	119	22	0.149	0.078	69	52
Apr.	164	60	0.178	0.202	149	110
May	31	9	0.042	0.033	29	21
Jun.	2	0	0.003	0.000	0	0
Jul.	0	0	0.001	0.000	0	0
Aug.	2	0	0.002	0.000	0	0
Sep.	3	0	0.003	0.000	1	1
Oct.	38	1	0.054	0.003	14	10
Nov.	206	118	0.285	0.338	221	164
Dec.	157	99	0.219	0.284	184	138
Annual	727	547	--	--	723	537

Water demand

Water demand determines the amount of water to be harnessed, and consequently the catchment area and storage requirements. Water demand is computed from per capita water consumption, number of consumers, and the design period. The design period, or time span, used for design is normally one hydrological year which corresponds to the rainfall occurrence cycle. The per capita water consumption rate varies between 15-40 litres per person per day and it can go as high as 60 l/day depending on the climate. Water consumption is also influenced by the economic status of the users and also the composition of the family. The per capita water consumption is lower in disadvantaged than economically endowed areas. The amount of daily water consumption vary considerably depending on whether the users waste or ration water. In practice, most households will use the water copiously during the rainy periods, especially if the tank is overflowing, and will ration it or find other sources during the dry periods. Nevertheless, in order to estimate the total water requirements, an inventory of all water consumers is a prerequisite.

Catchment area and storage capacity

The type and size of the catchment determines the amount of rainwater that can be harvested and hence the storage capacity for a certain design rainfall amount. A reliable RWCS requires optimal combination of catchment and storage systems in order to maximise the overall reliability at the lowest cost. The design of a RWCS, requires the determination of the optimal size of the catchment which would yield adequate water to satisfy the anticipated demand. The water demand hence becomes an input parameter, equivalent to Q_y in equation (1) below. This would then dictate the capacity of the storage system, and subsequently the cost of the whole RWCS. The water yield of a RWCS depends on rainfall characteristics; amount (P), reliability and distribution, and the catchment characteristics; type, size (A) and runoff coefficient (C). The water yield, Q_y (l) is given by:

$$Q_y = CAP \dots\dots\dots (1)$$

Furthermore, determination of the optimal size of the storage capacity of RWCS is a prerequisite because the storage tank is the key and usually the most expensive component. The storage requirement is taken as the volume of water that would be stored to meet the water requirements throughout the critical dry spell. Storage capacity depends on the water demand, length of the dry period, water use strategies and the available tank sizes. Therefore, the anticipated water demand dictates the size of the required storage capacity, while the amount of expected rainfall, and the size and type of catchment will determine whether this demand can be satisfied.

In most cases, empirical formulae have been developed to determine the design parameters (catchment area and storage capacity) for RWCS (Ndiritu, 1992). However, Ngigi (1996) found out that most of them are site specific, and hence inadequate without modifications to suit a certain locality. In addition, most of the empirical equations ignore one important input parameterCrainfall distributionCwhich is very critical in determining the design parameters. Another limitation of most of these empirical formulae is that they do not give the reliability levels in design. Ndiritu (1992) indicated that such formulae assume that the averages represent the rainfall series adequately, and thereby ignore the annual variability of rainfall. This variability is often high especially in ASAL and ignoring it could have a significant effect on the storage capacity and overall reliability. Therefore, application of these empirical formulae compromise their simplicity with reliability and the cost of the system. Repercussions can be far reaching and dangerous in terms of reliability of the RWCS. This revelations call for caution in applying empirical equations developed elsewhere. Unfortunately, empirical equations have been adopted and recommended by a number of authors (e.g. Kalders, 1986; Ndege, 1992; and Omwenga, 1984), for the Kenyan conditions without due consideration of their applicability and limitations. However, where applicable, modification of empirical formulae and consideration of reliability could give favourable results (Ngigi, 1996).

Nevertheless, the mass curve analysis is more appropriate in that it considers all the input parameters. It is also not site specific, and hence has a wide application. The mass curve analysis can also be used to monitor water management, by giving the tank volume at any time, provided that water inflows and outflows records are taken continuously. This is important, especially for regulating water utilisation, in case of unexpected drought. The mass curve analysis can be presented empirically by the following equation adopted from Ngigi (1996).

$$T \quad V_T = \sum_{t=1} (Q_t - V_{i,t} + L_t) \dots\dots\dots (2)$$

Where; V_T = storage capacity at time, T,
 Q_t = water demand at time, t,
 $V_{i,t}$ = volume of inflow at time, t, and
 L_t = losses from the system during time, t.

The mass curve analysis, in which for an adequate design, the cumulative water demand equals cumulative supply over a given hydrological period, the storage required at time T was found to be the most ideal procedure for determining the design parameters for RWCS, and hence the design curves. However, the effectiveness of the mass curve analysis depends on the accuracy of determining the starting month of the hydrological yearC-the beginning of the rainy season and/or the end of the dry

seasonC-when the tank is almost empty. The starting month was determined by carrying out the mass curve analysis, starting in turn with the most probable initial months; September, October and November, which correspond to the end of the dry spell and the beginning of the rainy season. Besides giving the lowest tank volume, the initial month also corresponds to the optimal catchment area. In our case, November is the starting month. Thereafter, the optimal tank size is obtained from the largest cumulative 'surplus' that represents the residual water quantity in the tank, which will be large enough to store water during the dry months preceding the rainy season, a characteristic of rainfall in the ASAL. The size of the tank should also be adjusted to available sizes, especially for ready made GI or PVC tanks.

The mass curve analysis, unlike most empirical equations, can be carried out using various rainfall amount and distribution reliability levels to give the design parameters at various reliability levels, and hence a set of design values. However, a 100% reliability of water supply could hardly be achieved due to the stochastic nature of rainfall which determines the inflow during any given period. The choice of the optimal design values depend on *inter alia* availability and cost of alternative water sources, cost of raw materials and available market sizes, technology and skilled manpower, and socio-economic status of the household. In this regard, the determination of optimal storage capacity is not a straightforward exercise because both the rainwater supply and the demand patterns are non-deterministic, and follow time dependent, non-stationary stochastic processes. Hence, to ensure optimal storage capacity, an iterative process is used in which water demand is compared with water yield for a specified time interval within a hydrological year.

If the water yield does not meet the anticipated water demand, other alternative water sources are adopted. However, in ASAL, especially during the dry seasons, this option may not be feasible. In such a situation, one alternative to increase water supply is to, where applicable, expand the size of the catchment area. Therefore, quite often, the hydrological design criteria, only provide the basis for determining the optimal design parameters. Thus where the catchment area is predetermined, the only other technical option is to lower the design reliability level, and incorporate water management strategies, such as measures to reduce water consumption through water rationing.

Development of the Design Curves

In view of addressing the technical design limitations, simple design curves were developed using the mass curve analysis. The mass curve analysis was carried out using the adjusted monthly rainfall at various rainfall amount and distribution reliability levels. The cumulative water inflows were computed by an iterative method for various catchment sizes until an optimal size which offset any given water demand was obtained. A range of design parameters were obtained by varying the water consumption rates between 60 and 600 l/day for various reliability levels. However, design values for higher water demands were computed by applying the law of proportionalityCwater demand is proportional to the storage capacity and hence the catchment area. The water yields were computed from equation (1) in which the runoff coefficient was, for convenience taken as 1. But for a particular RWCS, design parameters can be obtained by dividing the given values by specific catchment characteristics. Combinations of various water consumption rates, reliability of rainfall amount and distribution, produce a series of design parameters from which the optimal catchment area and storage capacity can be obtained for a given water demand.

The mass curve analysis may also be used to evaluate the adequacy for the design of the existing RWCS and their reliability. This could be accomplished by comparing the cumulative monthly catchment runoff and the cumulative monthly consumption throughout the year. If the difference is

positive for all months, the RWCS is adequate, otherwise a negative difference in any month indicates that the system is not sufficient. Precisely, an adequate design should give a cumulative difference between the water yield and demand close to zero at the end of the hydrological year, otherwise a large positive difference means that the system is over-designed whilst a large negative means that the system is inadequate, and hence the catchment area needs to be increased and/or water consumption reduced to make the system viable.

To ease the determination of RWCS design parameters, design curves presented in Figure 1 were developed for various water demand, reliability of rainfall amount and distribution. Such design curves simplify the process of design and/or evaluation of the RWCS. They also provide the designer with an option in terms of the reliability of water supply and thus facilitate the planning and operation of RWCS. However, the design curves are site specific and thus are not applicable to other areas, perhaps except with caution, to other localities with similar rainfall characteristics.

Conclusions and Recommendations

Rainwater harvesting is a potential source of adequate and reliable water supply, especially in rural areas, in particular, in less water endowed ASAL, where other water sources are not technically and/or economically feasible. Inadequately designed systems, in terms of storage capacity and catchment area, could only supply water for only a short period after the rainy season, and not the entire dry period. Further, incidence of tank overflow are also rampant during the rainy season. This clearly indicate a technical shortcoming in the existing RWCS designs for domestic water supply. Notwithstanding technical impendence, promotion of RWCS in Kenya, especially by NGOs and religious organisations through self-help groups, is recommendable. However, most of these organisations lack technical skills and design tools to promote sustainable and reliable RWCS. Therefore, there is an urgent need to develop simple design tools to enhance utilisation and adoption of technically optimal RWCS.

An attempt to address technical shortcoming in the design of RWCS has been made. This involve use of mass curve analysis to determine the optimal design parameters. This procedure take into accounts all the input parameters, especially rainfall distribution that is commonly ignored in the existing procedures. Otherwise, most of the simple empirical equations used for designing RWCS does not adequately consider all the input parameters related to rainfall characteristics. Notably, rainfall reliability and distribution are normally ignored. The rainfall time series analysis is not carefully integrated in the design procedures. In order to appropriately determine the design rainfall, the main input parameter, its reliability and distribution is important. As rainfall reliability and distribution varies from year to year, rainfall variability must be considered. Inadequate analysis of rainfall may lead to insufficient RWCS, especially storage capacity and catchment area. It is evident that variability in rainfall amounts only affects the catchment area while the variability in rainfall distribution affects the storage capacity.

The overall result of this paper is a simple design tool, in form of design curves for Kibwezi. Although emphasis has been put on domestic water supply, the same design curves can be used to determine design parameters for livestock and agricultural (runoff farming) water uses. Therefore, this paper goes a long way to initiate a process towards development of a design manual, by formulating a design procedure. It is envisaged that the proposed design procedure would be adopted to develop design curves for other regions, and subsequently a design manual for Kenya, and in general other parts of Africa, in the view of promoting rainwater as an answer to looming water crisis in the next millennium.

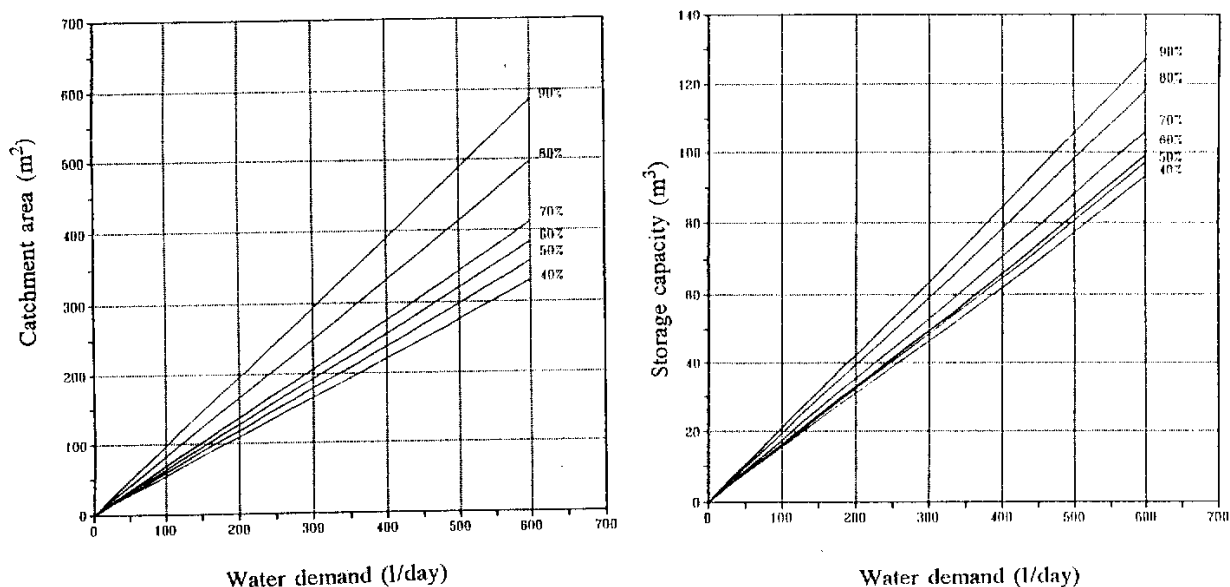


Figure 1: Rainwater catchment systems design curves for semi-arid Kibwezi region of Kenya.

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The Sizing of Rainwater Stores Using Behavioural Models

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Abstract

The collection of rainwater from roofs, its storage and subsequent use is a simple method of reducing the demand on both the public water supplies and waste treatment facilities. The capacity of the rainwater store is important because it affects both system and installation costs.

The rainwater store can be sized using one of three general types of model, namely, Critical period methods, Moran related methods and Behavioural models. This paper concentrates upon the use of behavioural models for the sizing of rainwater stores.

Behavioural models simulate the operation of a reservoir with respect to time. The operation will usually be simulated over a given period of time using a time step of a minute, hour or month. The operation of the store is simulated using either a yield after spillage (YAS) or yield before spillage (YBS) algorithm. This paper evaluates the accuracy of behavioural models using different time steps and different sizing algorithms applied to both large and small stores.

1. Introduction

The collection of rainwater from roofs, its storage and subsequent use is a simple method of reducing the demand on both the public water supplies and waste treatment facilities. Without extensive treatment the rainwater is suitable for a range of uses such as WC flushing, garden irrigation and clothes washing. The capacity of the rainwater store is important both economically and operationally.

McMahon and Mein [1] identify three general types of reservoir sizing model, namely; critical period, Moran and behavioural models. Critical period methods identify and use sequences of flows where demand exceeds supply to determine the storage capacity. Moran related methods are a development of Moran's [2] theory of storage. A system of simultaneous equations are used with this method to relate reservoir capacity, demand and supply. The analysis is based upon queuing theory.

Behavioural models simulate the operation of the reservoir with respect to time by routing simulated mass flows through an algorithm which describes the operation of the reservoir. The operation of the rainwater collector will usually be simulated over a period of years. The input data which is in time series form is used to simulate the mass flows through the model and will be based upon a time interval of either a minute, hour, day or month. This paper

investigates the use of behavioural models for the sizing of rainwater collection systems using different time intervals and different reservoir operating rules applied to a range of reservoir capacities and collection areas.

2. Background

Behavioural models have been used by other researchers [3, 4] to investigate the performance of rainwater stores. Jenkins et al [3] developed a behavioural model and identified two fundamental algorithms to describe the operation of the rainwater store. The yield after spillage (YAS) operating rule is:

$$Y_t = \min \begin{pmatrix} D_t \\ V_{t-1} \end{pmatrix} \quad (1)$$

$$Q_t = \min \begin{pmatrix} V_{t-1} + Q_t - Y_t \\ S - Q_t \end{pmatrix} \quad (2)$$

Where:

R_t	=	Rainfall (m) during time interval, t
Q_t	=	Rainwater run off (m ³) during time interval, t
M_t	=	Mains supply make-up (m ³) during time interval, t
O_t	=	Overflow from store (m ³) during time interval, t
V_t	=	Volume in store (m ³) during time interval, t
Y_t	=	Yield from store (m ³) during time interval, t
D_t	=	Demand (m ³) during time interval, t
S	=	Store Capacity (m ³)
A	=	Roof Area (m ²)

The yield before spillage (YBS) operating rule is:

$$Y_t = \min \begin{pmatrix} D_t \\ V_{t-1} + Q_t \end{pmatrix} \quad (3)$$

$$Q_t = \min \begin{pmatrix} V_{t-1} + Q_t - Y_t \\ S \end{pmatrix} \quad (4)$$

Jenkins et al [3] used the YAS algorithm and a monthly time interval. The reliability or performance of the rainwater store can be expressed using either a time or volume basis. In either case a reliability or performance of 100% indicates complete security in provision of service water. Latham [4] used a behavioural model but defined the reservoir operating algorithm in a more general form:

$$Y_t = \begin{pmatrix} D_t \end{pmatrix}$$

$$\min \left(\begin{array}{l} (V_{t-1} + \theta Q_t) \\ (S - (1 - \theta)Y_t) \end{array} \right) \quad (5)$$

$$Q_t = \min \left(\begin{array}{l} (V_{t-1} + Q_t - \theta Y_t) - (1 - \theta)Y_t \\ (S - (1 - \theta)Y_t) \end{array} \right) \quad (6)$$

Where θ is a parameter between 0 and 1. If $\theta = 0$, the algorithm is YAS and if $\theta = 1$ the algorithm is YBS. Latham [4] developed a model using the YAS algorithm with a monthly time interval and observed this model could predict storage sizes that were uneconomically large compared to the capacities determined using a daily time interval. The YAS, monthly model was modified by Latham [4] to predict storage capacities which were comparable to the store sizes modelled using a daily time interval. The storage capacities predicted using a YAS monthly time interval with a 99% volume reliability were found to correlate well with the storage volumes determined with a YAS daily time interval model which satisfied a 100% volume based reliability.

3. The proposed behavioural model investigation

Two generic types of rainwater storage system can be identified:

- i) Large volume stores that conserve a large proportion of household water ($\geq 95\%$) and reduce flows into the surface water sewer network.
- ii) Small volume stores which conserve a small but useful proportion of household water [$\leq 50\%$] compared to other conservation measures. Flows into the surface water sewer network are reduced but not by the same order of magnitude compared to large volume stores (type (i)).

All of the models reviewed in the previous section relate specifically to large volume stores with high reliability levels (type (i)). Small volume stores (type (ii)) offer a number of advantages; ease of integration within the building structure, low capital cost and short duration rainwater retention times within the store. Previous research has also concentrated upon the development of behavioural or critical period models using a monthly time interval although it is recognised that hourly or daily time series result in a more accurate simulation of system performance than monthly time intervals [5]. However the most appropriate time intervals for modelling the performance of systems using different combinations of store capacity and collection area have not been identified. The use of both YAS and YBS models has been reported in previous studies but the development of a more generic approach and the estimation of the parameter, θ (section 2), has not been investigated.

The objectives of this paper are summarised below:

- i) Investigate behavioural models using different time intervals when applied to a range of store capacities (large and small) and collection area combinations.
- ii) Determine values of the general reservoir operating algorithm parameter, θ , for different model time intervals when applied to a range of store capacities (large and small) and collection area combinations.

iii) Provide design guidance for the sizing of large and small rainwater stores using behavioural models.

4. Development of the behavioural model

The rainwater collection sizing (rcs) model consists of two parts:

- i) Provision of rainfall supply and usage demand patterns or time series.
- ii) Simulation of system operation.

A comprehensive twelve month historical data set of rainfall and WC demand time series collected during the field testing of a rainwater collection system [6] was used as input to the system simulation model. The demand in this study was limited to WC usage which accounts for approximately 30% of potable household water usage in the UK [7]. The general form of the reservoir operating algorithm was used in the system simulation model as defined in section 2 (eqn 5 & 6).

The performance of the rainwater collection system is described by its water saving efficiency (E_T) [8]. Water saving efficiency is a measure of how much mains water has been conserved in comparison to the overall demand of the WC and is given by equation (7).

$$E_T = \frac{\sum_{t=1}^T Y_t}{\sum_{t=1}^T D_t} \times 100 \quad (7)$$

Where T = Total time under consideration.

5. The accuracy of different rainwater collection sizing models

Previous research [6] has investigated the validity of using a YAS behavioural model to predict the water saving efficiency (E_T) of a rainwater collector and the sensitivity of a YAS model to the time interval of the input time series. During the field testing of a rainwater collection system the water saving efficiency of the installation was measured at the end of each month over a monitoring period of one year. The system utilised a 2000 litre capacity store and collected rainwater from a roof area of 85 m². The measured water saving efficiencies of the system were compared with the water saving efficiencies predicted by a YAS model using both hourly and daily time intervals. The results of this preliminary analysis indicated a YAS model using either hourly or daily input time series could be used to predict system performance. In this section, the previous research [6] outlined above is extended by modelling the water saving efficiencies of a rainwater collector using a range of store capacities and roof areas. Hourly, daily and monthly input time series using both YAS ($\theta = 0$) and YBS ($\theta = 1$) reservoir operating algorithms are investigated.

The different combinations of roof area and store capacity are expressed in terms of two dimensionless ratios, namely the demand fraction and the storage fraction. The demand fraction is given by, D/AR where; D = annual demand (m³); A = roof area (m²) and R = annual rainfall (m). The storage fraction is given by, S/AR where; S = store capacity (m³).

The performance of rainwater collection systems with demand fractions of 0.27, 1.25 and 2.5 each with a storage fraction range of 0.0015 to 1.08 were investigated.

The aim of the analysis in this section is to identify the maximum rainwater collection sizing model time intervals which can be used with different combinations of demand fraction and storage fraction whilst modelling water saving efficiency within specified limits of accuracy. Data acquisition costs reduce as the time interval of the model increases. The relationships between water saving efficiencies predicted by the hourly (YAS) model and water saving efficiencies determined by the other hourly, daily and monthly models are analysed. Each model was investigated for demand fractions of 0.27, 1.25 and 2.5 with the storage fraction ranging from 0.0015 to 1.08, the models output the water saving efficiencies at the end of each simulated month of operation.

The water saving efficiencies predicted by the hourly (YAS) model were plotted in turn against the water saving efficiencies predicted by the hourly (YBS), daily (YAS), daily (YBS), monthly (YAS) and monthly (YBS) models. For each plot a straight line was fitted to the data points using linear regression. In each case the intercept of the straight line was set to zero before determining the gradient (m) of the straight line and the coefficient of determination (R^2). The values of m and R^2 for both YAS and YBS models with storage fraction ranges of 0.0015 to 1.08 are given in Tables 1, 2 and 3 for demand fractions of 0.27, 1.25 and 2.5 respectively.

For the YAS model with a demand fraction of 1.25 and storage fraction of 0.0015 (Table 2) there is a strong correlation between the water saving efficiencies predicted by the daily model compared to the performance modelled by the hourly models. The coefficient of determination (R^2) between the straight line equation predicted by the linear regression and the data points is 0.94. However the gradient (m) predicted straight line equation which has a value of 1.51 (Table 2) indicates the daily model underestimates the water saving efficiency by approximately 33%. A value of $m = 1$ represents perfect estimation of water saving efficiency whilst $m < 1$ indicates overestimation. For the corresponding monthly (YAS) model $R^2 = 0.07$ and $m = 14.99$ (Table 2). The coefficient of determination between the straight line equation predicted by the linear regression and the data points is therefore poor and water saving efficiency is underestimated by approximately 93%.

Generally for YAS models as the storage fraction increases the value of m decreases and approaches unity whilst R^2 increases. In the case of YBS models both m & R^2 increase with increasing storage fractions. In order to assess satisfactory combinations of demand fraction, storage fraction and model time interval arbitrary limits were imposed upon the values of m and R^2 . It was assumed the accuracy of the modelled system performance would be preserved within acceptable tolerances if the following limits were observed:

$$1.11 \geq m \geq 0.89 \quad (7)$$

$$R^2 \geq 0.9 \quad (8)$$

The limits of m result in modelled water saving efficiencies within the boundaries of $\pm 10\%$. Combinations which do not satisfy these constraints are shaded grey in Tables 1, 2 & 3.

Generally daily YAS and YBS models are satisfactory for all demand and storage fractions except small stores with demand fractions of 1.25 and 2.5 when hourly models should be used. Monthly models can only be used to predict the performance of large stores. The

analysis suggests the following constraints can be applied to the time intervals of behavioural models:

- i) Hourly models, $S/AR \leq 0.01$ (9)
- ii) Daily models, $0.125 \geq S/AR > 0.01$ (10)
- iii) Monthly models $S/AR > 0.125$ (11)

6. Assessment of the storage algorithm parameter (θ)

The performance of rainwater collection systems, except those utilizing small stores, can be accurately predicted using a YAS model with a daily time interval. When daily data is not available a model using a monthly time interval and appropriate value of the parameter, θ , (Sect. 2) can be used to produce comparable predictions of water saving efficiency. Values of the parameter, θ , were estimated for combinations of demand fraction and supply fraction within the ranges 0.27 to 5 and 0 to 1.08 respectively. The water saving efficiencies of a rainwater collection system were modelled for each demand and supply fraction combination using both daily (YAS) and monthly (θ) models. In the case of the monthly (θ) model a value of the parameter θ was chosen to predict the water saving efficiency within 0.01% of the value determined by the daily (YAS) model. The daily (YAS) and monthly (θ) models used fifty years of historical rainfall time series for the Nottingham area within the UK. The demand for each system was assumed to occur at a constant daily or monthly rate.

The variation of the parameter, θ , against storage fraction for the following ranges of demand fraction, 0.27 to 0.55, 0.55 to 1.00 and 1.00 to 5.00 are illustrated in Figures 1, 2 and 3 respectively. The average variation of the parameter, θ , against storage fraction associated with each of the demand fraction ranges and the overall average curve for the complete demand fraction range of 0.27 to 5 are illustrated in Figure 4. Each curve demonstrates a characteristic skewed distribution.

The validity of the water saving efficiencies predicted by the monthly (θ) model using average values of θ (Fig 4) was investigated using linear regression analysis. The water saving efficiencies predicted by the monthly (θ) model were plotted against the corresponding values predicted using the daily (YAS) model. For each plot, a straight line was fitted to the data points using linear regression and the values of m and R^2 determined (Table 4). In each case the intercept of the straight line was set to zero. Overall the agreement between the water saving efficiencies predicted by the monthly (θ) model and the daily (YAS) model is very good as indicated by the large proportion of correlation coefficients exceeding 0.94. There are three exceptions which occur at demand fractions of 0.27 and 5 (Table 4). The monthly (θ) model using average values of θ therefore provides a flexible and accurate method of predicting water saving efficiency for the range of demand fractions likely to be encountered in practice.

7. Limitations of study and further work

The analysis described has been restricted to one set of rainfall data for the Nottingham area of the UK. The average annual rainfall for Nottingham is 630 mm which is low compared to the UK annual average of 1205 mm. Further research is planned using rainfall data from at least two other areas of the UK which experience average and high annual rainfall levels compared to the national average. The analysis using the additional rainfall data sets will

confirm the extent to which the results of the present research can be generally applied to other regions of the UK.

8. Conclusions

A preliminary mapping exercise has been successfully undertaken which evaluates the accuracy of behavioural models for the sizing of rainwater collection systems using both different time intervals and reservoir operating algorithms applied to a comprehensive range of operational conditions. Initially the general reservoir operating algorithm used in behavioural models to describe the operation of rainwater stores was reviewed. The model parameter, θ , was defined and two extreme reservoir operating conditions identified, namely, yield after storage (YAS) when $\theta = 0$ and yield before storage (YBS) when $\theta = 1$.

The accuracy of behavioural models using different time intervals applied to a range of demand fractions and storage fractions has been evaluated. The analysis enabled constraints to be proposed for the application of hourly, daily and monthly models expressed in terms of storage fraction.

Hourly models should be used for sizing small stores with a storage fraction below or equal to 0.01. Daily models can be applied to systems with storage fractions within the range 0.01 to 0.125. Monthly models are only recommended for use with storage fractions in excess of 0.125.

Generally monthly models can only be used to predict the performance of large stores whilst hourly models are required for the sizing of small stores.

Values of the parameter, θ , have been determined for a monthly model operating over a comprehensive range of demand and storage fractions. The water saving efficiencies predicted by the monthly (θ) model using average values of the parameter, θ , correlate well with the corresponding values determined using a daily (YAS) model over the range of demand fractions likely to be encountered in practice. Further research is required to confirm the results of this study are generally applicable to other areas of the UK which experience different levels of annual rainfall. When this further work has been undertaken a flexible method of assessing the performance of rainwater collection systems in the UK using monthly data will have been developed and validated.

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Table 1 Values of m and R² for a demand fraction of 0.27

		STORAGE FRACTION [S/AR]																			
		0.0015		0.0024		0.01		0.02		0.05		0.125		0.25		0.5		0.75		1.08	
MODEL	TIME INTERVAL	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²
YAS	HOURLY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
YAS	DAY	1.0	0.9	1.0	0.9	1.0	0.9	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		1	8	3	9	0	9	0	8	0	0	0	0	0	0	0	0	0	0	0	0
YAS	MONTH	7.8	-	6.2	0.0	3.8	-	1.0	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
		6	0.5	1	4	2	0.0	1	9	9	7	9	7	9	7	9	7	9	7	9	7
			3				2														
YBS	HOURLY	0.9	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		9	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YBS	DAY	0.8	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
		9	8	1	7	7	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
YBS	MONTH	0.5	0.4	0.6	0.4	0.7	0.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
		7	3	4	4	8	0	7	4	9	7	9	7	9	7	9	7	9	7	9	7

Table 2 Values of m and R² for a demand fraction of 1.25

		STORAGE FRACTION [S/AR]																			
		0.0015		0.0024		0.01		0.02		0.05		0.125		0.25		0.5		0.75		1.08	
MODEL	TIME INTERVAL	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²
YAS	HOURLY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
YAS	DAY	1.51	0.9	1.26	0.9	1.0	0.9	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
			4		8	4	9	1	0	0	9	0	0	0	0	0	0	0	0	0	0

YAS	MONTH	14.9 9	0.0 7	11.0 3	0.0 7	5.1 9	0.2 3	3.1 4	0.3 6	2.0 0	0.6 9	0.9 9	0.8 4	0.9 8	0.9 0	0.9 8	0.9 0	0.9 8	0.9 0	0.9 8	0.9 0
YBS	HOURL	0.97	1.0 0	0.98	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0
YBS	DAY	0.63	0.9 5	0.74	0.9 7	0.9 3	0.9 9	0.9 7	1.0 0	0.9 9	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0
YBS	MONTH	0.30	0.8 0	0.38	0.8 0	0.6 8	0.8 0	0.8 0	0.8 5	0.8 9	0.9 2	0.9 8	0.9 0	0.9 8	0.8 0	0.9 8	0.9 0	0.9 8	0.9 0	0.9 8	0.9 0

Table 3 Values of m and R² for a demand fraction of 2.5

		STORAGE FRACTION [S/AR]																			
		0.0015		0.0024		0.01		0.02		0.05		0.125		0.25		0.5		0.75		1.08	
MODEL	TIME INTERVAL	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²
YAS	HOURL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
YAS	DAY	1.89	0.8 7	1.48	0.8 5	1.0 8	0.9 9	1.0 4	0.9 8	1.0 6	0.9 1	1.0 3	0.9 2	1.0 3	0.9 2	1.0 3	0.9 2	1.0 3	0.9 2	1.0 3	0.9 2
YAS	MONTH	18.9 3	0.0 4	14.3 2	0.0 5	5.9 2	0.1 9	3.7 3	0.3 0	1.9 9	0.6 0	1.1 1	0.9 2	0.9 5	0.8 9	0.9 5	0.8 9	0.9 5	0.8 9	0.9 5	0.8 9
YBS	HOURL	0.92	0.9 9	0.94	1.0 0	0.9 9	1.0 0	0.9 9	1.0 0	1.0 2	0.9 8	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0
YBS	DAY	0.53	0.9 4	0.62	0.9 6	0.8 8	0.9 8	0.9 5	0.9 9	1.0 1	0.9 8	0.9 9	1.0 0	0.9 9	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0
YBS	MONTH	0.29	0.7 4	0.35	0.7 6	0.6 3	0.8 5	0.7 8	0.9 4	0.9 5	0.8 9	0.9 5	0.8 9	0.9 5	0.8 9	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0	1.0 0

Table 4 Values of m and R²

AVERAGE PARAMETER, θ , CURVE RANGE	DEMAND FRACTION (D/AR)											
	0.27		0.55		0.75		1.00		1.25		5.00	
	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²	m	R ²
0.27 - 0.55	1.03	0.96	0.99	1.00	-	-	-	-	-	-	-	-
0.55 - 1.00	-	-	1.01	1.00	1.00	1.00	0.99	1.00	-	-	-	-
1.00 - 5.00	-	-	-	-	-	-	1.02	0.94	1.04	0.96	0.92	0.83
0.27 - 5.00	1.02	0.80	1.02	0.98	1.01	0.99	0.99	1.00	1.01	0.99	0.89	0.73

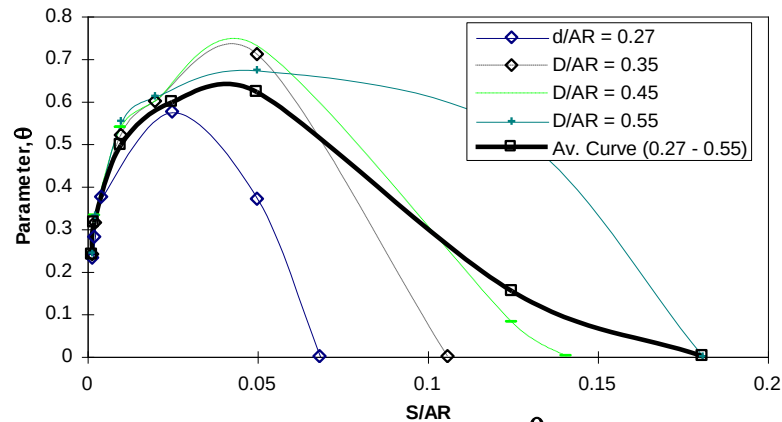


Figure 1 The variation of parameter, θ , with storage fraction
($D/AR = 0.27 - 0.55$)

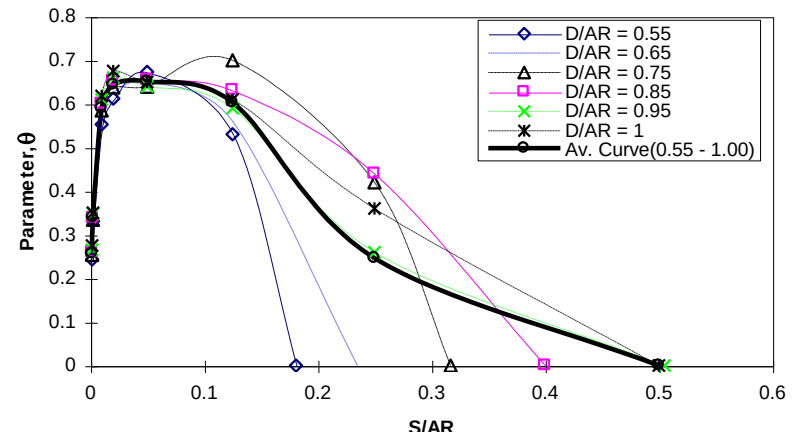


Figure 2 Variation of parameter, θ , with storage fraction
($D/AR = 0.55 - 1.00$)

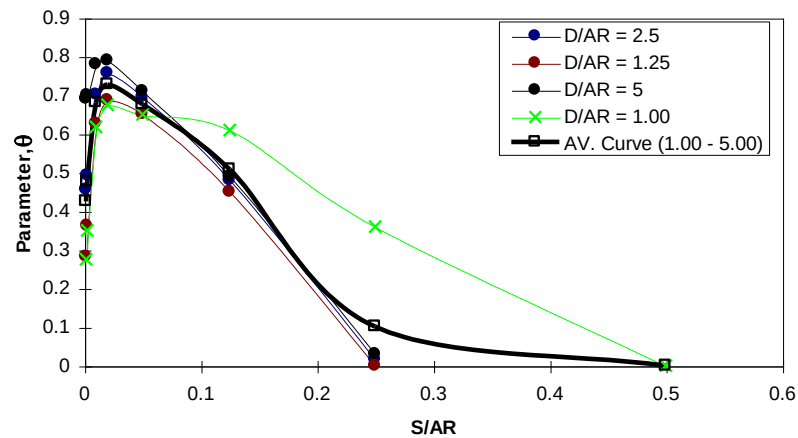


Figure 3 The variation of parameter, θ , with storage fraction
($D/AR = 1.00 - 2.50$)

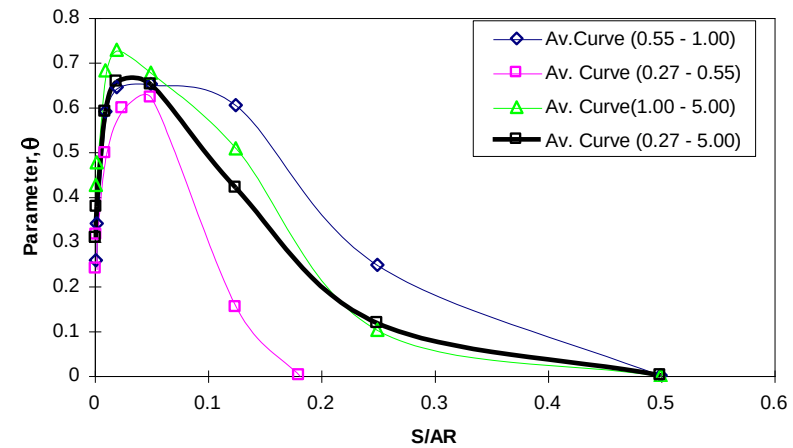


Figure 4 The average variation of parameter, θ , with storage fraction
($D/AR = 0.27 - 5.00$)

Evaluation of Rainwater Storage Alternatives on San Andrés Island, Colombia

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Abstract

We proposed and evaluated different options for a cistern of a “typical” house on San Andrés, Colombia, a very small island (27 km²) in the Caribbean facing Nicaragua's coast. On San Andrés, underground water supplies are very limited and the geologic conditions for storing surface water are not favorable.

We have carried out an economic study for the different storage alternatives to determine the most suitable material for the construction of the cisterns, be they concrete, modular, polyethylene or wood. 5 people inhabit a "typical" San Andrés house. We calculate a gathering area of 75 m² and an optimal cistern volume of 20 m³.

Rainwater storage alternatives

Concrete cistern

The best way to get a bigger area using a minimum of construction materials is the circumference. But due to the difficulty of constructing cylindrical cisterns and since they are not adjusted to the urban development patterns, this cistern is build as a rectangle, in such a way that it can change the shape according to the available space.

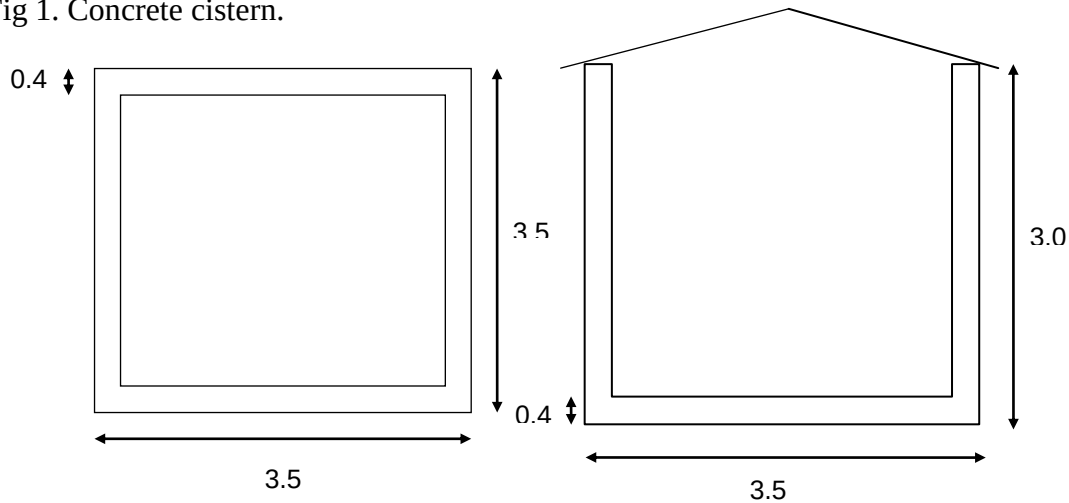
To estimate the dimensions of the cistern, side of the cube (tank) to be build, we have to get the third root of the storage volume, for a “typical” house:

$$\sqrt[3]{20} \approx 2.7$$

The cistern will be a cube with a side of 2.7 m.

One part cement mixed with two parts of sand and three parts of gravel (1:2:3) is used for the construction guaranteeing the strength of the cistern. The structure doesn't have steel bars, because of the salt in the environment. With time this material will be oxidized breaking the walls of the cistern.

Fig 1. Concrete cistern.



On San Andrés Island this storage system costs US \$ 1,000.--

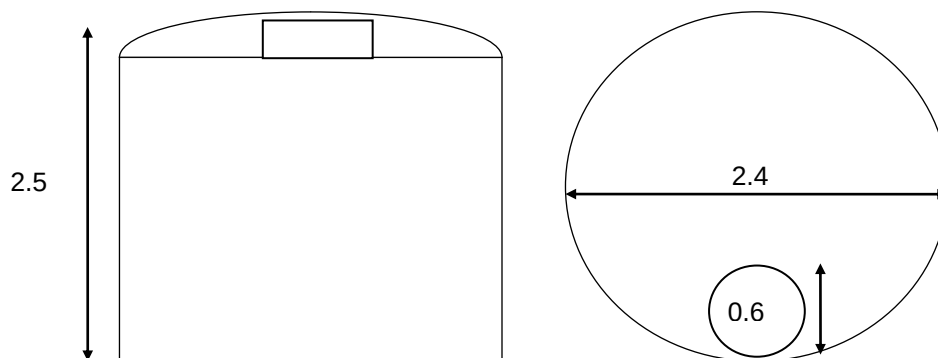
Modular cistern

The modular cistern consists of a series of interconnected plastic tanks, adjusting the stored volume to the requirements of the house. The proposed system is formed by 12 plastic tanks of 1500 liter each, interconnected by PVC tubes. On San Andrés Island this storage system has a total cost of US \$1,450.--

Polyethylene cistern.

This tank is made of polyethylene and has a storage capacity of 10.5 m³. It can be accessed from the top allowing maintenance and cleaning. This is an option to consider due to its easy and fast installation.

Fig 2. Polyethylene cistern.



On San Andrés Island this storage system has a total cost of US \$ 4,350.--

Wood cistern

Photographic records show that this technology was broadly used in the past, but changes in the traditions and the difficulty to obtain hard wood relegated. Currently none of these cisterns are in use.

The wood for the making of this cistern needs to be cut precisely. No nails, screws or glue are used - and the rigidity of the structure is achieved with the help of a metal ring wrapped around the cistern. When the cistern is wet the wood increases its volume sealing it perfectly and making it waterproof.

The design of a 20 m³ of capacity wood cistern is shown. In order to save wood, the radius of the base should have the same dimensions as the height, however the dimensions can change according to the available area.

Fig 3. Upper view of the wood cistern.

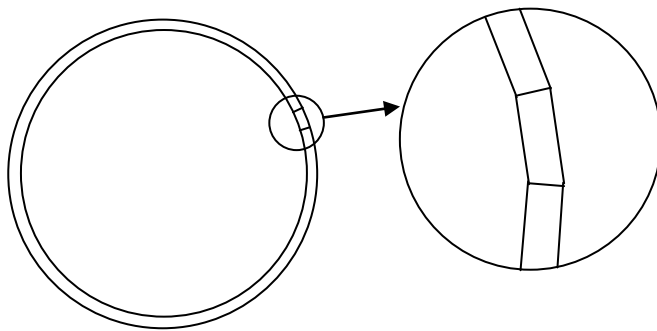


Fig 4. Front view of the wood cistern.

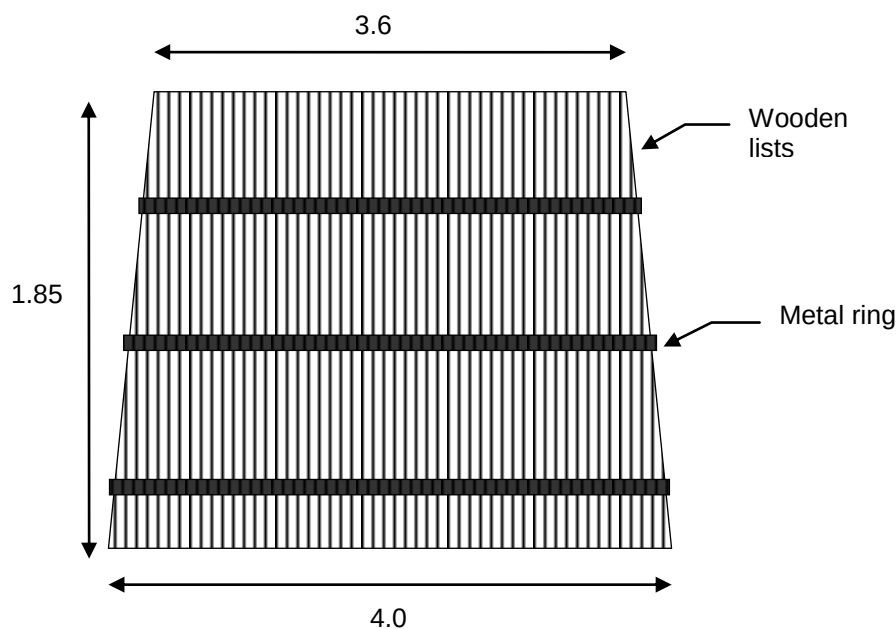
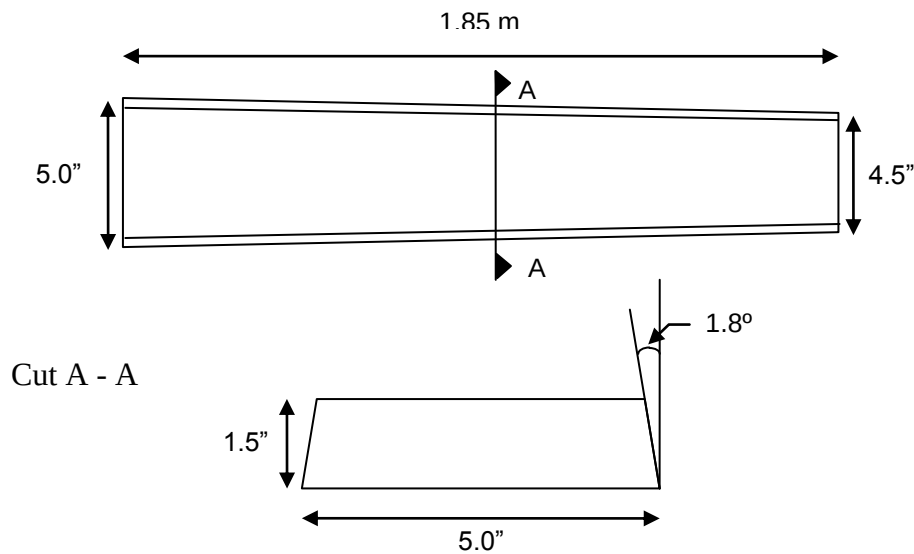


Fig 5. Detail of each of the 99 pieces of wood of the cistern.



Since the cistern remains wet all the time, it is recommended to use hard woods like cedar or mahogany to guarantee the cistern's durability. On San Andrés Island this storage system has an estimated cost of US \$ 1,600.--

Economic analysis

Compared with other drinkable water supply systems, the storage of rainwater requires considerable capital. Most families lack these financial possibilities. There are neither connection fees nor monthly rate payments. For the rainwater system the user has to pay the equivalent of 20 or 30 years of supply in the first year, which makes this technology less attractive.

Table 1. Cost per m³ during the whole life of the cistern.

System	Useful time	m ³ /year	total m ³	Cost of the cistern	cost/m ³ U.S
Concrete cistern	30	70	2100	1000	0.48
Modular cistern	15	70	1050	1450	1.38
Polyethylene cistern	15	70	1050	4350	4.14
Wood cistern	15	70	1050	1600	1.52

Selection of the system to implement

The modular cistern is the least attractive due to the high area requirements and the high economic costs. The polyethylene cistern, in spite of the high costs, is an attractive option due to the fast and easy installation, and for being a "mobile" system. This is very useful on the island since most people are renting and are therefore not willing to invest in fixed systems. The wood cisterns, due to their relative low cost and their mobility are a very reasonable option.

Unfortunately neither skilled carpenters nor the required hard woods are available on the island for building wood cisterns. The concrete cistern, in spite of being fixed, presents the smallest cost per m³ of water and there are skilled artisans trained in their construction.

Table2. Characteristic of the cisterns.

Cistern	Advantages	Disadvantages
Modular cistern		Space requirements, costs
Polyethylene cistern	Mobility	Costs
Wood cistern	Mobility, costs, space	Construction difficulty.
Concrete cistern	Costs, duration	Is not mobile, cracks if not used

Conclusions

If one keeps in mind that the costs per m³ of a rainwater system is less than the costs of desalinating water, that it has the best quality and that it doesn't have polluting byproducts, it's clear why this type of project should be promoted to make up for the current deficit of drinking water on the island

The use of rainwater, in spite of the high costs per m³, remains an option for the community. This system allows people to have control over it, in contrast to the public systems, which have a low reliability due to the frequent interruptions.

Rainwater harvesting is an alternative to implement sustainable systems where other alternatives have reduced technical, economic, environmental or social viability.

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Effective Application of First Flush Device to Improve Rainwater Quality

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Abstract

Rain water harvesting helps to reduce the burden on other sources of water in the context of proper water resources development. Rainwater collected while using a first flush system enhances the quality of drinking water and considerably reduces water borne diseases. There are automatic and manual operated first flush systems for rainwater harvesting. The most suitable, technologically appropriate and tested systems for developing countries are being outlined.

1. Introduction

Rainwater harvesting has been used since ancient times and evidence of roof catchment systems in modern times in our country dates back to the beginning of this century. Rainwater collection and storage is a feasible option for enhancing the living standards of millions of our countrymen currently facing serious water supply problems, especially in the dry zone. In isolated rural areas occupied by subsistence farmers engaged in slash and burn cultivation and for dispersed settlements, it is a very attractive supplement to traditional water sources (sometimes polluted) because it relieves the burden of fetching of water (by women and children) from a distance and having it closer to the dwelling. In certain instances availability of rainwater lowers the pressure on finite ground water sources.

The choice of a rainwater harvesting system would depend on the needs and preferences of people, their current water supply coverage and service level, as well as their knowledge concerning various types of water supply sources, systems and their characteristics. Generally, most households are encountered with a number of equally important daily commitments in collection of water and firewood, child care, food production etc.

Rainwater harvesting ventures should therefore have obvious benefits which address the strongly felt needs of consumers, particularly if it requires significant time and energy inputs or financial contributions from them. Potential of rainwater harvesting and major benefits could be highlighted as:

- * Smooth out fluctuations in water availability; where rainfall occurs for only a limited period, by collecting the rainwater and storing it efficiently in closed reservoirs, a more reliable access to water can be assured;
- * Collect and store water near the dwelling; this avoids the need to walk long distances and prevents waste of time;

- * Provision of safe drinking water, where ground water or surface water is saline or polluted;
- * High emphasis on rural development in an attempt to stem migration of population into urban slums;
- * Ease pressure on rural water supplies due to population growth;
- * Reduce problems of ground and surface water supplies such as salinity, contamination and unreliability as a result of increased demand, more intensive agricultural practices and deforestation;

Availability of impervious roofing materials (tiles, asbestos, corrugated iron sheets etc.) replacing traditional cadjans, grass palm thatch and others; and

- * Appropriate cost effective technology application (low cost tanks, ferrocement technology etc.)

In a domestic rainwater harvesting system, the rainwater falling on a roof catchment is collected by gutters and directed to the storage tank using a downpipe. Usually, the roof of the house is exposed to the atmosphere having the influence of the sun, wind, rain and interacting with surroundings. As a result of this, bird droppings, dust, leaves of trees and other matter get deposited on the roof. It is of utmost importance to flush the harmful matter from the roof before collection of rainwater in the storage reservoir. An arrangement to remove the foreign matter getting into the reservoir has been named as the first flush device. Studies in various countries have shown the importance of this device: the faecal coliform in runoff water can be completely eliminated.

2. Existing First Flush Devices

Importance of the first flush device has been emphasised, its reliability for proper functioning of the rainwater harvesting system cannot be neglected. In different parts of the world, various types of devices have been experimented. There exist two types:

- * automatic; and
- * manually operated devices.

Some automatic first-flush devices in which a mechanism, usually a pivoting arrangement, diverts the initial runoff; these devices have proven inadequate due to malfunction or poor maintenance.

A simple detachable downpipe allowing the pipe to be swivelled to the side of the tank inflow and to be switched back a minute or so after the rainstorm has started, is

probably the most appropriate system.

Regardless of the device selected, they all need either regular maintenance or active operation to ensure good quality stored water.

Although provision of potable water is essential in most circumstances, effectively operated and maintained first flush and filter systems can greatly improve the quality of rainwater harvested.

Numerous ingenious devices have been developed and most simple appropriate and inexpensive devices have been paid due consideration.

The simple operation and maintenance of rainwater catchment systems are some of the most attractive aspects of technology.

2.1 Automatic First Flush Devices

An arrangement to carryout the first flush without the interference of human beings has been named as "automatic". Regular maintenance of clearing of leaves, debris, silt, etc. are of paramount importance.

2.1.1 Removable -- End Device

In this arrangement, the runoff with the debris directly falls into the downpipe of the rainwater catchment system, where the foreign matter is retained and the water is allowed further flow to the storage. The downpipe of chosen material (PVC, GI, Bamboo etc.) has a removable plug at the end. The size of the downpipe depends on the quantity of debris to be retained before allowing the rainwater to flow to the storage tank.

The removable end could be a wooden or rubber plug, PVC or G.I or any other replaceable device, which should be removed, cleaned and re-fitted after every rain.

Removable - end device is shown in figure 2.1.1.

2.1.2 Debris Collection in Ground Collector

In case the rainwater catchment system should trap a large quantity of leaves, branches, falling on the roof, having large quantities of foreign matter, the system in fig. 2.1.1 has been modified by extending the downpipe with the removable end to an air-tight collector of debris, made out of bricks, concrete blocks or other material, situated on the ground. The size of the collector depends on the amount of foreign matter falling on the catchment area / roof needing retention. An opening of a suitable size has to be provided for removal of collected rubbish and a stopper for sealing of the opening in the collector after cleaning (fig. 2.1.2)

2.1.3 Pivot and Weight

As shown in fig. 2.1.3 below the downpipe, a section of a gutter / semicircular length of a pipe has been pivoted either to the wall or balanced on a pole planted in the ground. On one side of the pivoted gutter directed upwards, an empty container/ bucket is hung with a string and the other side has a weight to keep the end pointed to the ground. When it starts raining, the foreign matter would be flushed out from the end pointed towards the earth and a tube at the same end would convey water to the bucket to flip that end to the water reservoir for collection of rainwater (after the first flush).

2.1.4 Balance System

The system explained in 2.1.3 has been adapted in a much more refined manner to function as a balance, as shown in fig. 2.1.4. When the rainwater from first-flush fills the float chamber, the balance flips to collect the rainwater from the gutter directly to the storage tank. The balance should be arranged in such a manner as to minimise sound generated from flipping as well as to ensure durability.

2.2 Manually Operated Devices

Unlike in the automatic first-flush devices, the flushing arrangement should be adjusted by a person / operator.

2.2.1 Manual Method

As shown in figure 2.2.1 before collection of the rainwater in the storage tank, the first-flush should be discarded by swivelling / rotating the downpipe manually.

2.3 Other Practical Devices

Depending on the conditions, situations etc. needing practical application of rainwater, a few practical devices having application in the world over have been presented in figure 2.3:

3.0 Conclusion

For provision of potable water, effectively operated and maintained first-flush and filter in a rainwater harvesting system can significantly improve the quality of roof runoff. In Sri Lanka, where roof surfaces are exposed to blown dirt and dust, faecal matter of birds etc., the first-flush device would play a great role to enhance quality of rainwater harvested.

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Barriers to the effectiveness of rainwater catchment systems

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Abstract

Guttering often is the weak link in the performance of a rainwater catchment system. Most of the time, collected rainwater is spilled before reaching the cistern. Problems range from gutter maintenance to its design. This paper addresses design issues, locally available materials and the relationship between rainfall intensity and roof area to gutter cross-sections area, shape, slope and length. Special consideration is given to aspects of gutter technology in developing countries.

The paper also recommends suitable measures for promoting rainwater harvesting techniques in drought prone areas of Uganda and other developing countries.

Introduction

Water harvesting can be applied in many locations in the world but is of particular importance in countries with arid and semiarid lands, where it may often provide the only feasible solution for an improved water supply. Its potential very dependent on climate hydrology, landscape, and vegetation.

In Africa arid and semiarid regions today, as much as 80% of the total rural population relies on unimproved traditional water points. These include shallow water holes, depressions among rock outcrops, ponds or lakes, permanent or seasonal rivers, springs and shallow ground water accessed by hand-dug wells.

Considerable potential exists to improve existing sources and better use the resource potential of the area. Yet these improvements are often not carried out due to lack of technical expertise and financial resources or because users are not organised to implement such improvements.

Roof tops and tank systems provide an on-site source of water supply next to homes or public buildings such as schools or health centres. They can be constructed wherever there are permanent settlements experiencing difficult water supply conditions. Usually they require roof areas of more than 30m² but even small areas can provide a partial supply to relieve some to the burden of fetching water. Roof top harvesting systems are comprised of the rooftop as the catchment area, connected by gutters and pipes to a storage container. The most suitable roof top surfaces are corrugated iron sheet, although tiled and asbestos sheet roofs can also be used. Thatched roofs pose problems as the run off is lower and generally of low quality. It is also more difficult to fix gutters to thatched roofs. The water collected from thatch is always coloured, unattractive and more often contaminated.

Commercial gutters are usually expensive, while home-made gutters of wood or bamboo are usually inefficient. Recently in Uganda, the North Kigezi Diocese Water Programme pioneered construction of simple, improved low-cost gutters and hangers from iron sheet and wire. Local production of gutters needs to be explored further, as it may contribute significantly to the effectiveness of programmes and offer a suitable source for generating income. Guttering systems made from bamboo have also been tried widely in some rural areas and has been proved to be effective.

However in general, very little concern has been shown for gutters internationally. Their purpose and installation are usually not part of the project and they are usually left to the owner to supply and install. The result is that valuable water is wasted. In low rainfall areas, collecting all the rainwater available is crucial to delivering all the benefits of the system. In high intensity rainfall areas, considerable attention should be put on ensuring that gutters are large enough to handle intense showers.

The gutter frequently inhibits the performance of a rainwater catchment system. Rainfall intercepted by the roof is blocked by debris; the problems is one of maintenance. If the gutters are improperly installed, the problem is one of construction. If the gutter is fundamentally undersized, too flat or too long, the problem is of design.

Technical feasibility

Even in the arid regions of Africa, there is often sufficient water available to supply drinking and agricultural needs through the dry season if only rainfall and run off are captured and stored for later use.

The technical feasibility of the various water harvesting systems largely depends on the skills of the community, the availability of local materials and labour, and for large systems on availability of equipment. In assessing the technical feasibility of a particular system it is very important to take into account the experience already acquired to avoid repeating mistakes previously made by others.

The qualities and types of materials required for the various options usually do not pose serious problems, perhaps with the exception of roofing materials, cement and chicken wire. Checking of a detailed materials inventory against the local contract suppliers or natural resource surveys will point to any shortfall.

Commercial gutters are usually expensive, while home made gutters of wood or bamboo are usually inefficient. While the manufactured metal gutters are expensive, they are more efficient. Therefore a balance must be reached.

Many designs of water harvesting systems are simple, labour intensive and require limited amounts of tools. Still checks should be made to see whether even these simple tools are

available. Whenever possible, labour intensive inputs should be optimised and simple tools and instruments should be used.

Identifying potential technologies

Insight into local conditions will provide opportunity to identify the most suitable technologies, which could be applied. If experience exists with traditional harvesting techniques, dialogue with users will give an indication of their appropriateness and acceptance. Often different technologies may be technically feasible, but not all may be equally appropriate.

The overall assessment of the project area can only provide a general indication of the technologies, which can be applied. Ultimate technology selection will largely depend on the skills, capacities, needs and preferences of the individual communities. It is essential, in order to assure system sustainability, that communities are provided with information concerning maintenance requirements and financial implications for each of the technology options considered. Preferably, arrangement of technologies and options should be identified, from which the community can choose the most feasible and affordable option closest to their needs.

Technical considerations

A carefully designed and constructed gutter system is essential for any roof catchment system to operate effectively. A property fitted and maintained gutter down-pipe system is capable of diverting more than 90% of all rainwater run off into the storage tank, the remaining being lost through evaporation, leakage, rain splash and overflow. In design calculations, it is usually better to assume a run off coefficient of 0.8 for roof catchments, lower values (0.2-0.6) apply for ground catchments. All too often both individuals and projects overlook the importance of guttering. This frequently results in only the run off part of the roof being utilised. In other instances, gutters have not stopped in the direction of the tank and down pipe or have rusted through and not been repaired.

Even where roofs have well constructed and maintained gutters, if they are too small, considerable quantities of run off may be lost due to overflow during torrential storms. In many tropical climates intense connectional rainfall accounts for a large proportion of total annual rainfall. A useful general rule is that 1cm^2 of guttering is required for every m^2 of roof area; a 100 m^2 roof area would require a gutter cross-sectional area of 100cm^2 . In other words a $10\text{cm} \times 10\text{cm}$ gutter would suffice.

A greater problem than gutter size is probably hanging gutters securely so that they do not sag or fall during heavy rainfall, and keeping flow and dripping flow from the edges of the roof. Ensuring adequate slope for the entire system so that water does not stand and damage gutters or attract mosquitoes, is also important.

Construction guidelines for placing gutters

Size and shape

The gutter must be large enough to channel water from heavy rains without overflowing. The shape is also important. If it is too shallow it may overflow. If it is too narrow the water from the roof may shoot over the gutter and be lost. For most roof catchments a gutter with cross-sectional area of $70\text{-}80\text{cm}^2$ is sufficient for the range of slope recommended here. The minimum recommended width for a square and semicircular gutter is 8cm. For a triangular shaped gutters the width should be at least 10cm. The minimum recommended depth is 7.0cm for any gutter.

Slope

The gutter should be placed at a uniform slope to prevent water from pooling and overflowing the gutter. For most roof catchments the slope should be in range of 0.8cm/meter to 1.0cm/meter.

Location

The gutter must collect all the water running off the roof during light and heavy rainstorms. To achieve this, the gutter should be located so that the roof overhangs the gutter by 1cm and 2 cm and the gutter extends beyond the edge of the roof by at least 7cm.

Supports

The gutter must be well supported. The number of supports depend upon the type of guttering material but it is recommended that most gutters be supported at least every 50-60cm. The simplest means of support is by tying wire round the gutter and fastening it to the roof. The gutter can also be nailed to the roof or be provided with wooden supports underneath.

Joints

All joints should be leak proof. Joints can be sealed using tar, pitch or a similar material. Strips of plastic can also be laid in the gutter to prevent leakage. The joining material should be one that does not contaminate the water.

Guttering Materials

The gutter material selected should be light in weight, water-resistant and easily joined. To reduce the number of joints and thus the likelihood of leaks, a material which is available in long straight sections is preferred.

Gutters and down pipes can be made of a variety of materials, wood, metal, plastic and bamboo being examples. Those made from organic materials will require more frequent replacement.

Manufactured metal gutters

Aluminium or galvanised sheet metal guttering is the technology of choice in most areas in developing countries. The gutter section are joined with special brackets and hung with metal straps or long spikes with sleeves which are driven through the upper part of the gutter's width and into wood backing. In the open market galvanised sheet is slightly less expensive but tends to corrode more quickly unless coated with high quality rust-resistant paint. Hardware for joining and hanging the system also is additional cost.

Thus higher costs or unavailability are likely to eliminate manufactured metal gutters as possibilities in most rural areas of developing countries.

Bamboo as local guttering material

Of all the locally available materials like split palm and wood boards, bamboo, if available offers the best choice. The bamboo to be used should be thick (15-20cm) and strong. It can be simply split length-wise with a machete and the diaphragm removed with a machete or knife. Bamboo can be cut in the lengths needed and overlapped at supports and tied firmly.

The gutters can be supported by simple poles with a V notch at the top and buried about 30cm in the ground to make them stable. The gutters are tied on the tripods using wire or locally available heavy string. Each pole or set of three poles (making up a tripod) in a row is cut shorter than the last in order to ensure a slope into the filter and storage vessel.

Foul flush and filter systems

Although not absolutely essential for the provision of potable water in most circumstances, when effectively operated and maintained, foul flush and filter systems can significantly improve the quality of roof runoff. If poorly operated and maintained however, such systems may result in the loss of rainwater run off through unnecessary diversion of overflow and even contamination of the supply. In every poor community where the provision of even a basic roof tank represents a substantial upgrading of the water supply, the addition of an elaborate foul flush mechanism to the catchment system would add unnecessary expense and complication to the system and could even risk jeopardising its effective use.

Manual systems

Usually lower cost and easier to devise, these will be the obvious choice in most poor areas. An attractive and simple approach is to attach the down pipe so that it can be propped in the 'waste position', then propped in the tank inlet after the roof is clean. Open down pipes like split bamboo can be suspended beneath the outflow of the gutter with wire of local fibre; closed down pipes with a flexible joint can be moved in the same manner.

The task of moving the down pipe can be performed consistently by anyone including children. People in developing countries tend to be conscious of the precise moment it begins to rain because drying laundry must be brought in.

Another simple technique for tanks with small covers is to leave the cover on, blocking the flow of water into the tank, until the roof is clean. A similar approach (for very small containers like jars) is to move the container in position under the down pipe only after an appropriate interval. Both these routines may be objectionable from a public health point of view; they cause mud and pools of standing water at the tank. Nevertheless, a more complex down pipe and foul flush arrangement is impracticable.

Automatic system

Automatic system roof cleaning devices are available commercially only in a few areas, but they may be fabricated from local materials in some situations. One simple automatic device is a container receptacle for dirty water called a 'roof washer'. After the roof washer receptacle, a screen is usually attached between the down pipe and the foul flush container, to keep out leaves and other large pieces of debris that would float on the water in the receptacle and clog the overflow pipe to the tank.

A problem with such a simple device is that the beginning of a rainstorm is torrential, water will pour vigorously into the roof washer from the down pipe, stirring dirt and bird droppings so that they are carried through the overflow pipe into the tank instead of settling at the bottom of the receptacle. To prohibit this stirring action, a baffle can be mounted cross ways, the roof washer and/or a vertical screen can be installed instead, dividing the down pipe side from the tank inlet side. Roof washers must have a drain and a removable cover so that they can be cleaned after each rain.

More complicated 'automatic' flush devices tend to require more attention and stronger structures with more hardware mounting in the down pipe.

Conclusions and recommendations

Design and construction specification and drawings should be easily available to the people. Fabricated items like gutters, down pipes, diversion systems as well as roof washers, should be available readily. All items must be of good workmanship without costing too much money. Successful implementation of rainwater techniques will depend a great deal on how well the people are conditioned to receive these new ideas. Conducting regular training programmes for the common people in a particular area will greatly benefit them.

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An Assessment of the Damage Sustained by the Gareh Bygone Plain Artificial Recharge of Groundwater System in the Deluge of 1995

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Abstract

In Iran, floods result in more than 200 deaths and US \$1 billion damage per year. The damage due to floods ranks second behind earthquakes. Floodwater spreading (FWS), particularly for the artificial recharging of groundwater (ARG), is a technique that could transform a curse into a blessing. The deluge of 1995, caused by 80 mm of rainfall during a 24-hour period, resulted in bringing an ARG system in the Gareh Bygone Plain (GBP), in southern Iran, into full operation. These floods, occurring at an interval of 50 years, cause considerable damage in the southern parts of Fars Province. Although the ARG systems are designed to withstand a once-in-every-15-year flood, the GBP scheme sustained very little damage. The flooding breached only 1% of the embankments and undermined about 19% of the chutes installed in the gaps. The cost of repairs and system maintenance are only 2.5% of the damage, which could have been inflicted on the properties, had it not been harnessed by the ARG systems. The overall government budget for prevention of flood-related damage is quite big and could be used better if there was a new flood mitigation strategy.

Introduction

“Among all the natural phenomena capable of producing disasters, flooding is by far the most significant in causing loss of human life. The severity of such disasters is often increased by the after effects: diseases and starvation” (Anon., 1995). This is one of the most significant ironies of the 20th century. While most of the developing countries are water deficient and many industrialised nations lack sufficient hygienic water, almost every nation is annoyed by flooding; an abundance of the very thing they complain of its deficiency.

Although flood prevention on a large scale is improbable, its mitigation, at least on a regional scale, is possible. Turning a problem into a solution should become the guidepost of the environmentally conscious people of the flood-prone areas. Accepting the flood as a blessing in disguise is solving contradiction by the harmony of design. One of the indirect benefits of floodwater spreading (FWS) for desertification control (DC) through the artificial recharge of groundwater (ARG) has been flood mitigation.

As our FWS - ARG system are originally designed to withstand breaching in the floodings of 15 year recurrence intervals, and “the number of floods of the century in any 100 year period has ranged from 1 to 13” (ibid.), therefore, some washouts of the

embankment and collapse of the solid hydraulic structures is accepted as minor risks in our flood mitigation projects.

The objective of this article is to report on the damage sustained by our floodwater spreading systems during a 50 year interval flood in December 1995.

Materials and methods

Setting

This study was performed at the Kowsar Floodwater Spreading and Aquifer Management Research, Training and Extension Station in the Gareh Bygone Plain (GBP, 28° 37' N, 53° 55'E, 1140 above mean sea level) in southern Iran. A debris cone formed by the Bisheh Zard River, which emanates from a 192 km² watershed formed in the Agha Jari Formation, is the study site. This area is covered mainly with a coarse-loamy sand; therefore, the embankments are constructed of sand and on a sandy base. Although we have successfully followed the Australian procedures with some modifications in planning and construction of the FWS systems (Phillips, 1957; Newman, 1963; Quilty, 1972), as sandy soils are extremely erodible, we had to install masonry drops and chutes in the gaps to be certain of the proper functioning of the systems. A more detailed description of the site has been given by Kowsar (1991, 1998).

The Flooding

December 1995 was an unusually wet month with a total rainfall of 180 mm, which was more than the mean annual precipitation of 150 mm for the GBP. A total rainfall of 80 mm during 24 hours on December 11 and 12, 1995 caused the flooding whose damage assessment is the subject of this article. As all of the 8 FWS - ARG systems were in full operation at this 50 year recurrence interval event we may compare the damage to what occurred in December 1986 which was entitled "flood of the century". The data reported here in were collected in March 1996 and the financial damage assessed at the market price of that period.

Results and discussion

Aggravation of the streambeds in this event delivered about three times the design capacity towards the systems. An overbank flow, which entered the systems, overloaded them, breached the embankments at the weak points and collapsed many chutes due to undermining. Moreover, the bed load that settled in the inundation and conveyance - spreader channels put them temporarily out of service. These shall be separately described below.

Earth Embankment Breaches

The total length of the level - silled channels (LSC) for each system, the total length of the breached sections and the percentage of breaches relative to the total length of the channels are given in Table 1. The banks in the BZ₂ system held perfectly, but those of

Rahim Abad₁ sustained 100m of breaches. On the whole, 0.99% of the banks gave away in this event as opposed to 7.5% for the deluge of 1986 (Kowsar, 1997). The presence of rodent burrows under the waterline in the banks, the root channels formed by the eucalyptus trees, and the passageway of livestock on the bank crowns facilitated the rush of floodwater through and over the banks and breached them. Although we cannot do anything to prevent such breachings, the invasion of snakes, owls and eagles which tend to check the proliferation of rodents has been a glad tiding for us.

Table 1. Assessment of damage to the banks and chutes of the FWS - ARG system at the research station in the GBP in December 1995.

Name and Notation of the FWS - ARG System	LSC length, m(1)	Breached LSC length, m(2)	Ratio 2/1, %	Ratio of Collapsed chutes Total No. of Chutes, %
Bisheh Zard ₁ (BZ ₁)	9940	60.5	0.69	$\frac{8}{31} = 26$
Bisheh Zard ₂ (BZ ₂)	6740	0	0	$\frac{4}{17} = 24$
Bisheh Zard ₃ (BZ ₃)	1000	40.0	40.00	$\frac{2}{3} = 66$
Bisheh Zard ₄ (BZ ₄)	920	20.0	2.17	$\frac{0}{3} = 0$
Rahim Abad ₁ (RA ₁)	7900	1000.0	1.26	$\frac{0}{23} = 0$
Rahim Abad _{2,3} (RA _{2,3})	10790	40.0	0.37	$\frac{4}{6} = 66$
Tchah Qoothch ₁	14350	251.8	1.75	$\frac{1}{16} = 6$
Total	51640	512.3	0.99	$\frac{19}{99} = 19$

Masonry Chute Collapse

Incompetent foundation (fine sand), penetration of eucalyptus roots under the chutes, with the resultant pipings and sand boils, and also poor workmanship were the main causes of masonry chute collapse in that storm event. Sod establishment in the gaps seems an environmentally friendly way to stabilise the eroding gaps. This might prove less expensive in the long term.

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Barragens de contenção de águas superficiais de chuvas

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Resumo

Cuidando do futuro das águas e de sua qualidade está sendo desenvolvido em Sete Lagoas, Minas Gerais, um projeto de Barragens de Contenção de águas superficiais de chuvas.

O sistema, em teste há 4 anos em uma propriedade isolada de 70 ha, com 30 mini-barragens, têm apresentando resultados altamente positivos.

Em 1998 concretizou-se a idéia de implantação em escala maior, contemplando toda uma microbacia--Ribeirão Paiol. Que consiste em dotar cada propriedade ou toda a microbacia, de pequenas barragens ou mini-açudes, nos locais em que ocorram enxurradas volumosas e erosivas, barrando-as e amenizando seus efeitos desastrosos, retendo juntamente materiais assoreadores e poluentes, como solo, adubo, agrotóxicos e outros, que iriam diretamente para os córregos e mananciais provocando contaminação, enchentes e outros danos.

Como funciona o sistema?

O solo como um telhado, coleta a água das chuvas e a concentra em forma de enxurrada; ao barrá-las com mini-açudes sucessivos serão barrados os seus danos. Ao encher a primeira barragem, o excesso verteu pelo sangradouro a Segunda e assim sucessivamente até chegar à da baixada.

Em todo o centro-oeste brasileiro, predominam solos porosos e profundos, os quais, sob barragens, funcionam como uma esponja armazenadora de água filtrada, sob chuvas de 1000 a 1600 mm ano.

O objetivo principal do sistema consiste em carregar e descarregar o lago, proporcionando a infiltração da água num rápido espaço de tempo entre uma chuva e outra, de modo que ocorram inúmeras recargas durante o ciclo chuvoso, elevando o lençol freático, carregando a caixa d'água natural do solo.

A construção de barraginhas tem como principal função a recuperação de áreas degradadas pela chuva; visa também a perenização de mananciais com água de boa qualidade e de tornar o vale numa vitrine, a exemplo do Ribeirão de Paiol, através do Projeto Piloto de Demonstração de Conservação de Solo e Água, para o Estado de Minas Gerais.

Outros objetivos: Provocar refrescamento de baixadas, amenizar veranicos (pequenas estiagens), proporcionar plantios de Segunda safra (safrinha), possibilitar a criação de peixes com abertura de tanques nos baixios, etc.

Introdução

O homem, desde a história antiga, armazenava águas superficiais de chuva em seu proveito. No ano 106 D.C., os nabateos já produziam alimentos no deserto de Neguev (com precipitação média anual de 100 a 150 mm), utilizando sistemas de captação de água superficial, que era concentrada em tabuleiros nas partes baixas dos terrenos (EVENARI, 1968). Antes disso, a umidade residual armazenada no solo já tinha sido usada nos tempos do Rei Salomão, há cerca de dez séculos A.C., na mesma região do Neguev (EVENARI, 1983).

Segundo LAL (1982), que desenvolveu trabalhos em região tropical semi-úmida, os danos causados pela erosão em solos cultivados são reflexos de manejo inadequado de solos.

No início da exploração de uma área virgem, quando as terras estão cobertas com matas ou pastagens naturais, a necessidade de conservação do solo é praticamente nula, pois o sistema está em equilíbrio e a erosão é mínima. Após o desmatamento para exploração da terra, verifica-se geralmente grande degradação causada pela erosão, principalmente na forma invisível, a erosão laminar, que remove o solo em suas camadas superficiais (ANDREAE, 1965).

Segundo dados obtidos pela Seção de Conservação de Solos do Instituto Agronômico de Campinas, o Estado de São Paulo perde anualmente, por efeito da erosão, cerca de 130 milhões de toneladas de terra (1989). Essa perda representa 25% da perda sofrida pelo Brasil inteiro em igual período. Para se ter uma idéia do volume de tais perdas, basta dizer que ela corresponde ao desgaste de uma camada de 15 cm de espessura, numa área de 60.000 hectares.

Com o desmatamento, foram introduzidas pastagens artificiais, com maior densidade de gado e conseqüente compactação do solo. Alguns produtores rurais mineiros, percebendo logo os danos que viriam a ocorrer em seus solos, facilmente erodíveis, começaram, a partir da iniciativa de alguns entusiastas, a construir barraginhas em regiões isoladas. Isso ocorreu há cerca de 30 anos, mas não houve continuidade e nem divulgação adequada, pois a época não era oportuna e não havia um clima ambientalista favorável, como o verificado a partir da ECO 92.

Antecedentes

Essa tecnologia, apesar de não ser nova, estava em esquecimento e praticamente sem uso. No ano de 1991, foi iniciada a construção das primeiras obras para contenções de enxurradas, na área experimental da Embrapa Milho e Sorgo, em Sete Lagoas, Minas Gerais.

Em janeiro de 1994, foram construídas 28 barraginhas, em um sítio no município de Araçaí. Uma percepção concreta e visível ocorreu a partir de novembro de 1995, quando foram construídas 30 barraginhas na Fazenda Paiol, hoje utilizadas como "vitrine" e que serviram de exemplo para a idealização e implantação do Projeto do Ribeirão Paiol, que consistiu na construção de barraginhas em toda sua microbacia.

Outra atividade decorrente da implantação das barraginhas foi a realização de 11 cursos em diversas regiões do estado de Minas Gerais, durante o período de 1997/98. Com toda essa mobilização, hoje há vários focos de ações em municípios mineiros, por onde têm atuado os reeditores dessa tecnologia. Como exemplo, somente no município de Sete Lagoas-MG já foram construídas mais de 3.000 barraginhas.

Barraginha: Um projeto social

Pensando no futuro das águas e em sua qualidade, foi desenvolvido, na Embrapa Milho e Sorgo, em Sete Lagoas-MG, um projeto denominado "Barragens de Contenção de Águas Superficiais de Chuva", utilizando um sistema simples e que não é novo, pois data de antes de Cristo, porém estava esquecido.

O sistema foi instalado em 1995, numa propriedade rural na microbacia do Ribeirão Paiol, no município de Sete Lagoas-MG, estando em pleno funcionamento, apresentando resultados altamente positivos, decorridos quatro ciclos de chuva. O objetivo principal desse projeto é a recuperação das áreas degradadas, provocadas por escorrimentos superficiais de águas de chuvas, visando a perenização de mananciais, com água de boa qualidade, bem como tornar o vale do Paiol uma vitrine demonstrativa de conservação de solo e água, para todo o Estado de Minas Gerais e outras regiões do País.

Em razão do sucesso verificado, o sistema foi implantado em escala maior, em toda a área de uma microbacia, de modo a contemplar todos os produtores rurais da mesma e possibilitar a observação do efeito que uma propriedade poderá exercer sobre outra vizinha e assim sucessivamente.

Também serão observados os desdobramentos da implantação desse sistema, ou seja, aqueles que dependem da criatividade e atenção de cada produtor, como, por exemplo, a detecção de áreas frescas propícias para o cultivo sem irrigação, a abertura de cisternas, o reflorestamento e o plantio de canaviais e de outras culturas para recuperação de áreas degradadas etc. A eficiência desse sistema para a conservação do solo e água poderá ser aumentada com a adoção de outras práticas conservacionistas complementares, como, por exemplo, curvas de nível, plantio direto etc. Este projeto-piloto do Ribeirão Paiol consiste em dotar cada propriedade e, no conjunto, toda a microbacia de pequenas barragens ou mini-açudes, nos locais em que ocorram enxurradas volumosas e erosivas, barrando-as e amenizando seus efeitos desastrosos, retraindo juntamente materiais assoreadores e poluentes, como terra, adubo, agrotóxicos em geral, esterco com antibióticos etc., que iriam diretamente para os córregos e mananciais, provocando contaminação, enchentes temporárias e outros danos.

Como funciona o sistema

O solo, como um telhado, coleta a água das chuvas e concentra-a em forma de enxurrada, que vai-se avolumando até tornar-se danosa. Ao barrar as enxurradas com mini-açudes sucessivos, também serão barrados assoreamentos e poluentes. Ao encher a primeira pequena barragem, na parte mais alta, o excesso verte pelo sangradouro à segunda barragem e assim sucessivamente, até chegar à da baixada (Figura 1). Na maioria das chuvas, as da baixada nem chegam a verter.

Na região denominada Brasil Central, após o desmatamento ocorrido nas últimas quatro décadas e também com a descapitalização dos agricultores, acelerou-se o processo de degradação dos solos. Nessa região, predominam solos de cerrado, porosos e profundos, os quais, sob as barragens, funcionam como uma esponja porosa armazenadora da água infiltrada. O objetivo da implantação desse sistema é carregar (Figura 2) e descarregar (Figura 3) o lago, proporcionando a infiltração num espaço de tempo rápido entre uma chuva e outra, de modo que, durante a estação chuvosa, ocorram de 12 a 15 recargas completas do volume do lago, bem como do espaço poroso do solo, funcionando como uma espécie de caixa d'água natural (Figura 4).

O sistema provocará a elevação do nível de água no solo, o que poderá ser percebido visualmente, pela elevação do nível das cisternas, umedecimento das baixadas e mesmo com o surgimento de minadouros.

Só para exemplificar, uma chuva rápida de 60 mm é suficiente para encher todos os mini-açudes de uma microbacia. Se não houver esses mini-açudes, cerca de 90% das águas retidas nos mesmos irão diretamente para os córregos, contribuindo para provocar enchentes e outros danos.

Além disso, esse sistema proporciona a filtragem da água retida e sua posterior liberação para os córregos e rios, de maneira lenta ao longo do ano, estabilizando e perenizando os cursos de água e mananciais. Isso é importante quando se pensa na necessidade de garantir o abastecimento de cidades e fazendas e também para a geração de energia elétrica, que depende da perenização dos grandes lagos.

O Projeto contemplou a implantação de 960 barraginhas durante o ano de 1998, na microbacia do Córrego do Paiol, afluente secundário do Rio das Velhas, no município de Sete Lagoas, consolidando-se como uma unidade demonstrativa do sistema de conservação de solo e água. As Figuras 5 a 14 demonstram a metodologia de construção das barraginhas.

Esse trabalho foi desenvolvido pela Embrapa, Emater-MG e Secretaria de Agricultura e Meio Ambiente de Sete Lagoas, com apoio da Secretaria de Recursos Hídricos-SRH, do Ministério do Meio Ambiente e Recursos Hídricos, e do Instituto Interamericano de Cooperação para a Agricultura-IICA. O projeto teve a gestão administrativa e financeira da Fundação de Apoio à Pesquisa e ao Desenvolvimento.

Metodologia de construção das barraginhas

As Figuras 5 e 6 demonstram os formatos possíveis das barraginhas, sendo que a Figura 5 é trapezoidal, para barramentos mais reforçados em calhas e grotas e a Figura 6 é piramidal, para situações de enxurradas na beira de estradas e calhas suaves.

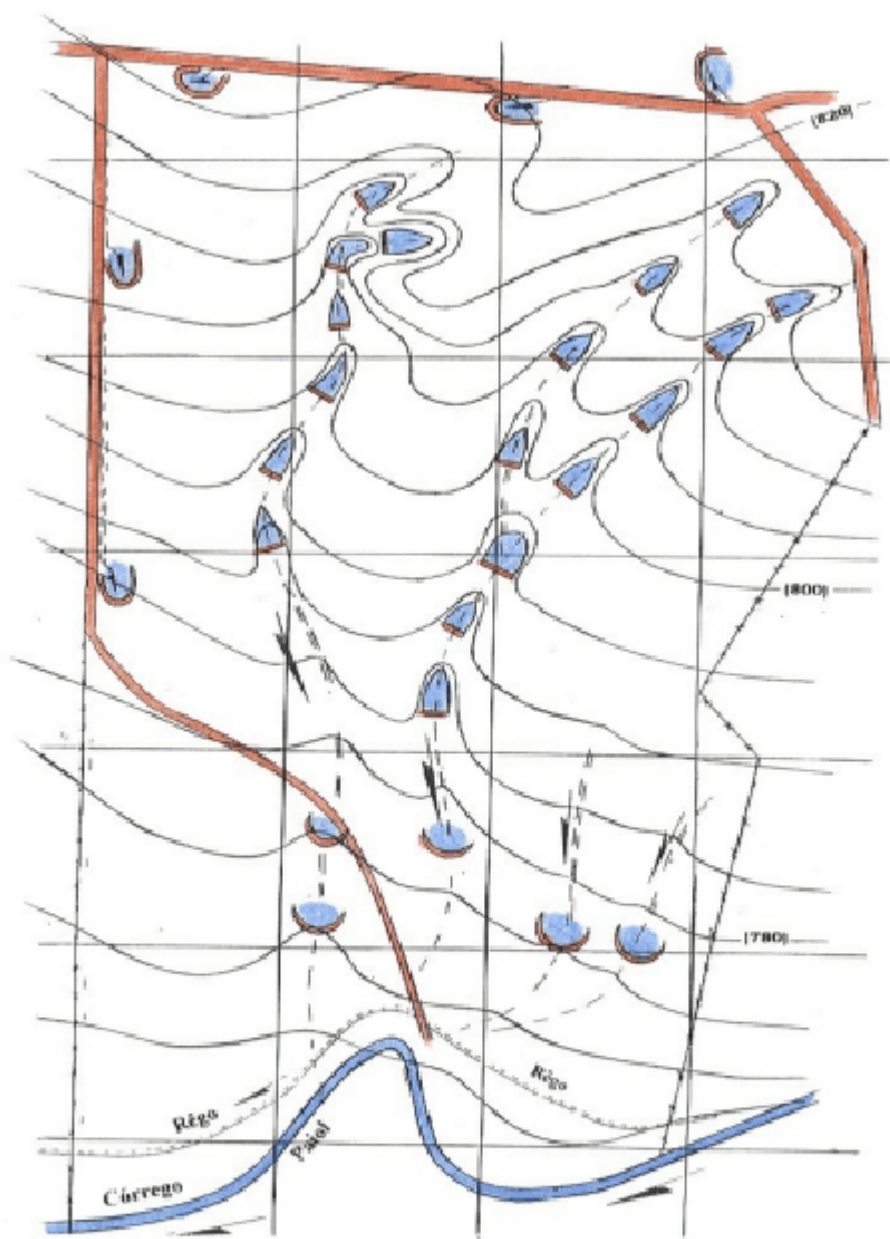
As Figuras 7, 8, 9, 10 e 11 demonstram as fases evolutivas da construção da barragem no formato trapezoidal. Os círculos representam leirões paralelos de terra solta colocados pela pá carregadeira e a base "a" da Figura 7 representa a terra já acomodada e compactada pela mesma máquina. O mesmo se repete na Figura 8, na formação da base "b". As Figuras 7 e 8 são vistas de forma transversal. A Figura 9 mostra as fases "a", "b" e "c" do aterro dentro da calha. A Figura 10 mostra a fase "d", que é o abaulamento final na forma de travesseiro. A base do travesseiro é o próprio nível da água no lago. A Figura 11 mostra o lago temporário formado pelo barramento.

As Figuras 12, 13 e 14 mostram os locais onde usar os modelos trapezoidal ou piramidal. A Figura 12 mostra a situação de grotas acentuadas, em que a construção de barraginha não é viável. Nesse caso, delineiam-se e constroem-se curvas de nível com ligeiro gradiente no sentido da grota e constrói-se a barraginha piramidal no eixo da curva próximo à grota, de modo que a mesma sangre o excesso ainda na própria curva, antes de cair na grota coletora. Na Figura 13, pode-se ver a situação que ocorre em áreas conservadas com curvas de nível antigas e que arrebatam freqüentemente todos os anos, tornando esses pontos frágeis. Nesse caso, o único recurso é a construção de barraginhas piramidais. A Figura 14 demonstra barraginhas trapezoidais em grotas de até 3 m de profundidade, aplicando as fases "a", "b", "c" e "d". Acima dessa profundidade, não se recomenda a construção de barraginhas.

Observações: a) o processo de barraginhas é planejado para calhas secas (enxurradas) e não para córregos. São barramentos de até 3 horas de serviço de máquina e a média não superior a 1,5 hora por barragem; b) ingredientes novos ao sistema barraginha: período de construção no período das águas e até três meses após o encerramento do ciclo chuvoso, pegando ainda umidade residual do solo, que facilita a construção, baixa os custos e dá qualidade de compactação às mesmas. Outro componente importante é o uso da pá carregadeira, que aumenta em até três vezes o rendimento em relação ao trator de esteira. Há, ainda, outras vantagens, como: deslocamento próprio, agilidade, facilidade de manutenção e grande número de equipamentos disponíveis no mercado.

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PLANTA GERAL
FAZENDA PAIOL
PROPRIETÁRIO: Antônio Carlos de Alvarenga,
Município de Sete Lagoas - MG

Fig. 1

Barragens de Contenção de Águas Superficiais de Chuvas (*Small Dams for Rainfall Surface Runoff Collection*)



Luciano Cordoval de Barros
Embrapa Milho e Sorgo

- Conter enxurradas, erosão e assoreamento (*Runoff, erosion and sediment transport*)
- Provocar infiltração da água no solo com elevação do lençol freático (*Force water infiltration and raising water table*)
- Filtragem da água poluída com posterior liberação aos mananciais (*Filtering polluted water prior to releasing to the watercourses*)
- Umedecer baixadas e amenizar enchentes e veranicos (*Wetting lowlands and minimizing flooding and drought periods*)
- Perenizar mananciais (*Revitalizing watercourses*)



Fig. 2 e 3
Momento da Chuva (foto superior) e
Infiltração uma semana após chuva (foto inferior)

ESQUEMA DO SISTEMA EM OPERAÇÃO

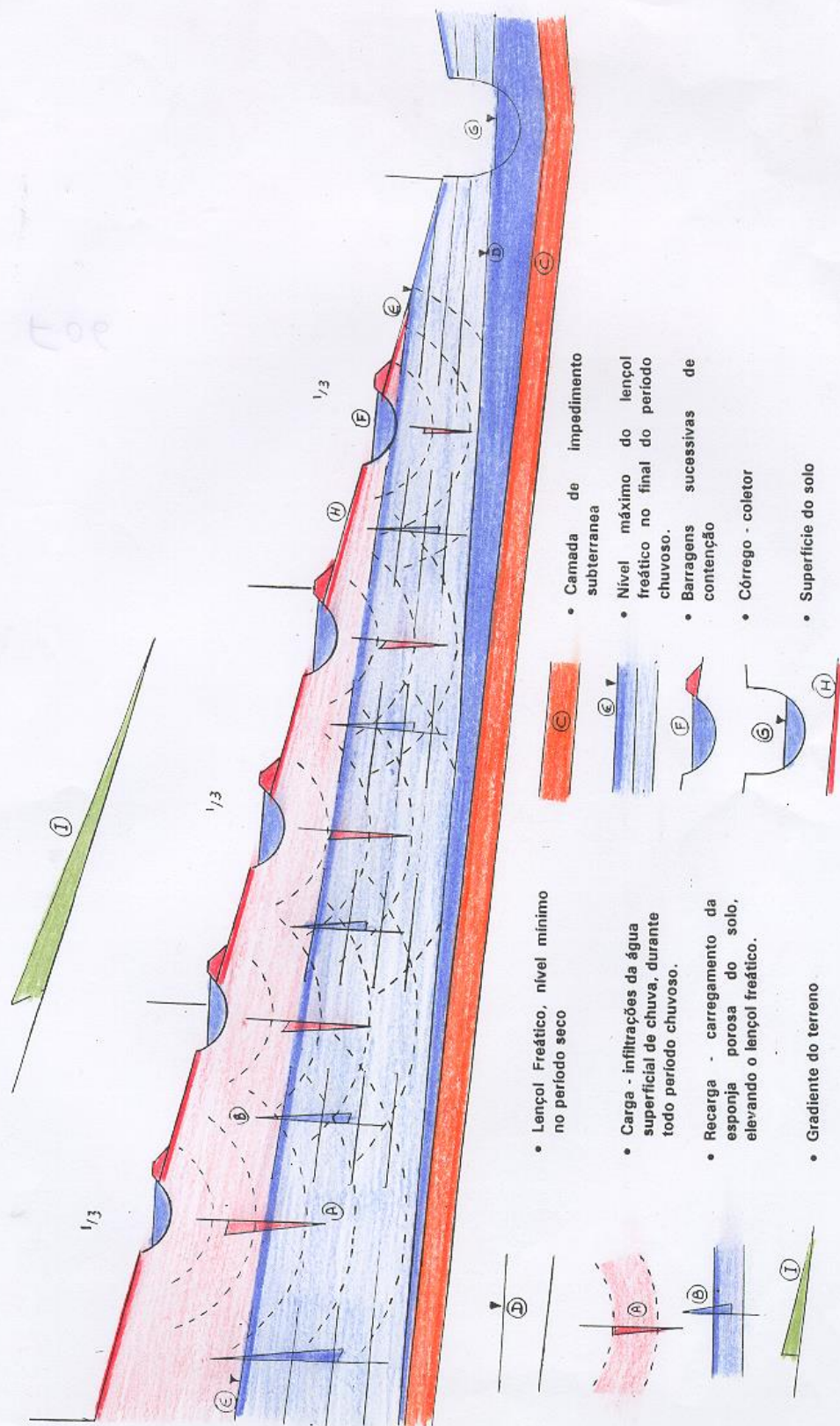


Fig. 4

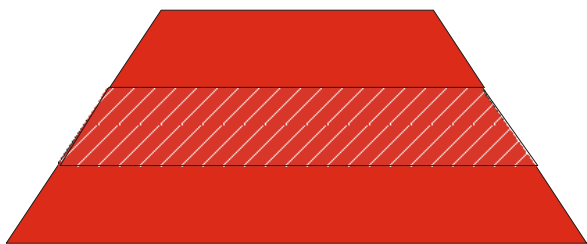


Fig. 5

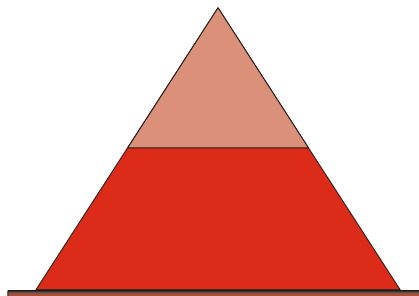


Fig. 6

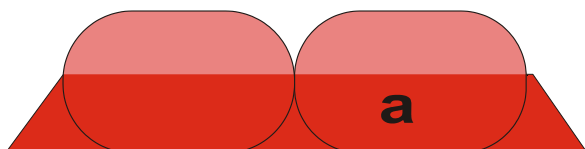


Fig. 7

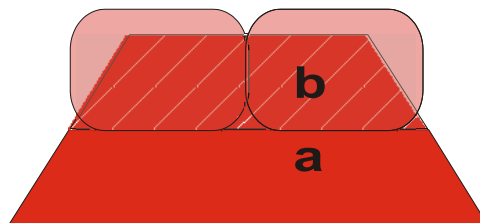


Fig. 8



Fig. 9

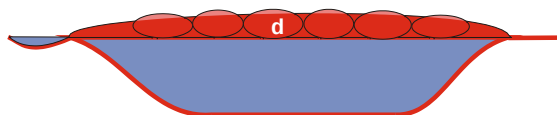


Fig. 10

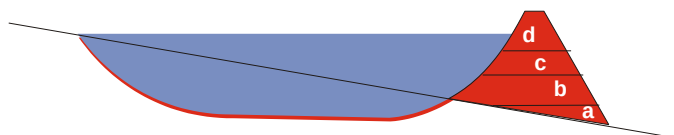


Fig. 11

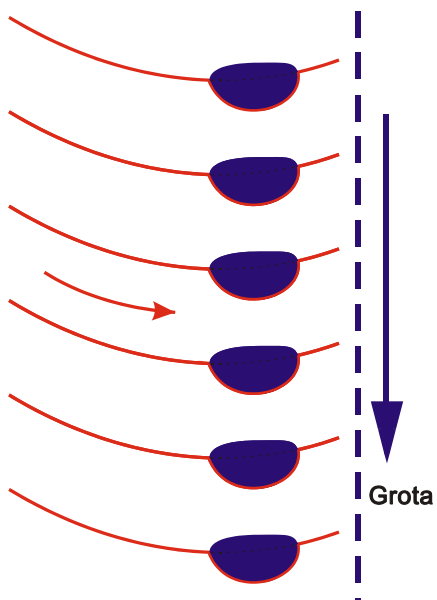


Fig. 12

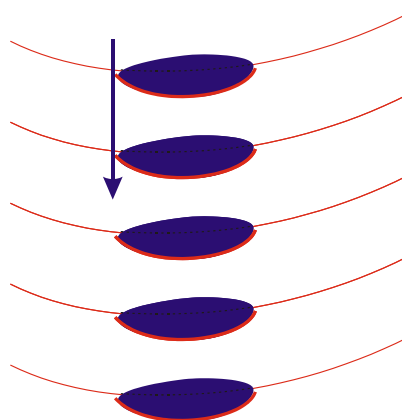


Fig. 13

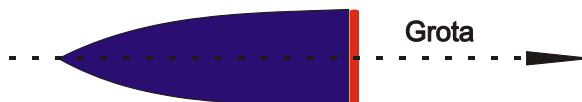


Fig. 14

Technologies for enhancing ground water recharge

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Abstract

In countries like India, with an ever-increasing demand for water, the importance of rainwater harvesting and groundwater recharge cannot be overemphasised. With this background in view, the laboratories of the Council of Scientific & Industrial Research have developed and demonstrated various technologies for the enhancement of recharge through various means. These are: the use of injection bore holes in hard rock; recharge through tanks wells; siphon recharge; enhancement of run off through treatment of catchment with polyamine material; use of chemicals for control of evaporation and also for stabilising and sealing of soil through hydrophobic chemicals, etc. This paper attempts to consolidate the experiences gathered in respect of the case studies in various rainfall regions with different soil characteristics.

Water Harvesting

In the context of the National Drinking Water Mission, the term "Water harvesting" connotes collection and storage of rainwater and also other activities aimed at harvesting surface water and ground water, prevention of losses through evaporation and seepage and all other hydrological studies and engineering interventions aimed at conservation and efficient utilisation of limited water endowment, of a physiographic unit such as a watershed or a geomorphic basin.

The various activities and structures covered under Water Harvesting are:

- Construction of permanent/portable water storage structures with accompanying collection systems;
- Farm ponds, for soil conservation and storage of supplement water or for recharging the aquifers;
- Check dams: these are normally constructed for soil conservation but they also effectively serve the objectives of water retention and recharge;
- Percolation tanks, constructed at appropriate sites selected on geological considerations and designed for said purpose,
- Reclamation/revitalisation of traditional water harvesting structures such as tanks, pushkaranis and ponds, which have deteriorated over the years due to silting and poor maintenance;
- Artificial recharge of aquifers through injection wells using seasonal surface water surplus.
- Control of evaporation from surface water bodies and bare soil surfaces;

- Prevention of seepage losses in appropriate situations;
- Enhancement of runoff through mechanical and chemical treatment of catchment in low rainfall areas;
- Subsurface dams across ephemeral streams to arrest loss of ground water through base flow (subsurface flow along the stream bed);
- Soil and water conservation practices comprising contour and terrace bunding besides trenching;
- Control of sea water incursion as well as subsurface discharge of fresh water into the sea in the case of coastal aquifers;
- Control of transpiration losses of water through plants without affecting the normal growth through spraying of appropriate chemicals;
- Adoption of crops and cropping patterns appropriate to the agroclimatic condition of the region (eg) Presently paddy rice and sugarcane are cultivated in the drought-prone districts of Anantpur of Andhra Pradesh and Kachh of Gujarat respectively, which is an absurd situation.

Council of Scientific and Industrial Research Technologies:

1. Artificial recharge through injection boreholes in hard rocks:

Artificial recharge through injection involves transfer of surface water to aquifers through boreholes drilled for the purpose. The technique requires availability of surface water, which is not always assured in the low rainfall region. Two experimental approaches using the existing surface storage structures were tried:

i. Artificial recharge through in-tank wells:

This approach comprises of the construction of a bore well at a hydrogeologically geophysical selected site in the percolation tank bed, when it is dry. The well is surrounded by a filter-bed and the entire assembly is so designed that only filtered water enters the well after the assembly is submerged under the tank water for several months.

ii. Siphon recharge:

A silted up minor irrigation tank is selected and the supernatant water collected in the tank during monsoon is transferred continuously for a long period (6 months) into a borehole drilled inside an open well in the command area, by using a siphon.

2. Enhancement of runoff through treatment of the catchment surface

In the western parts of Rajasthan, traditionally tanks (Johads) and Nodis are constructed for the collection of runoff water, which is used for drinking purposes by human beings and livestock. In a natural situation, the efficiency of runoff in terms of the fraction of the precipitation depend on factors such as antecedent moisture content of the soil, intensity of the event. It is thus possible that for the same total rainfall, the amount of runoff and consequent collection in the storage structure in two consecutive years can be quite different. Thus, in addition to the low quantity of total rainfall at a site, the changes in its pattern from year-to-year also give rise to uncertainty about adequate storage.

Detailed study of rainfall pattern of a few stations in Rajasthan shows that the component of rainfall contributed through thunder storms increase as the average annual rainfall increases. In other words, most of the precipitation is received through a few intensive showers. These intensive events are separated from each other only by a few weeks, even during the monsoon months. The antecedent moisture in the hot desert soil is negligible and a large fraction of the rainfall is infiltrated by the soil to a shallow depth and is again returned to atmosphere in the subsequent dry period.

An approach toward solving this problem would comprise treatment of the soil surface of the catchment area of a tank in order to (a) stabilise it to a depth of few centimetres and (b) make its surface water-repellent. The runoff efficiently can increase up to 70-80% of precipitation after such a treatment. The tank can then get filled in abnormal rainfall years and also irrespective of the rainfall pattern for the year.

Several soil sealing, stabilising and hydrophobic chemicals are known and laboratory experiments for suitably modifying the soil properties have been performed. However, field trials have been proposed to be carried out at a few sites in the districts of Rajasthan selected for Mission studies (Barmer, Churu and Nagaur).

The main advantage of this methodology, if found successful, is that it can be practised at any remote location in the desert. Even low rainfall (100mm) is adequate for drinking water purposes if it can be harvested properly.

3. Evaporation control:

Evaporation control or retardation is required for practically all types of surface storage structures. At present very little attention is paid to this aspect. The annual evaporation loss from surface water even in hill stations is as much as 1.0 m and in desert places is up to 2.5 m.

Evaporation reduction can be effected through two approaches:

4. Design of the storage structure:

The average depth of the storage structures should be increased to the extent permissible by the local terrain and also by economic considerations.

5. Insitu harvesting of rainfall:

In situ harvesting of rainfall over a catchment area (wastelands) through the use of a minipercolation tank and augmenting the aquifer tapped for drinking water supply and sustaining it by arresting the subsurface outflow. The ground water sanctuary thus created can be utilised for development of wastelands around for further protecting the area from encroachment. The re-forestation of catchment area may help in soil fixation and less sedimentation load in minipercolation tank. Such a system may be applicable for reducing the dissolved impurities in ground water.

Training and demonstration

Although rainwater is plentiful in areas like Cherapunji, the lack of harvesting systems resulted in non-availability of safe drinking water throughout the year.

As a result of extensive training/demonstration programs organised by the Structural Engineering Research Centre of Ghaziabad, a number of governmental and voluntary agencies have been motivated to build rainwater harvesting structures in places U.P., M.P., Meghalaya, Nagaland, Tripura, Rajasthan, Karnataka, Andhra Pradesh & Lakshdeep. The know-how has been released to 80 parties in above states. About 85 demonstration/training programs have been conducted thus far. More than 2,000 technicians/resource persons from state governments/ NGOs etc. have been trained. 175 rainwater harvesting structures have been fabricated during training/demonstration program in almost all the states.

Under a UNICEF sponsored program SERC (G) conducted demonstration/training in states i.e. Manipur, (Marm Hills 5 villages) M.P., (Indore) A&N Kavaratti Island, Himachal Pradesh, (Simla District) Kangra U.P. Ranikhet & Almora.

At the international level, SERC (G) organised many training/demonstration program for the:

Asian Institute of Technology, (AIT) Bangkok and Malaysia.
Indonesian Project Leader Course, a US-AID sponsored program.

Future Research & Development Programme

- Selection of appropriate chemical sealants for water- proofing through multi-trench testing;
- Tracing and mapping of the intake area of a spring, monitoring its natural discharge and quantifying the increase in the discharge after construction of trenches;
- Cost-benefit assessment in both the cases stated above;
- Use of remote sensing and ground surveys for selecting a tank site in an area having a high permeability;
- Design of the tank to achieve maximum possible storage per unit area in order to directly reduce

evaporation losses;

- Trial of newly developed wind-resistant chemicals to further reduce evaporation losses;
- Monitoring of evaporation from the tank and seepage through the bunds;
- Inventory of the command area wells and a detailed study of their hydrogeology;
- Stable isotope ratio measurement in water samples from the tank and the command area wells to estimate the contribution from the tank to the wells and to assess the extent of the sub-surface command area;
- Calculation of overall efficiency of the tank and cost-benefit ratio;
- Measurement of the flow in the submerged injection well;
- Tracer studies for understanding the pathways of the dispersal of water transferred to the deeper aquifer at a point through injection well;
- Prevention of clogging;
- Improving the permeability of the injection borewell and surrounding aquifer through hydrofracturing.

Experiences:

Training and Demonstration

Although rainwater is available in plenty of areas like Cheerapunji, the lack of harvesting systems resulted in non-availability of safe drinking water throughout the year.

As a result of extensive training organised by SERC Ghaziabad, a number of governmental and voluntary agencies have since been motivated to build rainwater harvesting structures in places such as Madhya Pradesh, Gujarat as well as hilly regions.

Policy recommendation

Rainwater harvesting projects require initially a high cost but a low cost maintenance in the long-run. As such it is recommended that centrally funded projects should include a predetermined component of such projects for yielding a suitable mix of source pattern.

At the national level, an information centre as a common facility of a complete package for technique/process may be available for common use. As a policy, a rainwater harvesting structure should be made compulsory for any building in rain-fed areas.

Micro-Minor Methods of Rainwater Conservation and Groundwater Recharge

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Abstract

This is a study of location-specific rainwater harvesting techniques from the past to the present. To evaluate ancient methods of water harvesting/conversation, large-scale experiments were laid out using essentially two modern methods: spreading and water injection. The spreading techniques comprised of slopes, trenches, ponds, percolation tanks, etc., whereas injection techniques comprised of augured piles, dug wells, injection of water through tube wells, roof water collection and pouring it into tube wells.

In an area of 250 hectares, slopes along roads, trenches in and around the cultivated fields of 2 to 3 hectares, small ponds in low lying areas, percolation tanks for small catchments were developed. Water recharge in the deep aquifer through such spreading techniques was found to contribute around 23 % of rainwater available for conservation. An innovative Indore technique was applied to abandoned dug wells by pouring in runoff water. Round hole piles with a diameter of 22 cm and 2 to 3 m deep were augured and filled with pebbles and sand in places such as parking lots, gardens and empty areas. During the monsoon season, when surplus clean water was available on the surface or in dug wells, water was injected in the tube wells up to a depth of 30 to 50 meters with the help of motor pumps. The deep aquifer accepted water to its full capacity. Abandoned tube well bores and dug wells were used for pouring collected roof water. All these injection techniques contributed 77% of artificially recharge ground aquifer.

The estimated average recharge index over a period of nine years was 2,25% more. Simultaneously the integrated techniques of water recharge were extensively adopted by several industrial units and became part of a national watershed programme. This shows the current relevance and cost benefits of micro-minor methods of water conservation and ground water recharge.

Ancient water conservation practices

Rainwater is a precious gift of nature. Ancient cultures flourished near potential water resources. Findings on water as described by Varahamihira in the 5th Century AD at Ujjain in Central India withstood scrutiny and verification on the scale of modern scientific norms. The technology of constructing wells, infiltration galleries, Kanat, Kundis - underground tanks, roof water harvest, networks of ponds, tanks, stop dams have been developed in India, Iran, Italy, China and in many other old civilisations.

Underground baked earthen pipes/ tunnels, with masonry hollow pillars to maintain the flow of water with gentle gradient, suction and gravity without any external source of energy, are still functional at Burhanpur in Madhya Pradesh, India, at Golkunda and Bijapur in Karnataka and at Aurangabad to transport water to a distant place.

The study of ancient rainwater harvest techniques and their impact on civilisation, convinces one that

ancient and modern systems can function simultaneously without any conflict. To support this contention, the experiment was undertaken, the details of which are as follows.

Rainwater harvest

Rainwater needs to be collected and conserved during the short span of the rainy season. Adoption of location-specific micro-minor measures in an integrated manner at the JNKVV College of Agriculture, Indore, Madhya Pradesh, India and also adopted by several industries at Dewas and Pithampur in M.P. has imparted encouraging results. Attempts have been made to assess the contribution and economics of each of the techniques, and their implications, in brief, with reference to JNKVV are as follows.

Ground water - invisible source

Ground water usually has the great advantage over surface water, as it is free from pathogenic organisms. Moreover, in the arid and semiarid regions, surface water evaporates at a faster rate, leaving concentrated salts on the surface. However, ground water too is not always available and the amount that can be withdrawn is usually limited. But under suitable situations it is possible to supplement the natural recharge of ground water aquifer so as to add to its capacity. Ground water is an invisible source; it is a sort of reserve fund.

One of the ancient practices of tapping ground water is through wells. With the sinking of deep tube wells, in recent years, most of the dug wells dried up and had to be abandoned; in many parts of India such dug wells were utilised in which to pour runoff water to recharge ground water.

Ground water recharge by dug well

The water recharge techniques through a dug well clearly indicate that the recharge of ground water through dug wells was the most effective measure. This method was found to be very economical, as diverting water into the well through trenches provided with filters cost around Rs.3000/- to Rs.4000/- per well and the yearly maintenance was also not much.

Roof water harvest

Rainwater after a first shower is mostly free from any contaminants. Roof water harvest was found to be effective in recharging ground aquifers. Collection of water from the roof and pouring into well/tube well cost around Rs.500/100 m².

Tube well injection

Clean water collected in a dug well was pumped into the deep aquifer of a tube well using electric motor pump at the rate 9,000 gallons per hour. It accepted water until it filled to capacity. The method was found to be useful in arresting and raising water table.

Percolation tanks

The cost of percolation tank and ponds was around Rs. 70,000/-. Expenditure incurred in making trenches

around the fields and the cost of deepening of collectors and their bunding at a distance of 30-40 m, required an expenditure of about Rs. 1000/- per hectare.

Trenches & drilling of holes

The possible contribution of trenches in recharging ground water appeared to be quite low, but increase in water holding capacity in increasing production was quite perceptible. Drilling of holes of 25 cm diameter to a depth of 2 meters filled with pebbles and sand cost around Rs.100/- per pile hole. Such measure enhances infiltration of water in the deeper soil profile.

Water recharge by spreading vs. injection method

The various measures adopted to augment the ground recharge mainly comprised of water spreading and water injection. The details of each technique and its possible contribution in augmenting the water recharge revealed that an individual contribution was quite low. However, overall contribution of spreading versus water injection techniques revealed that the spreading techniques contributed around 23 %, whereas the injection techniques contributed 77 %, of the artificially recharged ground aquifer.

Cost

The total cost of the project, which was implemented in a phased manner, was around Rs.1.5 lakh (Rs. 4/m³ of water). The yearly maintenance cost was found to be less than 3 per cent of the cost of the whole project.

Index of recharge

The index of overall recharged water was used as a comparison of the draft prior to adoption of various measures of recharge since 1990-91. The average draft from ground water since 1990-91 was calculated to be 49,250 m³, i.e.2.25 times more in comparison to 21,710 m³ draft available prior to adoption of artificial recharge techniques. The effective recharge in this technique was found to be around 65 per cent. (Table 1).

Table -1 Artificial Water Recharge & Annual Draft at College of Agriculture, Indore (Madhya Pradesh)

Year	1988-90 2 Yrs	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99 up to Nov	Mean
Total Precipitation in meters	0.852	1.090	0.745	0.550	1.060	1.440	0.957	1.320	1.186	0.969	
Water Recharge method	Natural Recharge	Artificial Water Recharge m ³									
Trenches/ Collector	-	-	7930	2293	9460	13480	8295	12710	10185	9000	9166
Percolation tank / pond	-	6250	4870	2250	6100	7500	3396	6910	6965	4500	5415
Roof Water (Area 300 m ²)	-	-	-	96	250	380	245	310	195	200	239
Dug well	-	40556	30430	13245	43750	55770	36750	49585	46370	40500	39773
Tube Well (injection @ 4 litres/ second	-	-	1220	-	1395	2275	1630	-	-	-	1630
Augured Pile Holes 2 m depth	-	-	-	-	-	115	95	175	105	105	119
Total	-	46816	44450	17884	60955	79520	50411	69690	63820	54305	55442
Annual Draft	21710	55100	50300	32250	68920	62350	42270	55485	52785	45025	49250
Average increase in draft	-	-	-	-	-	-	-	-	-	-	27540

NOTE: US 1\$ = Rs. 42.50

Results

The need of artificial recharge of ground water with reference to Malwa Plateau of Central India has been seriously felt, as most of the ground water basins reach faster to a critical stage of depletion adversely affecting the yield of crops and eco environment.

The present study also revealed that the hydrological situation in basaltic terrain varied widely. Therefore, the technique to be adopted depends on the basis of the study of their nature. Study of potential wells and tube wells for the purpose of artificial recharge proved to be quite effective in increasing ground water reserve.

Trenches in and around the fields, ponds, tanks, augured pile of around 2.5 m. depth filled with pebbles and sand also proved to be effective in augmenting ground water recharge.

Benefit

Cost ratio is calculated by Annual benefits divided by Annual cost, Major structure (like wells, tube wells, tanks, etc) and artificial recharge techniques adopted in such structures remain effective for at least 25 years. The yearly cost in the present study is computed to be around Rs.15,000/- which includes depreciation, interest on the capital invested and annual maintenance cost. The increase in draft by 27,540 m³ could provide one irrigation in about 50 ha of additional land area. Additional availability of water made it possible to give one life saving irrigation to Kharif crops in drought years. Moreover, it was possible to raise Rabi crops (through with only one irrigation). It also increased production to the extent of 25 to 30 per cent. The cost of the water for one irrigation (along with operation cost) is estimated to be around Rs.600/- per ha. If only the increase in production by 2 to 3 quintals/ ha is accounted for, then on an average the benefit earned per irrigation per hectare is around 3 to 4 thousand rupees.

On the basis of experience gained at JNKVV, Indore, and industries at Dewas and Pithampur, Madhya Pradesh, India, it can be concluded that the techniques of rainwater harvest have a relevance even in the modern era and their use in artificial recharge of ground water in the Peninsular basaltic terrain of Malwa Plateau is cost effective. The judicious use of artificially recharged water make it possible to give life saving irrigation to Kharif crop or make it possible to harvest a Rabi (Winter) crop in a dry land area. Rainwater harvest has been adopted even with great advantage in urban area and by industries.

Barragem Subterrânea: Experiência Em Pernambuco

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Resumo

Durante os últimos 7 anos diversas experiências tem sido feitas no Estado de Pernambuco com barragens subterrâneas, tanto por ONGs como pelo poder público. Existem aproximadamente 500 barragens desse tipo implantadas no Estado e outras 500 locadas por técnicos. As maiores barragens alcançaram profundidade de 10m, e poderão acumular cerca de 80.000 m³, volume esse que poderia assegurar o abastecimento de até 500 famílias, ou ainda a irrigação de 15 ha. Neste trabalho são discutidas as potencialidades deste tipo de reservação hídrica.

Introdução

A **barragem subterrânea** é uma obra singela e de baixo custo, já sendo conhecida na bibliografia desde mais de 60 anos, a exemplo do trabalho de Marcelo Conti (1938), onde se refere às regiões agrícolas das Calábrias e da Sicília com irrigação dos seus famosos pomares e plantações de hortaliças a partir de barragem subterrânea; também se refere ao “dique subterrâneo” no rio Los Sauces na Argentina com uma barragem subterrânea que tem capacidade para irrigar 1.000 ha.

Apesar de ser uma tecnologia bem antiga e de simples execução, não vinha sendo aplicada no Brasil, e principalmente na região semi-árida onde a falta de água vem sendo uma tônica secular.

No início da década 80, pesquisadores da UFPE, sob a coordenação do Prof. Waldir D. Costa desenvolveram um tipo de barragem subterrânea que foi aprimorada paulatinamente, sendo o modelo patenteado com a denominação de COSTA & MELO pelos seus principais autores.

Em 1986 esse modelo foi aplicado pela primeira vez na Fazenda Pernambuco, no município de São Mamede na Paraíba, tendo sido construídas duas barragens com oito poços amazonas a montante. Como resultado dessa intervenção no riacho que banhava a citada propriedade, seu proprietário vem até hoje irrigando 45 ha com plantação de fruteiras, sendo inclusive exportador de mangas para a Europa.

Experiências bem sucedidas na construção e manejo de pequenas barragens subterrâneas foram implantadas pela organização não-governamental CAATINGA, no município de Ouricuri – PE, dando suporte à agricultura familiar na região há mais de 7 anos. Em 1997, a então Secretaria de Ciência, Tecnologia e Meio Ambiente – SECTMA interessou-se pelo tipo de barragem e efetuou experiências com a construção de seis unidades experimentais no município de Caruaru. Face ao sucesso alcançado, passou o Governo do Estado na época a admitir como um dos seus programas de Convivência com a Seca a construção de barragens subterrâneas.

Em 1998, foram ministrados cursos a alunos do Projeto RONDON que, sob a supervisão de geólogos da SECTMA, efetuaram a locação de 300 barragens durante os meses de fevereiro e março.

Características Construtivas Do Modelo Costa & Melo

Após constatada a existência de condições adequadas para a construção da barragem, em que são consideradas a espessura da camada aluvial, a sua composição granulométrica, a inclinação do terreno, a inexistência de soleiras rochosas, a relação morfológica do vale, a distância da área de recarga e a qualidade da água, procede-se a sua construção, mediante as seguintes etapas:

Escavação da vala - Escava-se uma vala transversalmente à direção de escoamento do rio, com largura total do vale e profundidade até encontrar a rocha inalterada. Essa escavação pode ser mecanizada, utilizando-se um trator de esteira ou uma retro-escavadeira, ou ainda, manualmente.

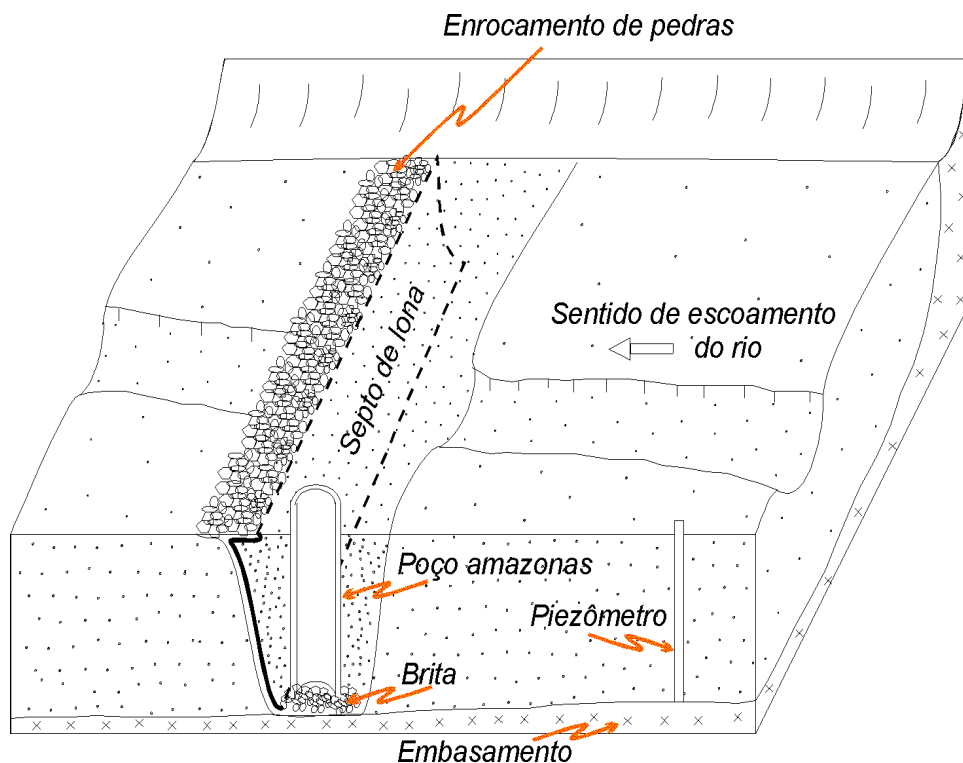
Impermeabilização - **A vala deve ser impermeabilizada com argila compactada ou, de maneira mais simples, rápida e econômica, através de uma lona recobrindo a parede da vala que fica oposta ao sentido de procedência do escoamento superficial**

Construção do poço amazonas - Na parte mais profunda da vala, deve ser construído um poço amazonas e o modo mais rápido é com anéis semi-porosos pré-fabricados, de 1,0 a 1,2m de diâmetro, por 0,5m de altura. Os anéis são colocados justapostos até alcançarem a superfície, ficando o último, totalmente acima do nível da superfície. Antes de colocar o primeiro anel deve ser colocada uma camada de brita para proporcionar maior permeabilidade do meio bem como impedir a entrada de areia no poço. Nos maiores barramentos, deve-se colocar também tubos semi-horizontais, na parte mais profunda da vala, com a parte superior do tubo devidamente ranhurada, que servirão de drenos para o poço amazonas, aumentando consideravelmente a entrada de água no mesmo.

Enchimento da vala - Concluídas as operações de enlonação da parede da vala e de construção do poço amazonas, procede-se ao enchimento da vala com o mesmo material dela retirado.

Enrocamento - Embora não seja imprescindível, é aconselhável a construção de um enrocamento de pequena altura (cerca de 0,5m) sobre a barragem, a jusante do poço amazonas, a fim de proporcionar maior infiltração da água que fica retida por alguns dias na superfície.

Piezômetros - **É aconselhável também a construção de um a dois piezômetros, a montante da barragem, com distâncias de 100 m e 200 m da mesma, a fim de melhor monitorar o rebaixamento dos níveis d'água com o tempo.**



Vantagens Da Barragem Subterrânea

Embora não deva ser considerada uma obra que vá resolver todos os problemas de água na região semi-árida, nem muito menos que deva substituir qualquer outro tipo de intervenção, as vantagens que essa obra apresenta, sobretudo para as barragens convencionais na superfície, são as seguintes:

- não há perdas de áreas superficiais por inundação, podendo ser utilizada a própria calha umedificada para plantio, o que implica numa sub-irrigação;
- devido a isso, dispensam os gastos com indenização das terras inundadas, como acontece com as barragens superficiais;
- há maior proteção da água contra a poluição bacteriana superficial, pois a água fica armazenada na sub-superfície;
- apresenta bem menor perda por evaporação, pois, não existindo “espelho d’água”, a insolação quase não atua (apenas na franja capilar);
- as perdas por infiltração em fraturas do embasamento, ou eventuais orifícios ou fissuras na lona do septo, são muito reduzidas, pois as diferenças de carga hidráulica a montante da barragem são muito baixas e o fluxo através do meio poroso é muito lento, obedecendo a lei de Darcy;
- representa maior facilidade de construção, pois, sendo o septo encaixado no depósito aluvial, não exige grande espessura de parede e nem ombreiras laterais no vale;
- pelo mesmo motivo, apresenta grande estabilidade da parede (septo) contra a erosão e nenhum risco de desmoronamento;
- apresenta grande economicidade na construção, pois constitui uma obra de pequeno porte, em geral de dimensões muito reduzidas comparadas com aquelas de barramentos superficiais;
- são de rápida construção, podendo ser executadas em um ou dois dias, quando a operação é mecanizada, ao contrário das superficiais que requerem vários dias, até meses para a sua construção;

podem ser construídas inteiramente com mão-de-obra localizada, gerando empregos para a população beneficiada; dispensam onerosos esquemas de tratamento, manutenção, operação, consumo de energia elétrica e outros gastos comuns nos barramentos superficiais.

Monitoramento Da Barragem Subterrânea

Embora dispensando os tratamentos mais complexos que são necessários à manutenção de uma barragem superficial, esse tipo de barramento necessita ser monitorado para evitar o processo de salinização da sua água, tendo em vista as elevadas taxas de evaporação na região semi-árida, que chegam a atingir 3.000 mm/ano.

O principal elemento do monitoramento é o poço amazonas construído junto ao septo impermeável da barragem, o qual desempenha as seguintes funções:

permitir a captação da água por bombeamento ou simplesmente com um sistema de sarilho/corda/caçamba, para consumo humano, animal ou irrigação;
coletar amostras d'água para análises físico-químicas periódicas a fim de monitorar a evolução da salinização na bacia de acumulação;
acompanhar a evolução do rebaixamento dos níveis d'água durante o ano;
exaurir a água da bacia de acumulação quando se iniciarem as primeiras chuvas do ano, a fim de que haja renovação das águas armazenadas, evitando o processo de salinização progressiva decorrente da evaporação das zonas mais superficiais.

A coleta de água para análises físico-químicas deve ser efetuada ao menos duas vezes por ano, nos períodos de chuva e de estiagem.

O processo de salinização é decorrente da concentração progressiva de sais devido à evaporação da água, processo esse que ocorre também com as águas na superfície. Se for observado o esquema de esgotamento da barragem a cada ano, não haverá condições para um aumento progressivo da salinização.

A Atuação Pioneira De Pernambuco

O Estado de Pernambuco foi a primeira unidade federativa brasileira localizada no semi-árido nordestino a adotar a barragem subterrânea como um programa de governo para minimizar o angustiante problema das secas e fixar o homem na terra, impedindo o contínuo êxodo rural para as cidades grandes, que aumenta a marginalidade e criminalidade.

Com a decretação do “estado de emergência” em 120 municípios do interior do Estado, por falta absoluta de condições de suprimento de água, o governo intensificou a construção das barragens subterrâneas, ao lado de outras ações mais imediatistas como a perfuração de poços e outras de médio prazo, como os barreiros e cisternas.

Muitas das barragens subterrâneas, ao serem construídas, já apresentaram um bom rendimento mesmo durante o período de estiagem, pois as reduzidas lâminas d'água que percolavam no fundo do depósito aluvial ao terem seu fluxo barrado, passaram a se acumular a montante das barragens, fazendo elevar-se o nível d'água dentro dos poços amazonas.

As melhores áreas encontradas até o momento, para construção de barramentos, localizam-se nos municípios de Belo Jardim e Jataúba, onde algumas dessas barragens subterrâneas no leito de riachos alcançaram profundidades de até 10m, como mostrado na Fig. 1.



Fig. 1 – Escavação de vala profunda para implantação do septo impermeável no Município de Jataúba – PE

No Quadro 1, pode-se ver as principais barragens construídas nos municípios de Belo Jardim e Jataúba, que irão proporcionar condições de abastecimento de centenas de habitantes daquelas localidades, além de fornecer condições para o plantio de culturas as mais variadas.

Quadro 1 - Barragens Subterrâneas de Maior Porte Construídas

Município	Local	Nome da barragem	Dimensões (m)			Número famílias beneficiadas
			Profundidade	Comprimento do eixo	Extensão (alcance a montante)	
Belo Jardim e Jatauba (o riacho serve de limite entre os dois Municípios)	Fundão	Fundão I	5,4	50	1.000	21
		Fundão II	4,4	50	600	15
	Cafundó	Cafundó I	4,3	36	1.000	24
		Cafundó III	5,5	42	1.000	18
		Cafundó IV	6,0	65	1.000	18
		Cafundó V	6,0	64	1.000	14
	Mimoso	Mimoso I	8,0	63	1.000	>15
		Mimoso II	10,0	55	1.000	>15
		Mimoso III	8,5	76	1.000	>15
		Mimoso IV	8,5	76	1.000	>15
		Mimoso V	7,5	52	1.000	13
	Travessão	Travessão I	6,0	110	1.000	18
Belo Jardim		Travessão II	4,0	30	1.500	12
	Mimoso	Rch.Salgado	10,0	56	1.600	>15
	Imbé	Imbé	6,5	53	1.500	>20
	Conceição	Quandus	4,0	30	800	>60
Jataúba	Minador	Minador	6,0	42	1.500	>60
	J.Vermelho	J.Vermelho	6,0	47	2.000	>15
	Jundiá	Jundiá	3,8	53	1.500	>300

As Figuras 2, 3 e 4 mostram uma barragem em fase de colocação da lona, outra concluída e na última cultivo de mamão implantado.



Figura 2 - Colocação da lona na vala escavada no aluvião



Figura 3 -Enrocamento de pedras sobre a barragem já fechada. Vê-se ainda o poço amazonas



Figura 4 - Cultivo de mamão implantado

Custos De Uma Barragem Subterrânea

Comparativamente com outras obras, como poço tubular e barragem superficial, uma barragem subterrânea pode ser construída com baixos custos.

A maior parte das barragens, numa percentagem superior a 90%, possuem profundidade máxima de 3,0m e extensão máxima de 50m do eixo barrável. Nessas condições uma barragem custa entre R\$ 1.000,00 e R\$ 1.500,00 a depender da distância do local para o mercado produtor dos materiais e deslocamento de equipamentos para escavação, da maneira de construção (manual ou mecanizada) e outros fatores de menor peso.

Para barramentos de grande porte, com profundidades entre 4,0 m e 10,0 m e extensão do eixo superior a 50,0 m, os custos são mais elevados, variando entre R\$ 2.000,00 até 8.000,00, a depender das suas dimensões, com tempo de atuação de trator diferenciado em função dos volumes de terra a remover e a recolocar na vala.

As barragens de pequeno porte (até 3,0 m de profundidade) podem ser construídas manualmente, porém as de médio a grande porte exigem a participação de trator ou retroescavadeira.

A componente de custo mais elevada é a de hora de trator ou escavadeira, pois os demais componentes pouco influem, inclusive a lona plástica é de custo relativamente baixo, ficando, em média da ordem de R\$ 0,42 o m².

Conclusão

As barragens subterrâneas podem se constituir em obra de grande importância para a reservação de água em regiões semi-áridas como o Nordeste do Brasil. As cerca de 500 existentes em Pernambuco se constituem em amostra fundamental para o aprimoramento da técnica. Como sua implantação é recente e ocorreu dentro de um período de anos sucessivos de seca, ainda não se dispõe de maiores elementos para uma análise regional integrada. No entanto, diversos experimentos isolados anteriores já sinalizam para o sucesso da prática, desde que racionalmente implantadas, monitoradas e aproveitadas.

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Improving Environmental Characteristics in a Wide Area Around a Flood Water Spreading System, "A case study"

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Abstract

Soil is a huge place for reserving rainwater from where it can be released gradually and with the lowest water loss. In an area where the soil does not exist or the soil thickens is negligible, the water capacity of the soil is quickly replenished. In arid and semi-arid zones, the rain intensity is high and rain distribution is low. Thus enormous amounts of rain are lost as flooding. Water spreading systems give enough time to spread the rainwater and to infiltrate deep into the soil. The Gareh-Baigan Plain, situated in Southern Fasa, in Iran's Fars province, is an arid zone often affected by floods. The water spreading project was designed for an area of 2500 hectares with the purpose of increasing rainwater content in the soil, artificial recharge of groundwater and improving environmental aspects. The total area affected by the project is about 7500 hectare. Using computer image processing of aerial photos and satellite imagery data of the area before and after the project shows the following:

- increased cultivated area due to utilization of more water from the aquifer
- improved rangelands and forest area due to a higher water content in the upper soil layers
- reduced wind blown lands and more desertification control due to vegetation developments
- reduced soil erosion, due to flood control, in the lower part of the area
- a pleasant and natural place was created in an arid zone.

The remote sensing method allows consideration and distinction of the mentioned improvements.

Application of such systems in arid and semi arid zones not only improve the water content of the soil, but also help to reduce the bad effects of floods.

Introduction

Water shortage is one of the most critical problems in the world. Some politicians believe that water shortage might cause future world wars. In recent decades, different climatic phenomena have increased this danger. Reduction of yearly rainfall and air warming are simple examples of these climatic changes. Storing water in the uplands increases the water shortage in lowlands and causes more severe conditions. Rain is the most essential factor in securing water for human needs. In arid and semiarid regions, where the annual rainfall is negligible, its distribution is also not appropriate. Irregular intensive heavy half an-hour rains in a short period (less than 4 months of the year) are obvious characteristics of these zones. Hence, only a part of the yearly rainfall has a suitable intensity and time in these regions and the remaining causes floods. Storing floodwater with dams or in aquifers is the only possibility for utilizing it in the long run. In many places, the building of huge dams is impossible due to the need of a high initial investment and special conditions. In addition, the evaporation of the stored water in the basins of dams in arid and semi arid regions is very high and causes water loss. Floodwater spreading is a simple project and has a high effectiveness. Even very negligible amount of waters can be stored that way.

Utilization feasibility of this stored water would create a positive change in the general view of an arid region. This paper tries to survey and document the general changes in the ecosystems of arid regions.

Materials and Methods

The Garth Bygone plain, part of the Sheebkuh region, is located 50 kilometers southeast of Fasa, between $53^{\circ} 50'$ and $54^{\circ} 15'$ latitudes and $28^{\circ} 30'$ and $28^{\circ} 45'$ altitudes. The maximum and minimum elevation of this plain is 1822 and 1100 meters above sea level, respectively. The nearest meteorological station is at Baba Arab (Tamshir) with 240 mm mean annual precipitation (1968 - 1996). Of the 600-km² of this region, 150 km² are a rather flat plain and the remaining are covered by mountains. There are four relatively large ephemeral rivers named Gehrab, Bishehzard, Tcheghooch and Bidzard. It is estimated that the yearly flood volume is about 20 million m³ with 200 mm rainfall on the average.

Ninety-four 1:20000 scale aerial photographs of a 26-year period before the initiation of the project were provided. They were examined in the form of row-column stereoscopic pairs. After preliminary visual interpretations, the photos were converted to a digital form with a scanner and entered into the computer. The conditions of the land were illustrated through special image processing. The extent and site of the wind blown land, very poor rangeland, poor rangeland, rain-fed farms and irrigated ones were recognized. A digital 1:20000 scale map was the result of the first phase of the survey. The last satellite imageries of land sat-5 of 1998, 17 years after the initiation of the project, were provided afterwards. They were entered into the computer in a digital form with 7 bands. After atmospherically, geometrical, and shadow corrections and suitable bands combinations (1,3,5), the data image processing was commenced. A map in the scale of 1:20000 with the new conditions of the region was the result of this second phase.

Results and Discussions

Results of the two mentioned phases showed that irrigated farms have increased considerably, especially for lands located lower than the project. These increases in farmlands are seen less in other areas of the project. Since ground water is the only secure water source, the increase in irrigated farms depends on the project. Statistical evidence also shows this increase. The number of wells has increased from 16 to 110. This evidence also shows a development in water quality. An increase in forage production is seen in the maps. Field surveys also show an 11 fold increase in forage production. Before the founding of the project, the trees in the region were thinly scattered, however, after the founding of the project, a plantation of Eucalyptus and Acacia species on the flood water system has turned into a tense jungle and changed the general look of this semiarid region. A remote sensing survey shows the effects of floodwater spreading on the ecosystem of the region. Reduction of wind blown lands, desertification control, and development of vegetation, particularly trees, led to protection of the sandy soils. Field surveys also show a considerable reduction of tornadoes. The comparison of the first phase of study to the second shows that the extent of land degradation due to effects of floodwater has decreased after the project had been established. The flood water volume in the lower part of the ephemeral rivers has much decreased due to the spreading of a considerable flood water volume on the lands in upper part of the rivers.

Studies of the satellite imageries show a very vast arid zone around this site. However, the system has created a tense jungle. This plantation has provided a suitable environment for wild life. Field surveys

inform about the return of different species of wild birds and animals. This site is now a favorable place for migrant birds and animals (fig.1).



Figure 1



Figure 2

This site is a favorable place for migrant birds. These favorable conditions have created a natural recreational place in an arid and desert region. Visitors from far cities and villages admire the project's success (fig.2).

Conclusion

For the mentioned surveys the remote sensing science has been used. These surveys were put to the test in field studies. There was an increase in irrigated farms from 184 ha before initiation of the project to 2832 ha. The wind blown and poor rangelands were reduced from 7500 ha to 2352 ha, indicating that the system has directly or indirectly affected the environment of more than 10,000 ha of land. The results presented are the cases that could be surveyed through remote sensing. Changes in living microorganisms, chemical, physical and biological characteristics of soil as well as its fertility could not be surveyed through remote sensing. The essential success of this research is feasibility of comparison of the area under the project with other areas around the project through obvious documents, aerial photographs and satellite imageries. Optimal use of rainfall through floodwater systems not only reduces the negative effects of the flood in low lands but also reduces the water shortage during dry seasons. It needs a simple technology and little investment and promises an environmental development.

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Caldeirão, Caxio e Cacimba: Três Sistemas Tradicionais de Captação de Água de Chuva no Nordeste Brasileiro

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Resumo

No Nordeste Brasileiro, uma grande área de aproximadamente 900.000 km² recebe a classificação de semi-árida. Nesta região porém não encontramos hábitos e tecnologias, relacionadas com a água e tipicamente presentes em regiões semi-áridas, como poços, cisternas etc. Isto pode ser creditada ao nível de desenvolvimento tecnológico da população nativa, pré-lusitana, mas também pela simples falta de necessidade. O Semi-árido brasileiro possui inúmeros núcleos úmidos e as áreas adjacentes possuem chuvas regulares.

O interior seco possui ainda, na sua maior parte, uma história de ocupação pelo homem e a mulher branco muito curta, insuficiente para o desenvolvimento empírico de tecnologias autóctones.

Uma grande parte da região semi-árida do Nordeste possui um subsolo cristalino, altamente adequado para reservatórios naturais de água tipo "caldeirão", para a escavação de caxios e para a construção de cacimbas-cisternas.

- O caldeirão: São cavernas naturais nas rochas cristalinas que, quando escavadas, representam reservatórios excelentes para a água da chuva.

- Caxio: O intemperismo transforma a rocha cristalina de uma maneira que pode ser cavada manualmente, com relativa facilidade, mas que preserva a total impermeabilidade. As medidas originais são 4,40 m. A construção de um caxio é uma tarefa de vários anos e, possuindo duas partes separadas, pode-se usar primeira a água da parte mais rasa e continuar o aprofundamento durante toda a época da estiagem anual.

- Cisterna - Cacimba: A obra é realizada dentro do leito de um dos inúmeros riachos ou rios.

Para evitar que a areia do leito do riacho caia na escavação, se levanta hoje, à partir da camada decomposta, mas resistente, uma parede de tijolos, - ou anéis de concreto, até pouco abaixo do nível superior do leito do riacho.

Acesso à água, um direito básico do cidadão:

A construção de fontes de água independentes e sob o controle da população rural, tem demonstrado sua eficiência do crescimento da consciência e atividade cívica, criando independências de dominações e tem se revertido em maior produção na área rural e redução do êxodo rural.

Introdução

No Nordeste Brasileiro, uma grande área de aproximadamente 900.000 km² recebe a classificação de semi-árida. A precipitação média fica em torno de 500 mm e a evaporação chega a 3.000 mm por ano. Não era sempre assim: a mudança climática ocorreu há ca. de 12.000 anos. Antes a região era chuvosa, coberta de vastas florestas. A espécie humana que, segundo as escavações arqueológicas realizadas, aqui perto, em São Raimundo Nonato Piauí, povoava esta região há mais de 50.000 anos, acompanhou a mudança climática, sem porém desenvolver hábitos e tecnologias, relacionadas com a água e tipicamente encontradas em regiões semi-áridas, como poços e cisternas no Oriente médio, qanats, desenvolvidas no Irã, e que são longas galerias subterrâneas que conectam aquíferas ou os chultuns, da península Yucatán, cisternas gigantes subterrâneas, cuidadosamente rebocadas e que captavam a água de uma área calçada, em torno da cisterna.

No Semi-árido brasileiro não encontramos nada disso. A explicação pode ser composta de vários elementos. De um lado, certamente, pode ser creditada ao nível de desenvolvimento tecnológico da população nativa, pré-lusitana, mas também pela simples falta de necessidade. O Semi-árido é cortado por rios perenes e semi-perenes, e existem inúmeros "brejos", onde a umidade se mantém o ano todo. A baixa densidade populacional exercia pouca pressão sobre os recursos hídricos. Além disso a região se limita, em todos os lados, com áreas chuvosas e férteis, para onde a população migrava com facilidade.

A chegada do homem branco perturbou o equilíbrio e não soube colocar alternativas tecnológicas adequadas ao clima e em relação ao aumento da densidade populacional. O interior seco possui porém, na sua maior parte, uma história de ocupação que mal chega a 100, 150 anos. Há vastas regiões que há uma geração, eram totalmente desabitadas.

Assim encontramos poucas opções tecnológicas duráveis, desenvolvidas nativamente na terra, que fornecessem água de maneira permanente. Até hoje a população retira sua água de acumulações naturais de água em baixadas ou de tanques ou aguadas, cavados braçalmente, todos nas camadas permeáveis do solo. Assim, a perda de água que já é grande pela própria evaporação, recebe ainda o aliado da infiltração.

Ou então das cacimbas de areia, cavadas nos leitos de rios e riachos secos. A profundidade varia de alguns palmos a vários metros. Nestes buracos se acumula a água que existe no leito arenoso do rio, mesmo depois deste ter secado. Especialmente em anos de estiagem prolongadas, precisa escavar funis gigantes, para chegar ao líquido precioso. Mas, as enchentes da próxima estação chuvosa, fecham com suas areias, as escavações abertas.

Uma grande parte da região semi-árida do Nordeste possui um subsolo cristalino, onde as rochas se encontram a pouca profundidade. Muitas vezes a camada do solo não passa de um metro. O subsolo cristalino é um sinal da inexistência de um lençol freático e somente possui, quando muito, água em fendas das rochas, o que significa pouca água, mesmo nos melhores poços. Além disso, essa água, muitas vezes, é salobra.

Em contrapartida, o subsolo cristalino é altamente adequado para reservatórios naturais de água tipo "caldeirão", para a escavação de caxios e para a construção de cacimbas-cisternas.

Caldeirão



Ilustração 1: Caldeirão

Nas regiões do Nordeste com subsolo cristalino é frequente que a rocha aflore à superfície. O formato das rochas é arredondada, em forma de lentes e apresenta muitas cavernas, onde a água da chuva se acumula naturalmente. A parte mais profunda é sempre cheia de terra e cascalho. Em geral é o bastante desobstruir estas cavidades naturais para obter depósitos de água eficientes. Possuem profundidades de até vários metros e muitos possuem uma abertura estreita o que proporciona uma evaporação reduzida.

Ao desobstruir as cavidades, muitas vezes, precisa despedar grandes blocos de rocha, antes de poder tira-las.

Vantagens:

- em geral completamente impermeável;
- água limpa, coletada na pedra;
- é o meio mais barato de todos, de abastecimento com água potável;

Desvantagens:

- a localização sujeita ao acaso, muitas vezes longe das casas;
- na rocha cristalina, muito dura, é praticamente impossível aumentar a cavidade natural. O uso do fogo ou explosivos pode causar rachaduras e a consequente perda da água;
- o volume de água disponível é limitado, pelo tamanho natural da fresta;
- existem perdas através da evaporação, pois não é coberto.

Caxio



Ilustração 2: Caxio

O cristalino possui uma característica que possibilita a construção de caxios, porém não encontrado em todos os locais. O intemperismo transforma a rocha de uma maneira que pode ser cavada manualmente, com relativa facilidade, mas que preserva a total impermeabilidade.

Esta camada decomposta, também chamada de piçarra, pode chegar a vários metros de profundidade.

O local escolhido, deve ser próximo a uma baixada, para onde a água escorre pela superfície e é direcionada por meio de valetas ou então, na direção de uma vertente natural. Porém deve-se evitar o curso principal das águas, para evitar assoreamento.

Normalmente é construído num declive, por menor que seja, para que desta forma a primeira enxurrada, a mais suja, não fique retida no caxio.

Os caxios sempre são cercados, para impedir acidentes e acesso indevido de animais. Muitas vezes encontramos caxios separados para uso animal.

Para a construção de um caxio, se retira primeiro a camada do solo, numa largura maior que a futura escavação, para evitar desmoronamentos em épocas de chuva.

As medidas originais são 4,40 m dos lados e também de profundidade. Muitas das construções, porém, possuem formatos irregulares, pelos graus diversos de dureza da camada decomposta, dificultando assim a escavação manual. Se costuma também escolher um formato mais alongado, de seis a oito metros de comprimento, deixando uma parede de pedra no meio, formando assim duas partes que podem ser escavadas separadamente. A construção de um caxio é uma tarefa de vários anos e, possuindo duas partes separadas,

pode-se usar primeira a água da parte mais rasa e continuar o aprofundamento durante toda a época da estiagem anual, com seus meses mais frios.

Quanto o caxio tiver sua profundidade definitiva, quer dizer a escavação ter chegada à camada cristalina dura, pode-se baixar um dos lados, em forma de rampa, para assim servir de bebedouro para os animais.

O trabalho da escavação é feito com xibancas, picaretas, ponteiros, marretas e pá. O material retirado é colocado em volta do caxio, para servir como quebra-vento e para diminuir a incidência dos raios solares sobre o espelho d'água. Do lado da entrada da água, pedras são empilhadas, para barrar a entrada de areia, gravetos e folhas que a enxurrada traz consigo.

A qualidade da água de caxio, evidentemente, não pode ser comparada com normas oficiais. A água costuma ser barrenta, opaca, mas translúcida, lembrando na cor a uma limonada, mas muito bem aceita pela população local e pelos agentes de desenvolvimento que com ela trabalha.

Certamente, contaminantes orgânicos, encontrados no chão, em parte são esterilizadas pela incidência dos raios solares constantes durante os oito meses de estiagem absoluta. Isto se soma a baixa densidade populacional.

Como temos constatado, ainda o problema da população rural não é a qualidade de água, mas sim a falta de água. Quando se considera a qualidade da água que grande parte da população é obrigada a consumir, no fim de cada período seco, se entende a alegria de dispor de uma água, assim tão translúcida, como de um caxio.

Este fato porém não quer dizer que não seja necessário almejar uma melhora na qualidade da água. Tanto que em todos os cursos e treinamentos, oferecidos pelo IRPAA, sobre questões de clima-água, sempre se transmitem tecnologias capazes de obter água de boa qualidade. Um meio muito apropriado, denominamos de filtro caseiro, que pode ser feito num pote de barro queimado, com camadas de seixo, carvão vegetal moído, areia fina e areia grossa. A qualidade de água filtrada desta forma, é comparável à água encanada, fornecido pelo Serviço Público de Juazeiro.

Nos anos das grande seca, de 1981 a 1983, os moradores do município de Casa Nova-Bahia, se lembraram desta tecnologia descoberta pelos antepassados. Os conhecimentos acerca dos caxios tinham caído em esquecimento com a chegada dos tratores de esteira que cavaram reservatórios com muita facilidade. Eram reservatórios grandes, mas muito superficiais e somente dentro da camada do solo permeável. Estas bacias secam, o mais tardar, na metade do ano. Assim a chegada da máquina fez agravar a crise de água na área rural.

]

A retomada da escavação de caxios, foi suportada com doações externas para compra das ferramentas. Mas desde então não parou mais e tomou uma dinâmica própria, independentemente, se o ano for de seca ou não; partindo de talvez de uma dúzia de caxios em 1980, contamos hoje aproximadamente 1.000 reservatórios desde tipo no município de Casa Nova, sendo a redescoberta da tecnologia se espalhada pelos municípios vizinhos.

Vantagens

- a construção condiz com o ritmo de vida do povo;
- depois de terminado o primeiro, anexo pode ser construído em segundo, deixando uma parede de pedra natural entre as duas partes; no decorrer dos anos, os dois serão aprofundados alternadamente;
- o depósito é absolutamente impermeável.

Desvantagens

- a água contém partículas em suspensão;
- as ferramentas necessárias, pesadas, normalmente não são encontradas entre os agricultores/as/criadores;
- não é viável em todos os lugares do Nordeste, somente onde existe subsolo cristalino, com uma camada intemperizada espessa e solo raso.

Cisterna - Cacimba

A região semi-árida do Nordeste brasileiro se caracteriza especialmente pela irregularidade das suas chuvas que caem em intervalos e quantidades absolutamente imprevisíveis. Às vezes são chuvas intensas mas rápidas. Todos já observaram este fenômeno: o céu escurece, surge um vento forte e durante pouco tempo chove fortemente. A água escorre superficialmente, mas pouco penetra no solo.

A natureza nos ensina que devemos aproveitar mesmo estas breves precipitações: um bom exemplo são as cactáceas, como, por exemplo, o conhecido cabeça de frade. Ele possui raízes que partem do tronco da planta em forma de estrela em todas as direções: o que chama atenção, é que estas raízes se encontram praticamente a flor do solo. Talvez um centímetro abaixo da superfície, às vezes só coberto por folhas secas. Mesmo que a chuva só molhe os primeiros centímetros do solo, a cabeça de frade consegue absorver a água e armazená-la para o seguinte período seco.

Todos os procedimentos em relação à água devem considerar esta brevidade das precipitações nas suas tecnologias de captação e armazenamento.

Quero-lhes apresentar uma fonte de água permanente e segura. Se trata de uma solução híbrida, uma mistura entre poço e cisterna, uma tecnologia conhecida há gerações, mas que tinha caído igualmente no esquecimento.

Vejamos este primeiro esboço:

A obra é realizada dentro do leito de um dos inúmeros riachos ou rios. Primeiramente a areia é afastada, depois abre-se um buraco de 2 X 2 metros na rocha relativamente mole. A profundidade em metros, varia; se deve cavar até encontrar um veio d'água.

Para ter certeza de encontrar água doce, o local já deve ter sido localizado anteriormente por um meio seguro, p.ex. pela hidroestesia.

Para evitar que areia escorre para dentro da escavação, os antigos usavam troncos de aroeira, encaixados em torno da boca de areia solta. A abertura era coberta igualmente por

troncos de madeira. Com o tempo porém, a madeira apodrecia, cedendo à pressão da areia e anulando o esforço humano.

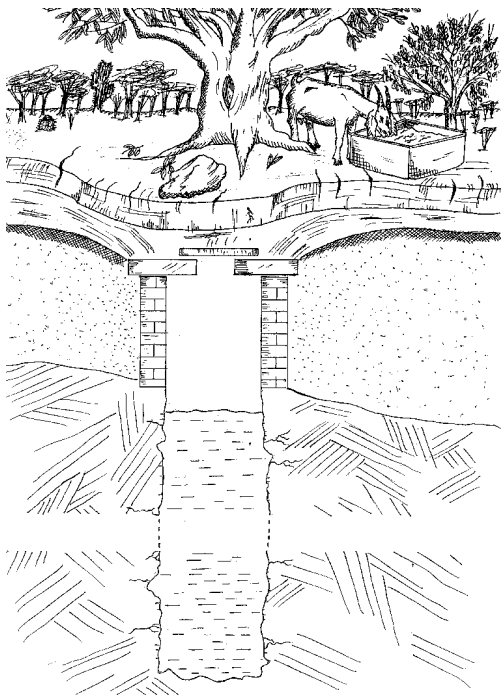


Ilustração 3: Cacimba - cisterna (corte)



Ilustração 4: Cacimba - cisterna

Igualmente na grande seca de 1981 a 1983 criadores no Município de Canudos - BA se lembraram das antigas cacimbas, feitas por seus antepassados. Localizadas e desenterradas foram adaptadas às tecnologias recentes.

De lá para cá, a re-descoberta tecnologia se firmou e a construção de novas cacimbas-cisternas se espalha pelos municípios vizinhos.

Para evitar que a areia do leito do riacho caia na escavação, se levanta hoje, à partir da camada decomposta, mas resistente, em torno uma parede de tijolos, - ou anéis de concreto, até pouco abaixo do nível superior do leito do riacho (muitas vezes não mais que 50 cm).

Esta murada é então coberta com uma laje de concreto, deixando só uma abertura de 50 X 50 cm como acesso e para a retirada da água. Esta abertura é coberta com uma tampa distanciada da laje ou então somente com galhos e gravetos e uma camada de areia, para que já durante as primeiras trovoadas no início do período chuvoso a água da chuva possa começar a encher por cima esta cisterna-cacimba. Depois dos quatro meses de estação chuvosa as reservas dos veios subterrâneos estão reabastecidas e o sistema passa a funcionar como poço.

Vantagens:

- fonte de água segura;
- a maneira de construir é apropriada para o ritmo de vida do povo;
- com uma escolha correta do local, a cacimba perdura até as estiagens mais catastróficas;
- é barato: cerca de 40 m arame farpado e um ou dois sacos de cimento tem que ser comprado para a laje e o muro baixo; areia e cascalho encontra-se no próprio leito do riacho; os custos externos ficam entre R\$ 20 e R\$ 50.
- a laje evita que a cacimba se enche de areia todos os anos;
- não há evaporação.

Desvantagens:

- o leito do rio ou riacho fica muitas vezes longe das casas;
- existe o perigo de contaminação, especialmente por animais que defecam em bebedouros próximos etc, mas o perigo é remoto, por se tratar de uma instalação permanente, fica assim em geral bem cuidada pela população;
- como na construção do caxio, é preciso usar ferramentas pesadas, como picaretas e marretas, que não estão normalmente disponíveis com os pequenos agricultores/criadores;
- o lançamento, por cima do chão, da salmoura de dessalinizadores, instalados rio acima, e que é lavada na época da chuva para dentro do riacho, saliniza e inviabiliza as cacimbas rio abaixo.

Acesso à água, um direito básico do cidadão.

A construção de fontes de água independentes e sob o controle da população rural, tem demonstrado sua eficiência do crescimento da consciência e atividade cívica, criando independências de dominações políticas locais que de estiagem em estiagem, procuram criar novas dependências e alargar seu poder econômico. Esta liberdade e autonomia da população rural tem se revertido em maior produção na área rural e redução do êxodo rural.

Porém não se deve esperar que um programa de abastecimento de água qualquer, melhor que seja, que fornece água de boa qualidade durante o ano inteiro, e que não englobe questão conexas, como a instalação de um sistema agropecuário produtivo e imune a qualquer "seca", a injusta distribuição das terras, educação adequada ao semi-árido, criação de profissões coligadas às atividades rurais e um sistema de saúde e de comercialização funcionando, consiga dar um lar permanente e confortável para o Nordeste.

Ilustração 1 e 2: Maria Oberhofer

Ilustração 3: José Ivomar Pereira de Sá

Ilustração 4: Harald Schistek

Local government's financial assistance for rainwater utilisation in Japan

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Abstract

Since rainwater hasn't been recognised as a valuable water resource in Japan, it hasn't been used to its full potential. Our main concern is the efficient rainwater collection. In the recent past people living in urban areas suffer from water shortage while occasional heavy rains cause flooding. A city's water supply usually depends on a far-away source.

One of the solutions to this problem is a rainwater utilisation system using cisterns or seepage pits. These have been popularised gradually in Japan, mostly equipping public buildings. To make rainwater collection more common practice, individuals have to start using it as well. Therefore some local governments have established a financial assistance program for people to equip their homes with rainwater collection systems.

In this paper, the existing state of financial assistance differing from one local government to the next is investigated.

Introduction

In Japan, as far as drinking water and domestic water use are concerned, no matter when and where we need water, we can usually utilise the required amount of water at once. As an exception, there are local and temporal water controls during draught periods. However, since it is considered natural for most of us that water is supplied to meet our demand, we hardly realise how blessed we are.

Recently in urban areas such as Tokyo there is an occasional water shortage [ARSIT (1998)]. Still rainwater in urban areas has not been utilised and has not been regarded as water resource.

Our main concern focuses on the rapid disappearance of rainwater into the sewerage so that our living environment can remain comfortable. However, if rainwater is considered as a valuable water resource, this is rather wasteful.

One of the solutions to this problem is to install rainwater utilisation systems allowing us to utilise rainwater directly. They have been popularised gradually, but in most cases, only public buildings have been equipped with large scale systems. [SHASEJ (1997)].

In the last years many local governments have created Web pages offering various information to the general public. In this paper, we attempt to categorise all the information available on the Internet on financial assistance programs for rainwater utilisation systems established by local governments.

Rainwater Utilisation Systems in Japan

Necessity of Rainwater Utilisation Systems

In mountain regions dams storing the inflow and regulating the outflow were constructed in order to utilise rainwater efficiently as water resource. Dams are usually built in the mountainous regions far from the urban areas.

In cities like Tokyo there is increasing concern about the ability to meet the demand for water, particularly during draughts, while at the same having to deal with flooding during occasional heavy rainfalls. There are two reasons for this. One reason is that the source of city water supply depends on the far away reservoirs. The other is that rainwater falling in the city cannot infiltrate into the ground since most of the surface has been paved. Rainwater that cannot infiltrate into the ground stays on the surface and flows into the sewerage during a short time. As a natural consequence the sewerage does not have the capacity to take in so much water at once, causing urban floods.

Rainwater falling in the reservoirs far from the cities is currently utilised as water resources. The same has to be done with rainwater falling closer to cities. Urban reservoirs have to be built and rainwater has to be stored there to be utilised as water resources as effectively as possible. This could settle the current contradiction in regards to rain in the urban area.

The Effect of Rainwater Utilisation Systems

One solution to this problem is to promote rainwater utilisation systems popular all over the world. In Japan, they have been installed gradually, but in most cases, large-scale systems are still being built and used. We use two kinds of water utilisation systems, e.g., a rainwater cistern system and a rainwater seepage pit. Each has a different function and certain similarities.

Expected advantages of installing rainwater cistern systems are as follows:

- a. Rain falling on the roof is collected through the gutters and stored in a container, keeping the rainwater from flowing into the sewerage in a short time period preventing urban floods.
- b. City-supplied water can be saved by using the stored rainwater for gardening and flushing.
- c. Stored rainwater can also be used as water to fight fires. In addition, it can be used as domestic water and as drinking water in an emergency. Disasters, such as earthquakes, can damage the water supply system.

Expected advantages of installing rainwater seepage pit are as follows:

- a. Rainfall on the roof, which is collected through the gutters and rainfall that falls in the garden flows into rainwater seepage pit. Rainwater is temporally stored in it and infiltrates the ground. This method prevents urban flooding the same way as the rainwater storage container described above.
- b. Rainwater that infiltrates through the pit has the effect of aquifer charging and is thus useful in improving the natural environment e.g., prevention against land subsidence and

preservation of groundwater.

The effect of rainwater utilisation systems depends on the number of systems installed. More systems ought to be installed to increase the effect, not only such large systems as installed in public buildings, but also small scale ones installed in individuals houses. If stored rainwater is utilised as temporary drinking and domestic water in an emergency, such as an earthquake, large scale water cistern systems have to remain without damages. If they are seriously damaged the water cannot be used. In this case it might be better to have many small systems; if a few get damaged one still has all the other ones to fall back onto. Therefore it seems safer to build many small scale systems covering a wide area.

The biggest hindrance to install small scale system together with individuals houses are the costs involved with it. Many people might not understand the benefits of the system in proportion to its expenses. The solution to this problem is the financial assistance program for rainwater utilisation systems by local governments. Various local governments have established such a program and have been promoting it. An increasing number of local governments are interested in establishing such programs in the future.

Information on assistance programs

Method for Collecting Information

Over the last years we have been able to obtain various items of information on the Internet. We can find web sites containing information relating to a particular subject we need with the help of search engines. Many local governments have created Web pages giving information on various subjects.

A certain search engine lists about 1,200 Web sites of local governments. Using this search engine, we searched for Web pages with information on rainwater and found about 1,500 entries. Many of them are related and lead to the same Web site. However, it shows that many local governments have information on rainwater and are interested in the topic. Examining each of them, we found that sixty-five local governments provide information on rainwater utilisation and of those nineteen have established an assistance program for rainwater utilisation.

Research Results

According to the subjects to which the assistance programs are applied, they are classified into three kinds of assistance programs. The systems for rainwater cistern system, the systems for rainwater seepage pit and the systems for converting of purifying chamber into rainwater cistern system. Outlines of these three kinds of assistance programs are shown respectively in

Table 1, 2 and 3.

Assistance programs for rainwater seepage pit have been established in eleven cities. Eight cities have assistance programs for converting purifying chambers into rainwater cisterns. This system also helps to recycle and to reduce waste. In a city with sewerage, the contents of the purifying chambers turns into waste. After cleaning and disinfecting, these chambers can be used as rainwater cisterns thus contributing towards both recycling and reduction of waste. Only five cities have assistance programs for rainwater cistern systems. Since the converted

chamber can be considered as a rainwater cistern, thirteen cities in total offer these assistance programs. Three cities offer both systems, for rainwater cisterns as well as for rainwater seepage pit. Each city offers a different programs e.g., maximum of costs, number of systems installed, etc.

Table 1 Assistance programs for rainwater cistern system

Kawagoe City	19,000 yen in the case of 1 unit 38,000 yen in the case of 2 units
Kamakura City	25,000 yen or less in the case of volume between 100 L and 200 L 30,000 yen or less in the case of volume greater than 200 L Two units or less and within 1/2 of total cost in both cases
Chofu City	Between 25,000 yen and 55,000 yen and half of the price of the product Only products designated by the City is available. Two kinds of volume, 100 L and 200 L
Sumida Ward	1,000,000 yen or less in the case of 1,000 l 300,000 yen or less in the case of between 500 L and 1,000 L 25,000 yen or less within 1/2 in the case of less than 500 L
Takamatsu City	100,000 yen or less and within 1/2 of total cost in the case of volume between 100 L and 1,000 L 40,000 yen per ton and 1,000,000 yen or less in the case of volume over 1,000 L Once per year in both cases

Table 2 Assistance programs for rainwater seepage pit

Kawagoe City	19,000 yen in the case of 1 unit 38,000 yen in the case of 2 units 46,000 yen in the case of 3 units 58,000 yen in the case of 4 units
Kamakura City	20,000 yen or less in the case of product made of concrete 10,000 yen or less in the case of product made of synthetic resin Four units or less and within 1/2 of total cost in both cases
Chofu City	Whole cost
Ichikawa City	400,000 yen per one place
Chiba City	24,000 yen or less and within 2/3 per unit and up to 4 units 35 cm or greater in the inside diameter or in length and width and 65 cm or greater in depth
Yokohama City	Whole cost
Mitaka City	Whole cost
Ohta Ward	Whole cost and only available in the regions designated by the Ward
Fuji City	A part of whole cost
Setagaya Ward	A part of whole cost
Musashino City	200,000 yen or less

Table 3 Assistance programs for converting of purifying chamber into rainwater cistern system

Takamatsu City	70,000 yen or less and within 2/3
Chiba City	60,000 yen or less and within 2/3
Toyokawa City	75,000 yen or less and within 1/2
Koshigaya City	35,000 yen or less
Fujisawa City	40,000 yen or less
Kumamoto City	70,000 yen or less
Takahama City	75,000 yen or less and within 1/3
Kumamoto City	70,000 yen or less

The information presented on the Web pages outline the assistance programs. For those interested in installing rainwater utilisation systems, more detailed information may be obtained from the contact person.

Conclusion

Nineteen cities offer information about the assistance programs for rainwater utilisation systems by local governments.

The results are as follows:

- a. The assistance programs are classified into three kinds: the systems for rainwater cistern systems, those for rainwater seepage pit and those for converting purifying chambers into rainwater cistern systems.
- b. Eleven cities have established assistance programs for rainwater seepage pit.
- c. Seven cities have assistance programs for converting purifying chambers into rainwater cistern systems.
- d. Only five cities have assistance programs for rainwater cistern systems. If the converted chambers can be considered as rainwater cistern, twelve cities in total have these assistance programs.
- e. Three cities have both systems, the one for rainwater cisterns as well as the rainwater seepage pit.

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Rainwater as a Source in an Innovative Urban Dwelling

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Abstract

The Toronto Healthy House is a duplex dwelling in downtown Toronto, Ontario, Canada that is completely independent of municipal water and wastewater services. Water for potable use is obtained from the roof and yard surfaces, and grey water and black water are recycled for other uses. The capacity of the rainwater cistern was determined using a program developed for agencies of the Nova Scotia government. Rainwater is treated by dual filtration and ultraviolet disinfection. Monitoring results confirm that potable water quality meets Canadian Drinking Water Standards.

Introduction

The Toronto Healthy House (THH) is a duplex dwelling, in downtown Toronto, Ontario, Canada, that is completely independent of municipal water and wastewater services. Potable water is supplied by a Rainwater Cistern System (RWCS), and all wastewater is recycled for non-potable uses. The THH was developed by Creative Communities Inc., with the support of Canada Mortgage and Housing Corporation, a federal government agency, in order to demonstrate a variety of innovative housing technologies. The THH was completed in 1997. One of the two dwellings, which is occupied by the owner, is the subject of this paper; the other has been used as a site to demonstrate the technologies described here and a variety of other innovations in residential construction.

This paper provides an overview of the water and wastewater management system in the THH (further details may be found in Townshend et al, 1997), and describes in particular the role of the RWCS in that system, the hydrologic design of the RWCS, and the water treatment process.

THH System

The RWCS collects rain water and snowmelt from roof and yard surfaces. This water is treated and used as the potable water source for the dwelling, supplying the kitchen and bathroom sinks and dishwasher. All other fixtures are supplied with recycled and treated wastewater. Water-conserving fixtures used in this house include:

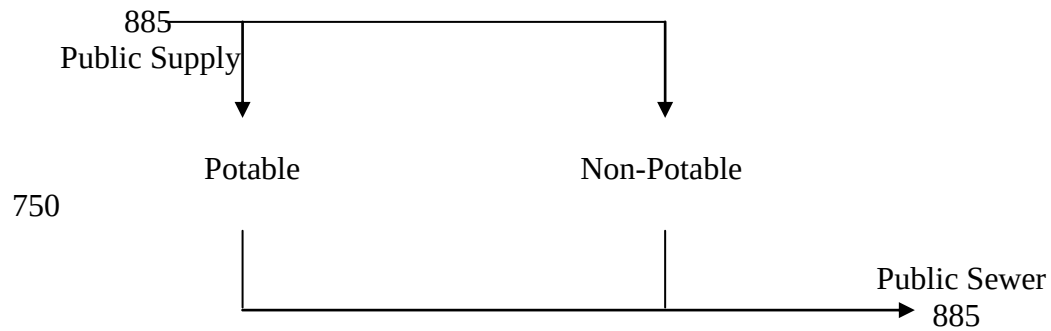
- 6 L toilets
- low flow faucets
- low flow shower heads
- 25 L/wash clothes washers (using 1/3 usual demand)

25 L/use dishwashers (using 3/5 usual demand)

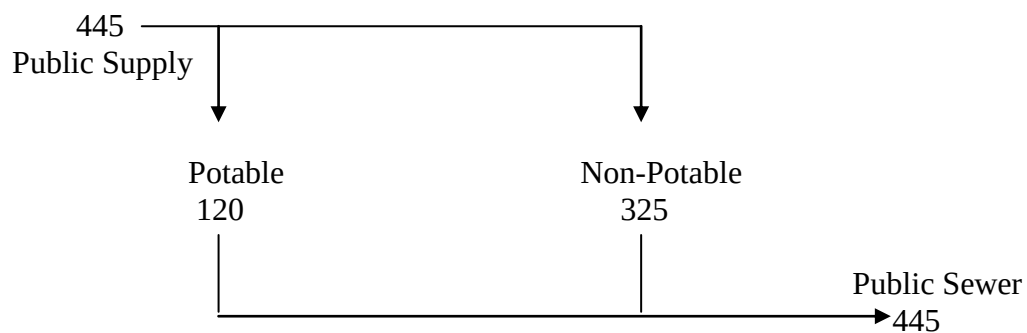
Figure 1 illustrates the water balance for the four-person THH, and compares it with a conventional system with and without water conservation.

It is apparent from Figure 1 that the total water demand in the THH is one-half that in a conventional system: 445 L/day vs 885 L/day. The potable water demand in the THH is only slightly less than in a conventional system, as a result of the water conserving dishwasher; sink use is primarily for cooking and is not considered to be significantly affected by water conservation devices.

1. Conventional – No Water Conservation



2. Conventional – Water Conservation



3. Toronto Healthy House – Water Conservation and Wastewater Recycling

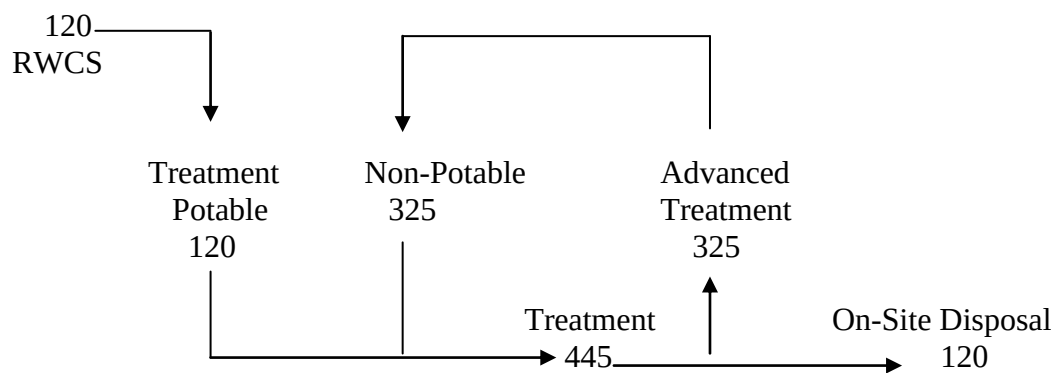


Figure 1. Effects of Water Conservation and Wastewater Recycling in the Toronto Healthy House, L/day.

Use of recycled wastewater for all non-potable uses reduces the demand on the RWCS from 885 L/day to 120 L/day. This is a crucial factor in the design of the THH system: the size of the available rainwater collection area, and the precipitation in Toronto, could not supply all of the demand for a conventional system at this site. Wastewater recycling makes it possible to use a RWCS as the only external water source for this system. Trucked water is available if required to supplement the RWCS in a prolonged dry period.

Figure 1 also indicates the effect of water conservation, and wastewater recycling, on the wastewater treatment and disposal system. All wastewater receives primary and secondary treatment in a septic tank and Waterloo BiofilterTM; water conservation reduces this flow from 885 to 445 L/day. Recycled wastewater receives advanced treatment (filtration and disinfection); water conservation reduces the capacity of this system by one-half. The size of the on-site wastewater disposal system—a sub-size gravel pack—is reduced by 85 percent.

RWCS – Hydrologic Design

The Centre for Water Resources Studies (CWRS), DalTech, Dalhousie University, applied a RWCS computer program, developed for the Province of Nova Scotia (Scott et al, 1995), to analyse Toronto precipitation and suggest the potential yield and storage requirement for a RWCS at the THH. This program has been incorporated into WATERSAVE, a program for planning and design of residential recycling and reuse systems, that has been developed by CWRS for Canada Mortgage and Housing Corporation (Waller et al, 1997).

The RWCS program uses a long-term record of daily precipitation, the size of the collection area, and storage tank capacity, to assess the reliable yield of the RWCS. The THH collection area—three roof surfaces and two ground level patios—is 80 m². The raw water is stored in a 20 m³ concrete cistern. This system is designed to deliver the potable water demand of 120 L/day indicated above. Overflow from the cistern is added to the renovated wastewater, or can be wasted into a sub-surface gravel pack.

Toronto Healthy House Potable Water Treatment

Consideration was given to including a layer of limestone in the rainwater cistern, to neutralize acid precipitation that is a characteristic of southern Ontario. However, experience in Nova Scotia (Scott, et al, 1995) and analyses of water from the THH System, included that the concrete cistern provides adequate buffering of acid rain.

The outlet of the cistern is located above the tank bottom, to accommodate solids accumulation or suspended solids settlement.

Initial samples of rainwater were contaminated by exposed bituminous roofing materials. This was easily connected by an inert roof membrane.

Water from the cistern is treated by slow sand filtration, activated carbon adsorption, and disinfection, then stored in a 600 L potable water storage tank. Water from the storage tank is disinfected again before being pumped to fixtures.

The sand filter and activated carbon absorber are contained in a single unit, 1.2 m high and 0.3 m in diameter. Flow through the unit is upward. The sand filter includes four layers, graded from coarse quartz sand (13 to 19 mm) at the bottom to fine silica sand (0.35 mm) at the top. The activated carbon is suspended in a basket above the sand.

The sand filter is intended to remove particulates, bacteria, and cysts. Activated carbon is intended to remove dissolved organic compounds and some metals.

Maintenance of the filters includes backwashing at monthly intervals, and annual replacement of the activated carbon.

Disinfection, before and after the potable water storage tank, is provided by ultraviolet (UV) treatment units. Each unit includes a sensor that automatically shuts down the water supply system if the UV light intensity is too low.

The water treatment unit was designed to assure that potable water meets Guidelines for Canadian Drinking Water Quality (Health Canada, 1996).

Sampling taps and pressure gauges are located throughout the treatment process for sampling purposes.

Water samples collected to date have met the Guidelines.

Summary

A rainwater cistern system (RWCS) is an essential component of the Toronto Healthy House, for which a RWCS supplies all potable uses. Effective use of the RWCS is made possible by reduction in water demand that results from recycling of all wastewater for non-potable uses. The yield of the RWCS was based on a computer program that considers long term precipitation records, collection area, and storage capacity. The treatment used in the THH provides potable water from rainwater collected from urban roof and yard surfaces in a large metropolitan area in a region with acid precipitation.

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The Study for Influencing Factors of Urban Rainwater Catchment System Capacity

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Abstract

This study initially examines the different water demand, catchment area and storage capacity. The water input is simulated using several rainfall record intervals, and the Critical Period Technique. Sensitivity analysis is conducted on the variables affecting the system that include catchment area, duration of rainfall records and water demand. The relationship between water release, storage capacity and rooftop catchment area is established under different water demand conditions. This information can be useful and essential for the planners and decision-makers in selecting and optimizing a rainwater catchment system design.

I. Introduction

Rainwater catchment utilization is one kind of alternative water resource. Rainwater catchment systems (RWCS) use roof and road surface to catch rainwater, which can supplement domestic and industrial water supply and reduce urban flooding load (Chu and Fok, 1991). RWCS have been applied broadly abroad. The Thai government completed a big water cistern plan in 1990. Nine million big water cisterns had been built to benefit eighteen million people (Fok, 1990). In densely populated island countries such as Japan, Hong Kong, Singapore, the study on high-rise building and airport RWCS has been performed (Waller, 1989). The Water Resources Bureau of Ministry of Economic Affairs is promoting the application of RWCS and proposing award measures. But water utilization technique is still in a developing stage in our country and there is no design specification. The major goal of the study is to research influencing factors of urban rainwater catchment system capacity.

II. Calculation Method for Catchment Capacity

Urban RWCS include 4 subsystems, such as collecting, distributing, reserving and water treatment units. It is very important for the determination of catchment capacity.

In urban RWCS, the roof is used as water collecting area and the reserving unit is the most expensive part of the system. Its capacity not only influences the system costs but also influence the water supply capability of system. This study uses critical period method (Mc Mahon, 1978) to calculate the design capacity.

The critical period includes the mass curve method, residual mass curve method and simulation analysis. This study uses simulation analysis to analyze the catchment capacity. It uses historical records of input flow rate, substituting into a continuous equation to simulate continuous variation of catchment capacity. In urban RWCS, the water-collecting area is often small and the collecting time is very short. Since the catchment system is closed, the evaporation and other loss can be neglected, and the continuous equation becomes as follows:

$$Z_{t+1} = Z_t + Q_t - D_t \quad (1)$$

Where, Z_{t+1} is catchment amount at time $t+1$; Z_t is catchment amount at time t ; Q_t is input flow rate at time t ; D_t is water amount discharged at time t .

III. Introduction to Water Intake Model

This study uses two kinds of water intake methods to simulate water intake at the actual operation of system. One is the yield after spillage (YAS) model; the other is the yield before spillage (YBS) model.

The operation rule of YAS model can be shown as follows:

$$Y_t = \text{Min} (D_t, S_t) \quad (2)$$

$$S_{t+1} = \text{Min} (S_t + Q_t, C) - Y_t \quad (3)$$

Where, S_{t+1} , S_t is catchment amount at time $t+1$, t , respectively; Y_t is discharge flow rate at time t ; Q_t and D_t is inflow rate and water demand amount at time t , respectively; C is catchment capacity.

The operation rule of YBS model can be shown as follows:

$$Y_t = \text{Min} (D_t, S_t) \quad (4)$$

$$S_{t+1} = \text{Min} (S_t + Q_t - Y_t, C) \quad (5)$$

In the actual operation, the water intake and spilling can occur simultaneously. So, YAS model and YBS model can not represent the actual situation. This paper will discuss their influence on water supply and their limitations.

IV. Analysis and Discussion

In order to evaluate the system design, two different factors are used to compare the results. One is reliability (Re) in which water supply is greater than or equal to water demands and considers successful times of water supply. The other one is the ratio of water supply and actual water demand (water supply ratio, Rv) considering water supply based on volume. Subsequently the influence of these two factors will be discussed in detail. Keelung Station's (1) rainfall data of 94 years are used for simulation, and the water supply target is the domestic toilet. The assumption amount is 0.041808m^3 per person per day for toilet (Water Resources Bureau, 1996).

1.The influence of different water intake method on water supply of systems

The influence of different water intake method has a great influence on system reliability. From the simulation results, the Re of YAS model is obviously smaller and can be easily understood from the water intake process. Besides, the simulation result, system design capacity shall be larger than 5m^3 for higher water demand (5 persons), for system to supply water. The home being the major water supply target in the study and since the design capacity of its RWCS is small, the phenomenon discovered is very important. We have to do further study the suitability of the YAS model.

The results of the suitability of the YAS model are displayed in Figure 1, which shows only if demand/capacity is greater than 0.5. Re approaches zero quickly under both settings. The YBS model does not show this phenomenon. From the point of view of RV, this condition doesn't occur in the YAS model, because water supply ratio is considered by “volume”.

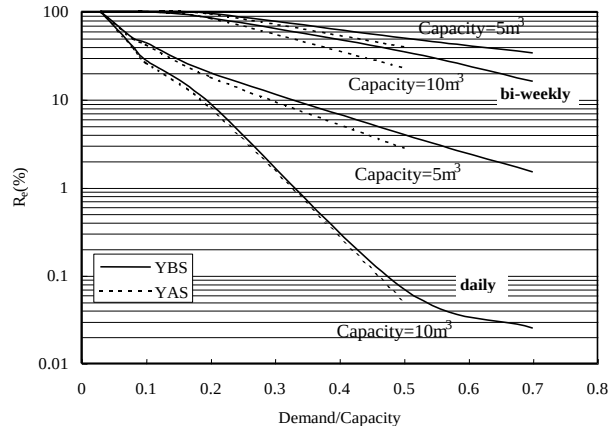


Figure 1 The Demand/Capacity Reliable Curve under Different Yield Model (Area=100m³, C=0.85)

The above result is an important finding. Because by designing large reservoirs, the water demand is seldom greater than a half its capacity, therefore reliability will rarely approach zero quickly. This shall be taken into consideration when designing small water supply system such as urban RWCS. Because the system often has small capacity, the water demand is often greater than half its capacity. While R_v is better than R_e in each aspect and meets the actual situation, it is recommended that the YAS model shall not be adopted for designing RWCS. Therefore the YBS model and its R_v are used for calculation and discussion.

2. The influence of water intake period on system

Generally speaking, one day and ten days are most often used for intake period. One day, 3 days, 5 days and 7 days are used as intake period to realize the influence on water supply ratio. Figure 2 shows R_v curve for different periods when less than six people are drawing on the water supply. It shows that the daily period has the highest R_v , meeting the actual water consumption situation. When the period is increasing, R_v is decreasing. And when the catchment capacity is increasing, the difference is also decreasing. Though longer period is advantageous to simplify calculation, different period may influence R_v at the same capacity and water demand amount, and it is more significant for a smaller catchment capacity. When actual water intake data can not be obtained, the assumption of the daily period meets the actual situation better.

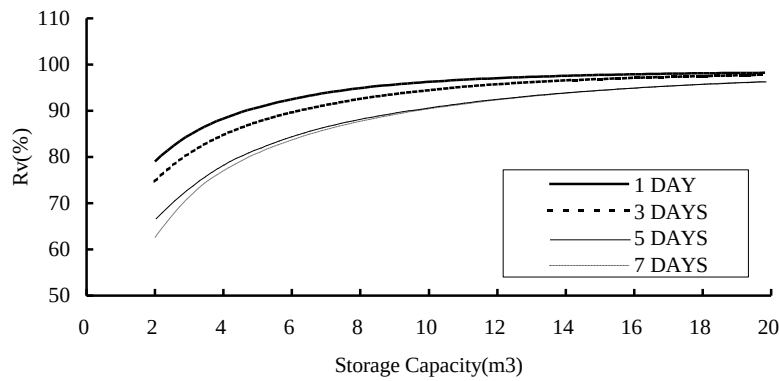


Figure 2 The Storage Capacity - Water Supply Curve for 5 Persons with Different Time Interval (Area=100m³, C=0.85)

3. The influence of data length on system

Rainfall data length influences the accuracy of water supply directly. From a statistical point of view, more samples will show the feature of the origin body. Less data can not represent the whole water supply situation and an unsteady simulating result can occur.

The result for data length analysis is shown in Figure 3. The calculation period is one day and catchment capacity is 5m³. When data length is very short, the difference between maximum value and minimum value of Rv is very large, showing that the simulated result is very unsteady. When data length is increasing, the system is approaching a steady state. Under 90% reliability, seventy years for data length can get steady state. Rainfall data of Keelung area is used for simulation, thus it is recommended to use 50 years data length at least for the design of RWCS in this area. Other areas shall perform further comparison.

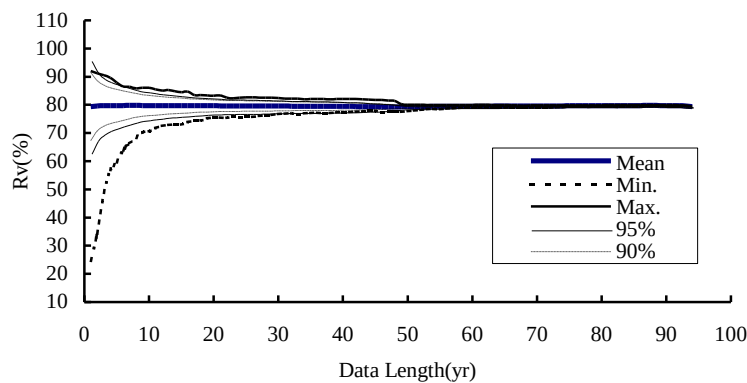


Figure 3 The Change of Water Supply Rate under Different Rainfall Record Length at Different Confidence Interval (Demand = 0.250848m³/day,

Area=100m², Storage Capacity=5m³, C=0.85)

4. The influence of water use type on water supply of system

The study used daily average water demand to substitute daily water demand in previous calculation. But in fact, from related statistical data (Taiwan Water Supply Company, 1995); Water Resources Bureau, Ministry of Economic Affairs, 1995), it shows monthly variation range of common living water assumption is around 30% of average water consumption. So, this section will analyze the influence of water demand variation on water supply ratio of system. Due to the limitation on getting actual data, the study assumes the variation range of daily water demand is maintained around 30% of daily average water demand. By calling a random series with average value, which is equal to 0 and standard deviation, which is equal to 1, to get a new daily water demand series through daily average water demand pluses or minuses 5% random number, 10% random number, 20% random number and 30% random number, to discuss the influence of daily water demand variation on water supply ratio. From this calculation, 100 sets of daily water demand series of 95 years are derived, and the absolute error of water supply ratio is less than 1%, in spite of daily average water demand, water cistern volume and water collecting area. When an urban RWCS is simulated, daily average demand can be used to substitute daily water demand series.

5. Creating relationship curve for different water collecting area-catchment capacity-water supply ratio

Urban RWCS have infinite sets of different (water collecting area, catchment capacity) combinations. Figure 4 shows water collecting area catchment capacity-water supply ratio curve for five persons supplied at Keelung Station (1).

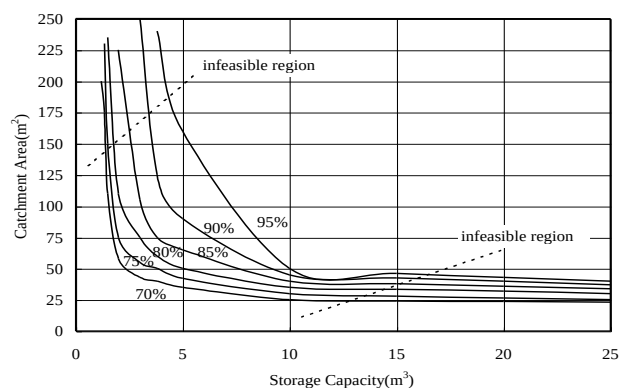


Figure 4 The Catchment Area - Storage Capacity - Water Supply Rate

Curve for Keelung (1) Station (Demand=0.20904m³/day, C=0.85)

Figure 4 shows the curve moves to the right upper side at increased water supply ratio. This curve supplies many sets of different water collecting areas and catchment capacities. The Engineer-designer can choose a set for the setup scale of RWCS by considering actual situation. It is not feasible for nearly vertical curve at left upper side and nearly horizontal curve at right lower side. If water demand is fixed, increase (decrease) water collecting area and decrease (increase) catchment capacity will have the same water supply ratio. If water-collecting area is decreased and the same water supply ratio wants to be maintained, the catchment capacity will be increased in order that the slope of curve approaches zero. It means the same water supply ratio can only be maintained at very large catchment capacity. So, it is not feasible at this area for engineering consideration, and it is the same for an increased water collecting area.

IV. Conclusions and Recommendations

(I)Conclusions

The capacity of RWCS is often small. If YAS model is used for design, water supply reliability will be too low, thus it shall not be adopted for design and planning, and water supply ratio shall be used for the judgement of system water supply capability. The data of drought years and abundant years shall not be used for water demand data, because extreme weather condition will influence water utilization habit, so it can not reflect actual water utilization condition.

Because the influence of water use type on water supply ratio of RWCS is not significant, in order to simplify simulation process and actual data collecting problem, daily average water demand can be adopted to substitute daily water demand series. The roof is only used to collect rainwater for RWCS without reserving rainwater, so the setup of RWCS will not increase roof-leaking problem.

(II)Recommendations

The study only analyzes water supply condition and different influencing factors of the system; it does not discuss water quality of rainwater. RWCS can supply water to different targets based on rainwater quality, so water quality in the study area has to be analyzed further. This study does not discuss optimal capacity of system; it can be determined from water supply ratio curve and input/output theory of economics in the

future. Rainwater catchment unit of RWCS can be installed near a building or on its roof. If it is installed on the roof, its influence on building structure shall be discussed.

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Estimation of Water Use by Vegetation Barriers Based on Climatological Factors and Soil Moisture Levels

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Abstract

Runoff management is one of the tools to increase the available water for agricultural production in areas where rainfall is erratic. Vegetation barriers have shown to increase the amount of water in the soil by slowing down runoff and thus allowing more time for infiltration. They do not cause upstream water logging problems due to the semi-permeable character of the barrier. However little is known about the water use of the vegetation barrier and thus whether its conservation effect is not being minimised by its own water use. This paper presents the results of a study conducted in Burkina Faso in 1996 in which a method has been developed to assess the water use of a vegetation barrier. Transpiration (sapflow) was measured on 3 barrier species (*Andropogon gayanus*, *Piliostigma reticulatum* and *Ziziphus mauritiana*). Transpiration was related to meteorological factors and soil moisture availability. The method used was found to be simple and reliable. The results can be used in other experiments focusing on the water use of (natural) vegetation and its competition with agricultural crop water use.

Introduction

The aim of runoff management in the Sahel is to enhance the amount of available water in the soil for plant growth and crop production. Improved local infiltration can be achieved by water conservation measures along contour lines. Hien (1995) gives an overview of these measures and their efficacy. Non permeable measures minimise runoff but can also cause waterlogging problems upstream. Semi-permeable stone and dead wood barriers result in an improved water balance and avoid waterlogging.

Vegetation barriers slow runoff and retain sediment and organic debris and still allow drainage of excess water due to their semi-permeable nature, thus positively affecting the upstream and downstream soil water availability. A vegetation barrier, using locally available species is often cheap and easy to establish. As both the crop and the vegetation barrier use water, competition for water may reduce yields of nearby crops as the extraction of water from the soil by the roots of the vegetation barrier (Smith et al., 1994). Since vegetation barriers present an appropriate measure in runoff management a method to assess the water use of vegetation barriers becomes necessary in order to optimise the design of this conservation practice.

For most agricultural crops a relation has been established between climate and potential evapotranspiration by the introduction of crop coefficients (Doorenbos and Pruitt, 1977) and the use of reference evapotranspiration. The method, recommended by the FAO (1992) requires crop factors, which are not available for non-agricultural crops used in vegetation

barriers, as well as extended climatological data. The reduction of the potential evapotranspiration as a result of non-optimal soil moisture conditions (Doorenbos and Kassam, 1979) is another unknown factor for vegetation barriers.

This paper presents results of a study conducted in Burkina Faso in which a method has been developed to assess water use by vegetation barriers based on easily measured variables. Various options are presented with increasing complexity and accuracy ranging from the use of a single climatological factor, a multi-climatological factor and a combination of climate and available soil moisture under the vegetation barrier.

Materials and methods

The study took place in Gampela, Burkina Faso, in 1996. Twenty-one plots of 20 x 20 m were laid out within a 3 ha experimental site in 1994. Plots were laid in the direction of the slope, which varied between 1.5 and 2%. At 5 m from the downstream side of each plot a 1 m wide vegetation barrier was planted. Seven plant species were planted in three replications. The choice of species was influenced by local availability, anticipated growth and soil and water conservation properties.

For the development of the water use assessment method three species were selected *Andropogon gayanus* (a perennial grass), *Piliostigma reticulatum* (a tree), and *Ziziphus mauritiana* (a shrub). Transpiration was monitored for two periods of approximately 5 days. Soil moisture content and climatological factors were measured throughout the whole period. Transpiration measurements started when the barriers were in the mid-season stage and since the vegetation barriers were maintained, the biomass of the barriers remained the same over the mid-season, thus a seasonal variation of the transpiration has not been studied.

For the measurement of transpiration use was made of the stem heat balance method (Baker and van Bavel, 1987). The 20 m vegetation strips were divided in 4 sections according to plant size based on visual observations. In each section the sapflow of a representative plant was monitored continuously for 5 days and averaged every 30 minutes. Since transpiration was directly related to the biomass of the vegetation barriers through the number of leaves on the sampled stem, correlations found were between 0.86 and 0.99 for all observations (Fig. 1), the transpiration of each section could be calculated from the area of the section and the total number of leaves in the section. The transpiration of the whole barrier was calculated from the weighted average of each section.

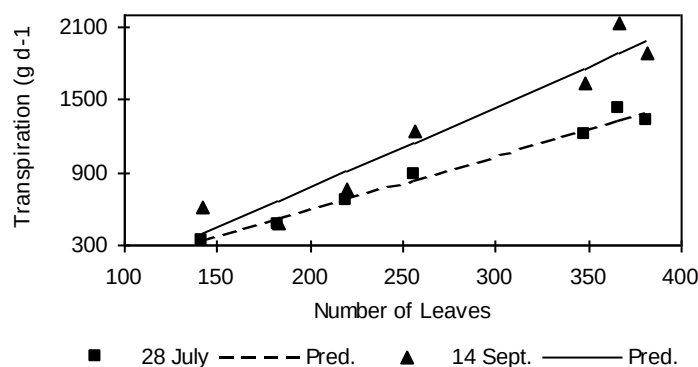


Figure 1: Relation between the number of leaves and transpiration for 28 July ($R^2=0.98$) and 14 September ($R^2=0.92$) of *piliostigma*. Gampala, Burkina Faso, 1996.

Soil moisture was measured using a TDR tube probe. Three access tubes were placed in the vegetation barrier and measurements were taken daily every 0.20 m to 1.0 m depth. The measurement depth was limited to 1 m because of a restricting soil layer at this depth. Total soil moisture in the profile was calculated by summing the depth of water in each layer of 0.20 m. In order to be able to detect stress conditions for plant growth soil moisture retention curves were made in the laboratory.

Continuous measurements of air temperature, wind speed and direction, humidity and incoming solar radiation at the experimental site were made using an agro-meteorological station and averaged for 30 minute periods. Rainfall was measured using a tipping bucket raingauge. Reference evapotranspiration was calculated for 24 h periods using the Penman-Monteith method (FAO, 1992).

Relations of single or multi-climatological factors and transpiration were made based on 30 min. averages. The relation between transpiration and reference evapotranspiration was made on the basis of 24 h. period data. This also counts for the relation between transpiration and available soil moisture and the combination of available soil moisture with climatological factors.

A validation of the relations was made by calculating the transpiration over short periods without rainfall and fitting it into the water balance.

Results

The relation between the transpiration and single meteorological factors is presented in Fig. 2 and Table 1. All relations are linear with high correlation coefficients.

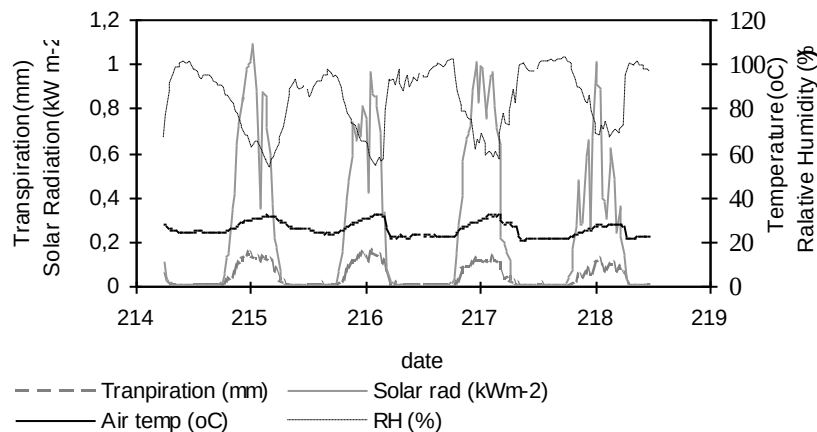


Figure 2: Relation between the transpiration of the ziziphus barrier and climatological factors, Gampala, Burkina Faso, 31 July - 5 August 1996

Table 1: Relation between transpiration ($\text{mm } 30 \text{ min}^{-1}$) of vegetation barriers and single climatological factors, Gampala, Burkina Faso, 1996

	Andropogon	Piliostigma	Ziziphus
Solar Radiation $R_s (\text{kW m}^{-2})$	$\text{Tr} = 0.46R_s + 0.008$ $R^2 = 0.88$	$\text{Tr} = 0.19R_s + 0.003$ $R^2 = 0.91$	$\text{Tr} = 0.14R_s + 0.007$ $R^2 = 0.89$

Temperature T (°C)	$Tr = 0.04T - 0.8$ $R^2 = 0.82$	$Tr = 0.02T - 0.46$ $R^2 = 0.78$	$Tr = 0.01T - 0.3$ $R^2 = 0.73$
Relative Humidity RH (%)	$Tr = -0.008RH + 0.8$ $R^2 = 0.83$	$Tr = -0.008RH + 0.8$ $R^2 = 0.83$	$Tr = -0.008RH + 0.8$ $R^2 = 0.83$

Over a period of 10 days in July the change in the soil moisture content under the piliostigma barrier was found to be 21.2 mm. The period was without rain. An estimation of the transpiration over the same period based on the relation of transpiration and solar radiation results in 23 mm. The difference between the estimated transpiration and the change in soil moisture content is only 1.8 mm. A possible explanation could be that the vegetation barrier distracts its water from the layers deeper than the measured 1 m. Although this layer was observed to be restricting it is possible that some roots entered. Soil evaporation over the period can be neglected since the vegetation fully covers the soil surface. Percolation over the period can also be neglected since the soil moisture potential was between -1000 and -3100 cm.

Linear regression of the transpiration of the vegetation barriers and a combination of two climatological factors resulted in relations with regression coefficients of 0.78 to 0.85 for a combination of temperature and relative humidity. Combining either temperature or relative humidity with solar radiation results in relations with regression coefficients of 0.93 to 0.95. The results of the linear regression of a combination of all 3 factors are presented in Table 2.

Table 2: Regression coefficients for the relation $Transpiration = aR_s + bT + cRH + d$ of vegetation barriers, Gampala, Burkina Faso, 1996

Factor	Solar radiation (kW m ⁻²)	Temperature (C°)	Relative Humidity (%)	Constant	Regression coefficient
Coefficient	a	B	C	D	
Andropogon	0.27	0.01	-0.002	-0.05	0.96
Piliostigma	0.14	0.004	-0.0006	-0.04	0.95
Ziziphus	0.10	-0.00021	-0.00135	+0.14	0.94

Over a period of 4 days in August without rain the change in the soil moisture content under the piliostigma barrier was found to be 12.9 mm. An estimation of the transpiration over the same period based on the relation $transpiration = aR_s + bT + cRH + d$ resulted in 11.9 mm. Some unsaturated flow might have occurred during the period since the soil moisture potential was between -200 and -500 cm.

Since the reference evapotranspiration was calculated for 24 h periods and related to the 24 h. transpiration of the barrier, the obtained relations are based on a limited data set. The obtained relations can be found in Table 3.

Table 3: Relation between transpiration and reference evapotranspiration of vegetation barriers, Gampala, Burkina Faso, 1996

	Andropogon (mm d ⁻¹)	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Reference Evapotranspiration (mm d ⁻¹)	Tr = 0.157ET ₀ - 0.05 R ² = 0.95	Tr = 2.1ET ₀ - 7.7 R ² = 0.77	Tr = 1.6ET ₀ + 0.58 R ² = 0.58

The above mentioned relationships all relate transpiration with one or more elements of the atmospheric demand causing transpiration. Since the actual transpiration is a compromise between the demand and the supply of soil moisture, measured transpiration is also related to total soil moisture (TSM) under the barriers. For two species linear relations between transpiration and soil moisture existed. (Table 4).

Table 4: Relations between transpiration of vegetation barriers and total soil moisture, Gampala, Burkina Faso, 1996.

	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Total Soil Moisture (mm m ⁻¹)	Tr = -0.019 TSM + 6.66 R ² = 0.87	Tr = 0.48 TSM - 10.94 R ² = 0.96

Since actual transpiration is a compromise between demand and supply it may be expected that a combination of a single climatological parameter or the full atmospheric demand (ET₀) and TSM will yield the best correlation with actual transpiration. Since the best fit of transpiration with a single climatological factor was found with solar radiation, this factor was used. The obtained relations can be found in Table 5.

Table 5: Relation between transpiration of vegetation barriers and a combination of total available moisture and solar radiation or reference evapotranspiration, Gampala, Burkina Faso, 1996.

	Piliostigma (mm d ⁻¹)	Ziziphus (mm d ⁻¹)
Total Soil Moisture (mm m ⁻¹) and ET ₀ (mm d ⁻¹)	Tr = -0.03TSM + 0.005ET ₀ + 7.8 R ² = 0.66	Tr = 0.49TSM + 0.46 - 13.5 R ² = 0.97
Total Soil Moisture (mm m ⁻¹) and Solar Radiation (MJ m ⁻² d ⁻¹)	Tr = -0.01TSM + 0.07R _s + 4.9 R ² = 0.94	Tr = 0.5TSM + 0.02R _s - 11.29 R ² = 0.97

Conclusions

The aim of the study was to find a method to assess water use of vegetation barriers based on simply measurable parameters. The method consists of a brief measurement period with subsequent data analyses leading to simple predicting equations for each barrier species. Under conditions of good maintenance whereby the biomass and LAI of the vegetation barriers are kept at a more or less constant level, these equations can then be used for any other period in the growing season, except for the development stage. In a situation whereby

no maintenance of the barrier takes place more than one relation over the season should be established in order to find water use over the whole season.

Results indicate that the simplest option, whereby transpiration is predicted with the use of a single meteorological factor gives acceptable results for all 3 factors used. Linear relations with high regression coefficients were found, therefore no attempt was made to search for non-linear prediction equations.

There is no significant improvement in the prediction of transpiration when instead of using temperature or relative humidity in a single factor relation these two factors are combined. The solar radiation single factor relation improves when combining solar radiation with either temperature or relative humidity.

The results suggest that transpiration prediction using the reference evapotranspiration ET_0 is not as good as the relation found between transpiration and the three climatological factors combination. Reference evapotranspiration was calculated for 24 h periods. Since the number of observation days on each species was only 10 days, this relation is based on a limited data set. The other relations are based on 30 min periods, thus on a far larger data set. In the 10 days of monitoring the ziziphus barrier 5 days with rainfall occurred, influencing the relationship.

The influence of the available soil moisture on transpiration could be established for 2 species (piliostigma and ziziphus) only. The restriction of limited data sets also counts for these relationships. A more extended data set will improve these relations and probably a relation for andropogon can be found when more data become available. The combination of solar radiation and available soil moisture results in the best prediction of the barrier transpiration.

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Rainfall Runoff and Sediment Reduction Effect of Hedgerow Plants on Purple Soil Slopeland

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Abstract

Rainfall runoff and sediment reduction effect by hedgerows plants on purple soil slopeland were studied based on natural precipitation observations and simulated rainfall experiments. Measurement data revealed that hedge plants grown on 25 degrees slopeland can reduce runoff by 22-43 percent and sediment yield by 94-98 percent. These substantial decreases can be achieved at a cost of only 10-20 percent of the stone ridge horizontal terraces. Hence, it is an effective way to control runoff and soil loss in ameliorating slopeland utilisation in the Three Gorges Reservoir areas of Yangtze River, China.

I. Experimental plots and simulated rainfall experiment

Purple soils are mainly distributed in the upper reaches of the Yangtze River in China and are also seen in Provinces and regions south of the Yangtze River. Purple soils are the most fertile soil in the Sichuan Basin, exceeding 70 million mu (15 mu equals to 1 ha) in area. They are mainly used for rice, wheat, edible oil and sugarcane production (Division of Pedology, 1991). At present, erosion-prone areas account for 60 percent of the Three Gorges slopeland and exceeds 3 million mu or 22 percent of the cultivated area. It is one of the most important sources of soil degradation on cultivated land.

Zigui County is situated in the Xiling Gorge of the Yangtze River in the southwest mountainous region of Hubei Province. It is the head area of the Three Gorges with a 90-km long river course flowing through it. It covers an area of 2,427km² with a population 422,000, of which agricultural population totalled 385,000 and a population density of 169 persons per km². The available cultivated land area per farmer is 1.34 mu, and per capita farmland is 0.6 mu. Purple soil is the leading cultivated soil in the county, which is concentrated in the Zigui Basin and purple sandy shale zones of the adjacent areas (Editorial Committee, 1991).

The experimental plots are located in Hongshiyuan Branch of the nursery for variety improvement of oranges, Bureau of Farm and Local Products of Zigui County, Hubei

Province. Elevation is about 200 m. Slope aspect is southwest facing. Nine experimental plots were set up at the nursery. Four of them were used for studying the soil and water loss process of purple soils developed on residues of purple sandy shales at different slope gradients (20, 25, 30, 35 degrees). The parent rock is Jurassic Penglaizhen Formation. Soil thickness is about 50-70 cm. The other four plots of 25 degrees were used for observations of water and soil loss with different hedgerow plants, including *Hierochloe odorata*, *Coriariaceae*, *Vitex negundo*, and *Neoleucaena glauca*. The 9th plot was a check plot with normal farming practices. Five more plots were set up at Wangjiaqiao Soil and Water Conservation Experimental Station belonging to the Office of Soil and Water Conservation of Zigui at the mouth of Wangjiaqiao Basin gullies slope. These plots were used mainly for comparative studies between terraces and slopeland. During the last two years, in addition to year-round natural rainfall observations, simulated rainfall experiments were also carried out twice a year to observe rainfall-induced runoff and sediment yield processes to compensate for inadequate natural rainfall observations in the 14 experimental plots. Nearly 60 simulated rainfall experiments were completed in the 14 plots with down-sprayed rainfall simulator imported from Canada, and SPRACO cone-shaped sprayer made in USA. The momentum obtained from the simulated experiments was roughly equivalent to 90 percent of the iso-intense natural rainfall (Cai and Lu, 1992).

This study conducts quantitative analyses on the data from 16 relevant simulated rainfall experiments for studying impacts of different land use types on soil and water loss processes on 25-degree purple soil slopeland. Crop characteristics, antecedent topsoil and simulated rainfall conditions of the 16 experiments are listed in Table 1.

Reduction of water and sediment by hedgerow plants

One year after hedging *Hierochloe odorata*, *Coriariaceae*, *Vitex negundo* and *Neoleucaena glauca* (mixed with day lily) on 25 degrees slopeland, apparent reduction effects of water and soil loss have been observed in contrast to slopeland with normal farming activities. Accumulated runoff and sediment yield under different precipitation duration was measured on five experimental plots by means of simulated rainfall under heavy rainstorm conditions. Linear regression analyses of accumulated runoff process and sediment yield process were conducted based on fitting actual experimental data. Results obtained in Table 2 are similar to many previous research studies (Cai et al., 1990; Moly, 1981). The accumulated runoff and sediment correlate well with rainfall duration. The determinate coefficient reaches 0.86-0.98.

Table 2. Line fittings of accumulated runoff and sediment yield process from hedged slopeland and slope farmland.

Plot No.	Hedgerows	CR process	Determinate Coefficient	SD process	Determinate Coefficient	No. of Sample

			t		t	es
94H-5	Hierochloe odorata	CR=211+13.7 T	0.96	SD=37.7+3.2 T	0.98	14
94H-6	Coriariaceae	CR=386+23.8 T	0.93	SD=157.5+13 .3T	0.99	14
94H-7	Vitex negundo	CR=310.8+15 .9T	0.88	SD=61.7+4.7 T	0.92	17
94H-8	Neoleucaena glauca	CR=284.5+18 .4T	0.95	SD=185.3+10 6.4T	0.86	15
94H-9	Slope farmland	CR=261.5+23 .9T	0.98	SD=25476+1 886T	0.93	17

Note: CR: Accumulated runoff (l); SD: Accumulated sediment yield (g);
T: Duration of precipitation (min)

The slope of the fitted line obtained from Table 2 actually represents the rate of increase of accumulated runoff per unit time. Compared to the check plot (94H-9), different water reduction efficiency was gained in the hedged-in plots. Of which Hierochloe is the best followed by Vitex negundo. Runoff reduction per unit time is about 22 and 43 percent, respectively. The accumulated runoff process slope for the Coriariaceae hedged-in plot is similar to the check plot. The main reason is the survival rate of Coriariaceae planted in 94H-6 plot is very low. Hence, no perfect hedgerow belt was formed.

The normal plough and an artificial earth-up ridge of up a 10-cm-high have been formed after one-year hedgerow planting. This can stop sediment penetration, retain most sediment inside the hedgerows, and gain apparent sediment reduction efficiency. Table 2 indicates that slope of fitted lines for accumulated sediment yield in 94H-9 plot is 18 to 570 times higher than that of the hedged plots. This also shows that per unit time sediment yield reduction is about 94 to 98 percent. Hedgerows planted with Hierochloe and Vitex negundo are the best in hedging off

Table 1. Crop characteristics, antecedent topsoil and simulated rainfall conditions of the 16 experiments.

Plot No. Area (m ²)	Land use	Crops	Types of hedgerow Plants	Coverage (%)	Soil conditions at initial stage of Rainfall		Simulated rainfall	
					Water Content(%)	Resistance to Shear strength(kpa)	Intensity (mm/min)	Duration (min)
F25S 2*5	Waste slopeland	Grass		30	9.55	5.6	0.65	30
F25B 2*5	Waste slopeland	Grass		30	28.4	4.24	1.29	30
H25S 2*5	Slopeland	Newly-Ploughed		0	21.68	2	0.54	30
H25B 2*10	Slopeland	Newly-Ploughed		0	27.7	2	1.33	30
94H-5 2*10	Slopeland	Ormosia	Hierochloe odorata	45	19.7		1.39	51.5
94H-6 2*10	Slopeland	Ormosia	Coriariaceae	20	10.14		1.54	50
94H-7 2*10	Slopeland	Ormosia	Vitex negundo	70	8.1		1.66	58
94H-8 2*10	Slopeland	Ormosia	Neoleucaena glauca	35	8.21		1.46	56
94H-9 2*10	Slopeland	Ormosia	None	20	9.55		1.46	53
95H-5 2*10	Slopeland	Wheat	Hierochloe odorata	90	17.82	4.34	1.19	50
95H-6 2*10	Slopeland	Wheat	Coriariaceae	90	5.47	9.02	1.29	68
95H-7 2*10	Slopeland	Wheat	Vitex negundo	90	19.8	6.97	1.12	63

95H-71		Slopeland	Wheat	Vitex negundo	90	19.85	6.6	0.76	94
2*10									
D-1	5*10	Terrace	Orange		90	21		0.62	51
D-2	5*10	Terrace	Wheat		60	17		0.91	22.5
D-4	5*10	Slopeland	Wheat		60	23		0.58	63

sediment. Experimental results also indicate that it is possible to allow most water flowing through but sediment being trapped in the hedgerows. Sediment hedge-off effect is most apparent in heavy rainstorms.

Soil erosion is serious during heavy rainstorms on purple soil slopeland. Sediment yield module of an individual rainstorm reaches as high as $3600\text{t}/\text{km}^2$, close to the annual average erosion module of local purple soil slopeland. The main reason for this is that rill erosion often occurs on slope farmland under heavy rainstorms. Subsequently, severe rill erosion and headward rill erosion were formed within 15 minutes after the simulation experiment. This rapid development of rill system causes large amount of muddy flowing rill water. Rill erosion can only be developed with slope length of 15-20 m and on slope gradient of 16 degrees on Loess Plateau (Cai et al., 1995; Cai and Luk, 1995). The above experiments also indicate that coarse-grain purple soils with slope steepness exceeding 25 degrees and high-intensity rainfall are more susceptible to rill erosion than loess. During the experiment, rill erosion also occurred in isolated areas of the hedgerows plots planted with *Coriariaceae* and *Neoleucaena glauca* that were not well established. This is also the reason why sediment yield in plots hedged by these two plants is much higher than the *Hierochloa odorata* and *Vitex negundo* plots. Results imply that planting hedges on slopeland and shortening slope length are essential in mitigating soil erosion in the Three Gorges Reservoir area, especially on steep slopeland (Lal, 1988).

About 20-cm high hedgerows were formed by plough and earth-up stubble of various hedge plants after harvesting *ormosia* in 1994. Results of accumulated runoff and sediment yield processes obtained from heavy rainstorm simulation performed in April 1995 are listed in Table 3. Compared with experimental results obtained in fall of the previous year (Table 2), slopes of linear regression lines were further reduced indicating an increase in water and soil reduction efficiency of the hedgerows.

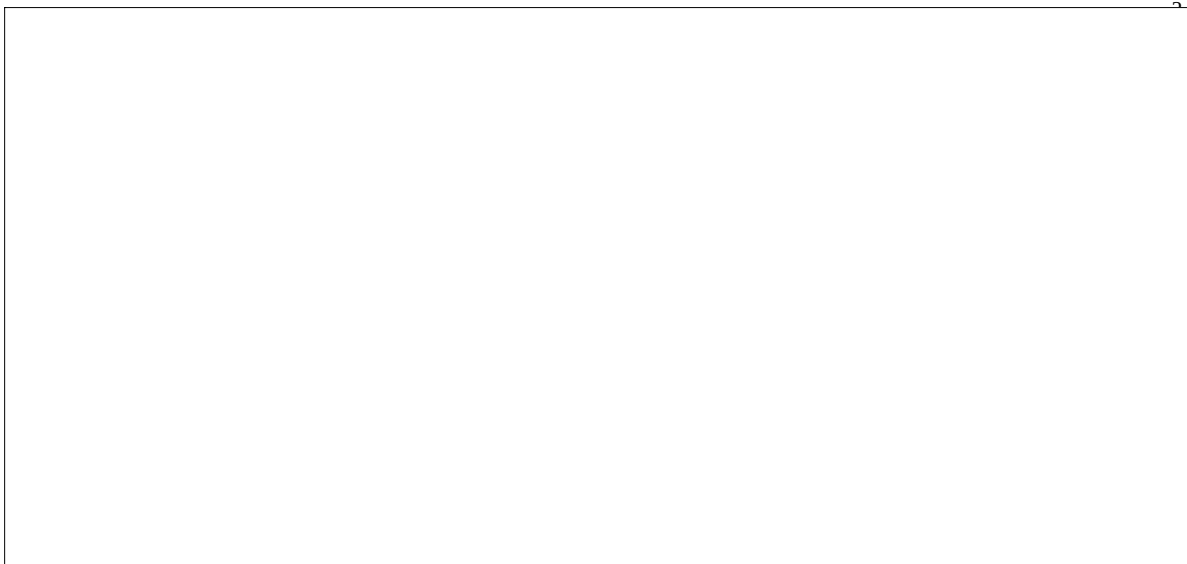
Table 3. Fitting of processes of accumulated runoff and sediment yield on hedged slopeland in spring of 1995.

Plot No.	Hedgerows	CR process	Determine Coefficient	SD process	Determine Coefficient	No. of samples
95H-5	<i>Hierochloa odorata</i>	$\text{CR}=47.4+3.8\text{T}$	0.90	$\text{SD}=33.8+2.6\text{T}$	0.90	16
95H-6	<i>Coriariaceae</i>	$\text{CR}=262.8+9.7\text{T}$	0.84	$\text{SD}=273.4+11.2\text{T}$	0.87	18
95H-7	<i>Vitex negundo</i>	$\text{CR}=289.9+19\text{T}$	0.99	$\text{SD}=83.7+6.3\text{T}$	0.99	18

III. Comparison between Hedgerow Plants on Slopeland and the Terraces

Research results from both within and outside China indicate that infrequent heavy rainstorms are the major cause of serious soil and water loss. In Missouri USA, a single rainfall event made up 50 percent of the total five years' soil erosion amount. Marzue experimental station of Zimbabwe also showed that soil erosion amount from one or two heavy rainstorm events might exceed half of the annual amount (Hudson, 1981). Runoff depth and sediment yield may differ greatly with different slope length for a heavy rainstorm with a return period of ten years. In Table 4, the slope length of 94H-9 and F25B is 10 and 5 m, respectively. Comparisons of experimental result shows that the slopes of the accumulated runoff depth fitted lines differ over 1 time. The slopes of the sediment yield modules fitted lines differ over 120 times, and sediment yield per unit runoff depth differs 56 times. Soil erosion and sediment yield is, therefore, very serious when farming is practised on steep slopeland with slope length exceeding 10 m. It is particularly so as farming is usually practised along the slopes in the Three Gorges Reservoir area. Rainfall characterised by concentrated precipitation and heavy rainstorms are the reasons behind the serious soil and water loss in the Three Gorges of the Yangtze River. This experimental result may also provide essential basis for designing hedgerow intervals on steep slopeland, for checking the effectiveness and efficiency of stone ridge terraces, hedgerows and various other adopted prevention and control measures. It is of practical importance to include soil and water loss process under intense rainstorms.

The fitted accumulated sediment yield module process line from hedgerow planted less than two years and the stone-ridge terraces is compared in Figure 1. The figure shows that although the accumulated sediment yield modules from hedged steep slopes are several times higher than that of the terraces, their actual values are not great. Even with one year growth (Table 1) of *Hierochloe odorata* (plot 94H-5) and *Vitex negundo* (plot 94H-7), the actual accumulated sediment yield module is merely around 16t/km^2 with a rainstorm intensity of over 1.39 mm/min . This value is quite tolerable in this area. With two year growth of *Vitex negundo* (plot 95H-7), its accumulated sediment yield module process line is quite close to that of the horizontal stone ridge terraces D-1 and D-2 under similar rainfall conditions. At the initial simulation stage, the sediment yield process in the hedged plots and the stone ridge



reduction effect of terraces and the hedgerow plants on slopeland is the similar. This is why the hedgerows are more superior. The actual input of the hedgerows is only 100 to 200 Yuan (US \$1 equal to 8.3 Yuan RMB) per mu in contrast to over 1000 Yuan per mu for stone ridge terraces at present in the Three Gorges Reservoir. In the case of slopeland greater than 25 degrees, the cost for stone ridge terraces would be even higher.

Table 4. Fitting of accumulated runoff depth process and sediment yield module process of slope farmland.

Plot No.	Land use	Accumulated Runoff process	Determine Coefficient	Accumulated erosion-Induced sand process	Determine Coefficient	Relation of erosion-induced Sand and runoff depth	Determine coefficient	No. of samples
F25S		$Rd=3.04+0.26T$	0.96	$Sm=4.53+0.4T$	0.94	$Sm=0.052+1.52Hh$	0.99	18
D-4	Sloped land	$Rd=6.78+0.22T$	0.96	$Sm=35.02+1.49T$	0.94	$Sm=10.8+6.66R^h$	0.97	36
94H-9	Sloped land	$Rd=13.07+1.19T$	0.98	$Sm=1273+94.32T$	0.93	$Sm=271+80.13Rh$	0.98	17

Note: Rd-Accumulated runoff depth (mm); Sm-Accumulated sediment yield modules (T/km²); T-Duration of precipitation (min)

Table 5. Relationships between accumulated sediment yield modules and runoff depth of hedged sloped land and terraces.

Plot No.	Land use	CD process	Determine Coefficient	SD process	Determine Coefficient	SD and runoff depth	Determine coefficient	No. of samples
94H-5	Hierochloa odorata	$Rd=10.56+0.69T$	0.96	$Sm=1.74+0.16T$	0.98	$Sm=15.66+0.23Rh$	0.99	14
94H-7	Vitex negundo	$Rd=1554+0.79T$	0.88	$Sm=3.09+0.24T$	0.92	$Sm=1.64+0.29Rh$	0.98	17
D-1	Orange terrace	$Rd=1.57+0.096T$	0.97	$Sm=0.16+0.013T$	0.99	$Sm=0.056+0.13Rh$	0.98	30

D-2	Terrace	Rd=0.95+0.08 7T	0.94	Sm=0.33+0.04 2T	0.84	Sm=0.08+0.49Rh	0.97	26
94H-7	Vitex negundo	Rd=13.07+1.1 9T	0.99	Sm=4.19+0.31 T	0.99	Sm=0.63+0.33Rh	0.99	18

Note: Meanings of symbols are the same as in Table 4.

IV. Conclusion

In heavy rainstorms, the hedge plants can lead to runoff reduction of 22 to 43 percent and sediment yield reduction of 94 to 98 percent on 25-degree slopeland. Hedgerow plant is effective in ameliorating slopeland in the Three Gorges Reservoir of Yangtze River since it can substantially reduce soil loss on slopeland with a cost of only 10 to 20 percent of the stone ridge terraces.

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The Effect of Spatial Averaging of Rainfall on Erosion at the Catchment Scale

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Abstract

Rate of raindrop erosion in most of physically based erosion models is a non-linear function of rainfall intensity. Owing to some practical constraints rainfall input data used in these models do not often represent the spatial and temporal variations of rainfall storms as important factors in simulation of raindrop erosion. Therefore the used rainfall input data are either spatially averaged or their spatial and temporal resolutions are not desirable for this purpose. In the present study the effect of spatial averaging of rainfall data and random selection of rainfall stations on the simulated rate of raindrop erosion in four catchments with different sizes (ranging from 1.4 to 1600 km²) using SHETRAN model were investigated. It was found that for frontal type rainfall data (generated by MTB method) the effect of spatial averaging of rainfall on simulated raindrop erosion in small catchments is much less than that in larger catchments. It was also found that the raindrop erosion could be simulated with enough accuracy where the rainfall data from at least four randomly selected rainfall stations across the catchment is used.

Introduction

Physically based, spatially distributed modeling systems are increasingly being used to predict the impact of land use and climate change on catchment hydrological and soil erosion response, in support of catchment management decision making (e.g. Bathurst and Wicks, 1991; Bathurst and O'Connell, 1992; Adams et al., 1995). To account for spatially varying responses, such models require rainfall input data with a fine spatial resolution. However, data are rarely collected at the required resolution and model inputs are effectively averaged values for larger scales (ranging from subcatchment to the full catchment scale). One of the outputs of this type of model could be simulated erosion at the catchment scale. Typically, physically based models determine soil erosion by raindrop impact as a highly non-linear function of rainfall intensity (e.g. Bathurst & Wicks, 1991; and Wicks & Bathurst, 1996). Given that erosion is greatest for short periods of high intensity rainfall occurring in limited spatial areas, model simulation results may be expected to show significant sensitivity to spatial averaging of rainfall. This effect was investigated using the SHETRAN hydrological, sediment transport and contaminant migration grid based modeling system developed by the Water Resource System Research Laboratory (WRSRL), University of Newcastle, from the existing Système Hydrologique Européen (SHE) (Abbott et al., 1986; Bathurst et al., 1995; Adams et al., 1995).

The specific objectives in this study were:

- to investigate the effect of different scales of spatial averaging of rainfall on soil erosion as simulated by SHETRAN, and
- to investigate the spatial resolution at which rainfall data required to support "true" simulation of erosion should be collected.

Four catchments were used for this study which will be described later. The Modified Turning Band (MTB) method was used to generate rainfall field inputs at the model grid scale, on the basis of which the "true" erosion field was simulated. Simulation then was carried out with the same rainfall averaged over progressively coarser spatial scales. Comparison of the results with the "true" output indicates their scale dependency. In addition, the random sampling technique was used to select various sets of rainfall stations from the MTB generated rainfall data across each study catchment to investigate the spatial resolution at which rainfall data required to support "true" simulation of erosion should be collected. The erosion simulation results from these selected rainfall sets were compared with those obtained from the simulation when all the originally generated rain gauge stations data were used as input in the simulations. The comparison showed the efficiency of this technique to find the minimum number of rain gauge stations needed for relatively accurate results at the catchment scale.

The study contributes to an area in which there has been little work and helps to define the conditions for successful application of physically based models.

SHETRAN and raindrop erosion

A brief description for the SHETRAN model used in this study is given here. This model which consists of a main hydrology section and two transport components, i.e. sediment transport and contaminant migration, is used for modeling the hydrology of catchments with zero flow boundary. The two transport parts of the model, developed by the Water Resource Systems Research Laboratory, UK, have been separately added to the model. The meteorological inputs of the model are those related to precipitation, evapo-transpiration and heat budget (for the rate of snowmelt). Subsurface flows are calculated for a heterogeneous, anisotropic unconfined aquifer. Surface flow is generated by either infiltration excess or saturation excess mechanisms. For simulation of hydrology and sediment transport in a catchment, the basic input data of the catchment is typically introduced to the model in distributed form, with grid elements as divisions of the catchment area. Each grid element is considered as a main computational unit in the simulations. In other words, across the whole area of a single grid element, at a given time, only one value for each input parameter can be allocated and only one value for a model output can be produced (Bathurst and Wicks, 1991). The model can simulate erosion continuously for any length of time with very high temporal and spatial resolution and for any catchment type and size. Detailed information on different components of the model has been given in SHETRAN (1995). However, owing to the importance of the sediment transport component, some of its main equations more relevant for this study are mentioned here.

In this component one of the major factors, i.e. raindrop impact, which plays an important role in erosion and sediment transport processes is introduced. The main inputs of this component are provided by the results obtained in the water flow component of the model. The rate of raindrop soil erosion in SHETRAN model is determined from Equation (1) (SHETRAN, 1995):

$$D_r = k_r F_w (1 - C_g - C_r)(M_r + M_d) \quad (1)$$

where D_r = rate of soil detachment ($kgm^{-2}s^{-1}$), K_r = raindrop impact soil erodibility

coefficient (J^{-1}), F_w = factor representing the effect of surface water depth on raindrop erosion, C_g = proportion of ground shielded by near ground cover (decimal fraction), C_r = proportion of ground shielded by ground level cover (decimal fraction). M_r and M_d are the momentum squared of raindrops and leaf drips respectively. The protective effect of a surface water layer in reducing the effect of soil detachment by raindrop and leaf drip is accounted for by F_w , where:

$$F_w = \begin{cases} 1 & \text{if } h \leq d_m \\ \exp(1 - \frac{h}{d_m}) & \text{if } h > d_m \end{cases} \quad (2)$$

Here h = water depth (m); and d_m = effective drip/drop diameter (m). The momentum squared of raindrops, M_r , in Equation (1) is nonlinearly proportional to rainfall intensity (SHETRAN, 1995). According to this relationship, a slight increase in rainfall intensity will result in very high increase in M_r . This nonlinear relationship between M_r and rainfall intensity plays an important role on the effect of spatial averaging of rainfall on raindrop erosion.

Catchments Description

Four existing catchments were used to provide a range of physical conditions for the study. The catchments range from 1.4 to 1600 square km in area (Table 1). Owing to the large computer resources required to produce simulation outputs for individual grid elements and to avoid the corner effects resulting from the irregular geometric shape of the catchments on the spatial averaging of rainfall, it was decided to include only a selected part from each catchment in the first part of this study, the effect of spatial averaging of rainfall on erosion. The shape of the selected parts was square and they were located as near to the center of the relevant catchment as possible. Depending upon the shape of each catchment the size of the selected parts varied. For example in the Arvan catchment it was possible to choose a square shape with 16 grid elements in each side, whereas for the Cobres one the number of possible grid elements from the catchment in each side of square was 8 and still two grid squares in the selected square shape were out of the catchment area which, obviously were not included in the simulations.

Table 1. The general size description for each catchment.

No	Description	Rimbaud (France)	Arvan (Iran)	Cobres (Portugal)	Agri (Italy)
1	Size of basic grid element (km x km)	0.1 x 0.1	0.5 x 0.5	2 x 2	2 x 2
2	No. of grid elements in each direction in selected part	8 x 8	16 x 16	8 x 8	8 x 8
3	No. of grid elements in the selected part (inside the catchment)	64	256	62*	64
4	Size of the selected area (km^2)	0.64	64	248	256
5	Total area of the catchment (km^2)	1.44	101	704	1532
6	Total No. of grid elements	144	404	176	383

In the Cobres catchment only 62 grid elements from the catchment area were inside the selected part (8 x 8) of the catchment map.

Method

Rainfall fields were generated as input to SHETRAN catchment simulations using the MTB method. This method generates synthetic space-time rainfall data using rainfall statistics specific to a particular catchment. It is built up of layers of randomly distributed and deterministic modulating functions, which when combined, form a synthetic rainfall field whose features resemble observed rainfall characteristics such as raincells, cluster potential regions and rainbands (Mellor, 1996). For this study the MTB was parameterized using rainfall time series data for the simulation catchments and physical field properties obtained from earlier studies.

The version of the MTB model used in this study generates a single storm having approximately the same total volume of rainfall for a given set of input parameters. The time resolution of generated rainfall data for all catchments is 5 minutes. The duration of generated storms ranged from 10 to 11 hours.

With this procedure the MTB method produces a separate rainfall data set for each catchment. In this data set, for each grid element in the catchment, a separate rain gauge station was designated. Therefore this data set is called rainfall input data with a scale of 1x1, indicating that the input rainfall data used in the relevant simulation is at its finest possible resolution, and the results of simulated erosion with this input are called the “true” erosion results. In the later simulations in order to investigate the effect of spatial averaging of rainfall on raindrop erosion, this base rainfall data set will be used to produce new rainfall data sets, which are spatially averaged. The practice of spatial averaging of rainfall is as follows.

The selected area was divided into squares with twice the original dimensions, i.e. each division containing four of the original squares. A new rainfall time series was obtained

for each set of four rainfall stations (located in the four original grid squares of the mentioned divisions) by taking the average of the original rainfalls of these rain gauges in each time interval. The simulation with this data set is called scale 2x2. Similar practices were done for the divisions of 4 and 8 times of the original dimensions, i.e. respectively containing 16 and 64 of the original squares, the simulations of which were called scales 4x4 and 8x8 respectively (Figure 1).

The volumes in all the scales remain unchanged, which showed that the mass balance is maintained in the averaging procedure. Figure 2 shows the percentage change of maximum rainfall intensity compared with that at the scale 1x1. As can be seen from this figure, the coarser the scale of spatial averaging of rainfall, the more reduction there will be in the maximum rainfall intensity. The bigger the catchment and the grid size, the more will be the effect of rainfall spatial averaging in reduction of maximum rainfall intensity in coarser scales.

To achieve the objectives of this study the following two types of simulations were made.

- (1) simulations with spatial averaging of rainfall data
- (2) simulations with random selection of rainfall stations.

Model input data and assumptions

To run SHETRAN for the simulations of soil erosion in this study the following main assumptions were made in setting up the model input files.

- The vegetation cover was shrubs covering only 10% of every grid element.
- Two nominated depths of the soil 1 and 4 m with initial phreatic surface depths of respectively 0.7 and 3.7 m below the ground were used.
- To avoid mixing the overland flow erosion with the results of the present study, the value of erodibility coefficient due to overland flow was kept zero.
- One soil type with same particle size distribution was used for all four catchments, as shown in Table 2.

Table 2. Soil particle size distribution in the catchments.

ssgn* >	1	2	3	4	5	6	7
diameter (mm)	0.1	0.37	0.89	1.59	3.25	6.9	13.5
% weight	32	19	12	11.1	16.8	6.5	2.6

* ssgn = soil size group number

- Strickler coefficient of hillslope roughness; i.e. CDR, was 10 (Wicks, et al. 1992).
- Four values of Kr, erodibility coefficient due to rain drop impact, were chosen; 0.1, 5, 20 and 30 J⁻¹ (Wicks, et al., 1992); i.e. covering a range of values for soils from less erodible to more erodible.
- A wide range of values for the coefficients of soil unsaturated, Ksat(uz), saturated, Ksat(sz)x and Ksat(sz)y, hydraulic conductivity; i.e. from 0 to 100 m/day, was used.

Simulations

Simulations with spatial averaging

The erosion simulations were carried out with the above mentioned assumptions for all rainfall data sets from scales 1x1 to 8x8 using the relevant generated storm data set for each catchment. Owing to the controlling role of the three main parameters; i.e. Ksat(uz), Ksat(sz) and Kr, the simulation of erosion was done for different values of these

parameters.

Model outputs (erosion depths) were obtained for the corresponding selected areas for all the adopted rainfall spatial averaging scales in the catchments for different values of $K_{sat}(uz)$, $K_{sat}(sz)$ and K_r (Norouzi Banis, 1998).

Simulations with random selection of rainfall stations

An ideal rain gauge network in a catchment requires a separate station for each plain, coast and valley in a typical site (Linacre, 1992). With the lack of rain gauge networks with sufficient resolution and the absence of enough information about the trend of spatial variation of storms across catchments, the random sampling technique can be an alternative technique.

In this technique simulations were done with random selection of the rainfall stations without spatial averaging. The reason for selecting this method is to investigate the minimum number of randomly selected rainfall stations for which the results of simulated erosion could be within the range of acceptable accuracy compared with that of the original resolution of rain gauge network; i.e. “true” simulation. In this practice for each catchment 10 sets of randomly selected rain gauge station numbers were adopted using relevant routines from NAG (Numerical Analytical Group). The number of stations in the first set, second set, and tenth set were 1, 2, 3, ..., and 10 respectively. The station numbers in each set have been recorded in the relevant grid square in the catchment grid element network and using the Thiessen polygon method the area of the catchment corresponding to each rainfall station in each set has been identified. Then accordingly, the appropriate frame data file was prepared for each set which allows the SHETRAN model to use the rainfall data of the specific rainfall station for the corresponding defined area. Ten simulations of total depth of erosion with these input data files for each catchment were done. For this set of simulations previously used model parameters and assumptions were adopted, but the simulated depth of erosion was calculated for the whole area of each catchment (Norouzi Banis, 1998).

Results and Discussions

Results of simulations showed that as the scale of spatial rainfall averaging becomes coarser the under estimation of simulated depth of erosion increases. This under estimation can be compensated by modifying the appropriate model parameters. For example according to Equation 1, the rate of raindrop erosion is linear function of K_r , raindrop erodibility coefficient. Therefore the modification of this parameter can be a good alternative for this purpose. Figure 3 shows the percentage corrections required in the value of K_r to compensate for the effect of spatial averaging in one set of simulations. The variation of this correction also depends on the size of the catchment. The smaller the catchment, the less is the required correction. The difference between these values for Cobres and Agri is as a result of high values of saturation factor (F_w) in Cobres catchment.

Under the hydrological conditions defined in this study, the percentage corrections for K_r at the maximum averaging scale, i.e. 8x8, for the higher values of $K_{sat}(uz)$, in the study catchments, Rimbaud, Arvan, Cobres and Agri are of the order of 2%, 5%, 7% and 20% respectively. It seems that there are more factors controlling this correction other than the

size of the catchment, because in the Agri and Cobres catchments, in spite of their having the same spatial averaging scale, their Kr percentage corrections are quite different. A controlling factor in this respect could be the difference in the degree of saturation (resulting partly from their general topographical differences) in the selected areas of the two catchments.

On the whole the simulated erosion is less for greater averaging for a given catchment. The main explanation for this is that the rate of soil detachment due to raindrop impact nonlinearly increases with rainfall intensity. Whereas in the spatial averaging practice, the rainfall intensity in each time interval represents the mean value of the corresponding rainfall data from contributing rain gauges. Therefore the more the spatial variation in the storm characteristics and the larger the averaging area, the lower will be maximum rainfall intensity and consequently the lower will be the rate of soil detachment due to raindrop impact.

The results of the simulation of erosion in the four catchments with the rainfall input of randomly selected rainfall stations were also produced.

The average depths of simulated erosion for each of them (10 sets) were compared with that of the basic rainfall time series; i.e. simulation with different rain gauges in each grid element. Figure 4 shows the percentage change in the average depth of erosion, where the effect of using different randomly selected rainfall station networks is compared with that of original rainfall station distribution. In general the figure indicates that by applying more randomly selected rainfall stations the simulated erosion depth will become nearer to the "true" erosion depth. It can be seen that when the number of randomly selected rainfall stations used in the simulation reaches 4, the results are very similar to the results for the basic rainfall station resolution.

The percentage difference between the "true" depth of erosion and the depth obtained from applying randomly selected rainfall stations for a given number of these rainfall stations is initially higher for the Agri than those of the other three catchments. This change is less for small catchments. In particular in the Rimbaud catchment no significant change occurs in the erosion. The reason for this is that the pattern of the given storm rainfall does not change spatially very much in terms of rainfall intensity, where the size of the area concerned is in the order of 1 square kilometer. This could be especially true if the storm is of a frontal type (Linacre, 1992). By contrast in a study carried out by Lopes (1996) for an area of about 6 km² with connective storms the measured rainfall data showed substantial spatial and temporal variations. The comparison of results in the two studies indicates the effect of different types of storms. Lopes concludes that the density of the rain gauge network, the spatial arrangement of individual rain gauges within the catchment, and the spatio-temporal characteristics of storm events all greatly influence catchment response predictions. For example, in this study, the model output resulting from 4 randomly selected rain gauges out of 10 rain gauges is accurate enough for the test storm. However, there might be a significant error in the model output with the same 4 rain gauges when data from other types of storms are used.

Conclusions

Rainfall data with good resolution (in time and space) as a basic input in erosion

modeling is not usually available. The required rainfall data is spatially averaged or data from very few rainfall stations exists. The effects of spatial averaging of rainfall and randomly selected rainfall stations on simulated raindrop erosion were investigated in four catchments, using SHETRAN physically based model. For catchments with small areas the spatial averaging effect is almost negligible (Rimbaud catchment). The reason behind this is that the spatial variation of rainfall in a frontal storm for such small areas (1 square kilometer) is not significant. For the Arvan catchment (with an area of 100 square kilometers), the effect is of the order of 4-6% for the scale of 8x8. For the Cobres and Agri catchments (with areas of 700 and 1600 square kilometers respectively), the effect is of the order of 20% for the scale of 8x8. For finer scales of spatial averaging the effects become less and can vary depending upon other factors.

The results of the present study suggest that in order to compensate the effect of spatial averaging, the originally defined soil erodibility coefficients might need to be slightly increased by certain factors, depending upon the simulation conditions. In large catchments, as long as the averaging scale is kept in the range of about 100 km² , one could ignore the effect of spatial averaging of rainfall on the model results.

The results of erosion simulation with the random selection method for the rainfall stations show that, the more the number of randomly selected stations used, the closer the results are to the "true" ones. In terms of the minimum effective number of rainfall stations, in most of the catchments 4 stations provide sufficient accuracy for the purpose of modeling erosion in frontal rainfall storms. In other words, the results of the present study also suggest that in catchments ranging from 1 to 1600 km² in area with frontal rainfall storms, the model can simulate raindrop erosion with reasonable accuracy, if rainfall data from at least four stations (randomly located across the catchment) is available.

Further study in this field can be done by including the presence of overland flow erosion, and investigating the effect of rainfall spatial averaging on the sediment yield in different hydrological conditions (e.g. rainfall type).

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Regularização Hídrica em Aluviões- Estudo de Caso no Semi-árido do Nordeste do Brasil

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Resumo

Grande parte da economia do Nordeste do Brasil ainda é baseada na produção de alimentos através da agricultura de sequeiro. O regime irregular de chuvas e a elevada evaporação que caracteriza a região, com clima semi-árido, além de impor a necessidade de irrigação para o desenvolvimento da agricultura, tendem a limitar significativamente a disponibilidade hídrica ao longo da estação seca. Apesar das intensas pluviometrias, estas são concentradas em curtos períodos de tempo, sendo a maior parte de tais aportes perdidos por escoamento superficial e evaporação. A existência de vales aluviais, à medida que incrementa a componente de infiltração, reduz a perda superficial e recarrega as reservas subterrâneas freáticas. Investigação da dinâmica hídrica quantitativa e qualitativa de aluviões vem sendo desenvolvida em área piloto irrigada. Os recursos hídricos subterrâneos apresentam marcante sazonalidade quantitativa em algumas regiões, entre as estações chuvosa e seca. Os períodos iniciais da estação chuvosa tendem a lixiviar o solo e reconcentrar as águas subterrâneas. Com a continuidade das chuvas, os níveis freáticos se recuperam e as concentrações salinas se reduzem, disponibilizando água para uso agrícola em pequena escala.

INTRODUÇÃO

Os aquíferos aluviais do Nordeste brasileiro vêm sendo utilizados dentre outros fins para a pequena agricultura irrigada. As manchas aluvionares presentes no Nordeste brasileiro, por constituírem fontes renováveis de recursos hídricos, apresentam alto potencial para o desenvolvimento agrícola de pequena escala. Devido a fatores climáticos, aos métodos de irrigação utilizados, e a condições edáficas, os sais dissolvidos contidos na água de irrigação e do aquífero podem-se acumular no perfil do solo. Os períodos chuvosos tendem a gerar lâminas de recarga, conforme será discutido a seguir. Estas lâminas contribuem para a lavagem de sais do solo, conduzindo-os para a zona saturada. Dependendo do grau de circulação do aquífero, os lixiviados tendem a ser naturalmente evacuados do domínio.

DOMÍNIO DE ESTUDO

O estudo vem-se desenvolvendo na Fazenda Nossa Senhora do Rosário, município de Pesqueira-PE, onde estão assentadas cerca de 50 famílias, desde Dezembro de 1991. A Fazenda localiza-se sobre um aluvião, que é utilizado para a agricultura irrigada, através de

quatro poços Amazonas e 14 cacimbões. O aquífero aluvial é raso, com profundidade média de 10 metros, possuindo cerca de 15 km de extensão e 300 metros de largura. Neste estudo, esta formação será referida como ‘aluvião Mimoso’. O vale aluvial desenvolve-se a partir da encosta da Serra do Mimoso, a qual tem influência hidrológica na área. A Figura 1 apresenta a topografia local, podendo-se observar variações de inclinação topográfica ao longo do eixo longitudinal do depósito. As áreas de menor inclinação apresentam menor competência no transporte de sedimentos, e tendem a acumular sedimentos finos em sua subsuperfície, conforme evidenciado na Figura 2. Em termos de captação da precipitação pluviométrica, além da recarga difusa direta no vale, deve-se destacar o importante papel das encostas no suprimento hídrico subterrâneo dos aluviões.

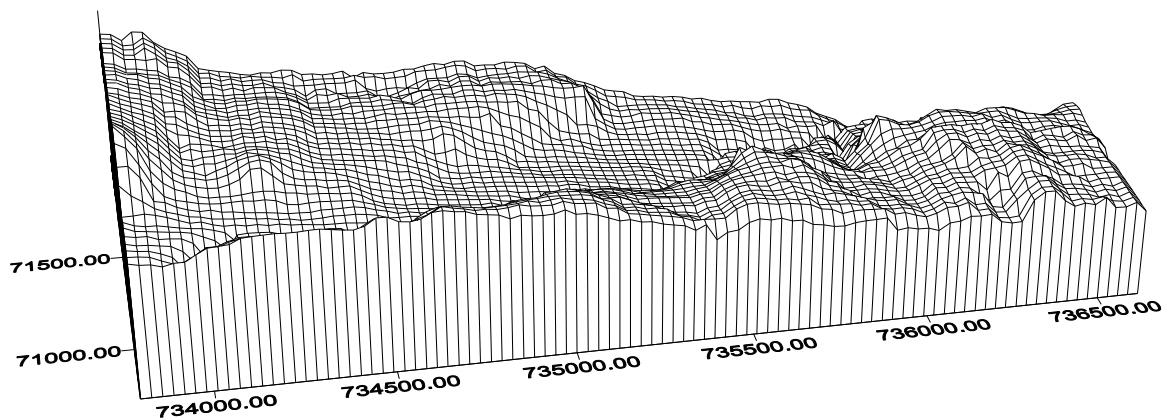


Figura 1- Topografia da área em estudo.

O município de Pesqueira está localizado na Região Agreste do Estado de Pernambuco, exibindo clima semi-árido muito quente tipo estepe, segundo Koeppen.

A Figura 3 apresenta os dados climatológicos da área. Com base em levantamento de campo para caracterização hidráulica do aluvião (**Montenegro(1997a)** e **Montenegro(1997b)**), solos lemo e lemo arenosos são dominantes. Utilizando metodologia geostatística, pode-se construir mapa dos solos dominantes no aluvião (**Montenegro, 1997b**) (Figura 2). Os pontos na figura 2 representam os piezômetros da área.

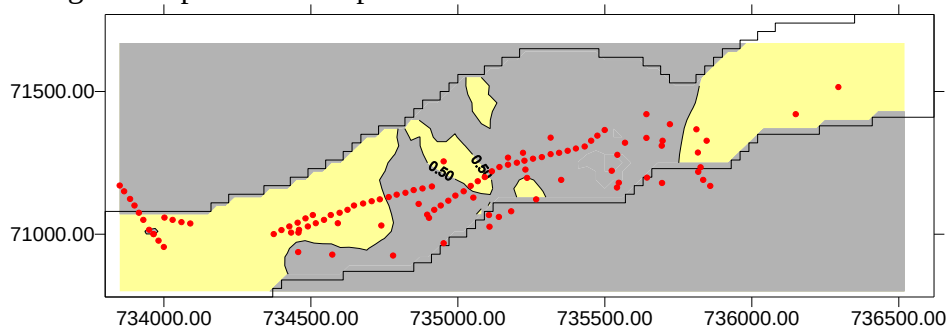


Figura 2- Distribuição dos solos lemo arenosos (amarelo) e lemo (cinza).

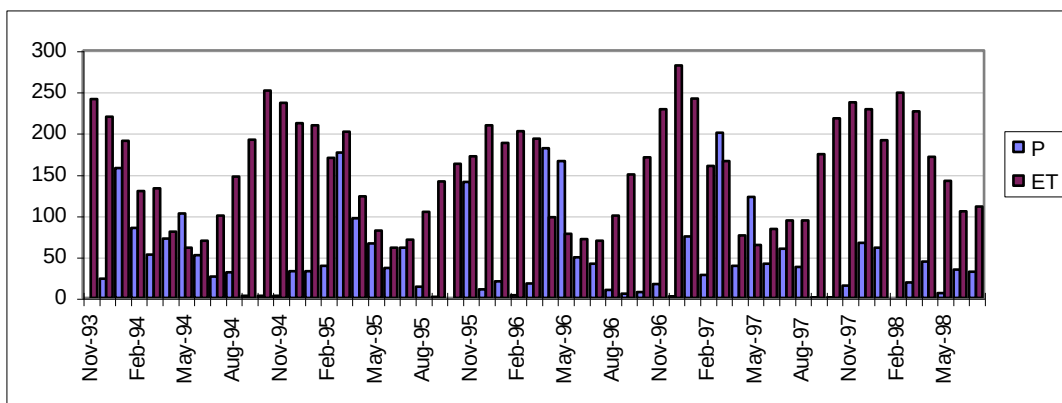


Figura 3 –Precipitação e evaporação mensais na Estação climatológica de Pesqueira, no período de Dez/93 a Jul/98 (INMET-PE)

DINÂMICA DE NÍVEIS POTENCIOMÉTRICOS NA ÁREA

As flutuações médias do lençol estão apresentadas na Figura 4, ocorrendo uma maior inércia das regiões com texturas siltosas em responder às recargas de origem pluviométrica. A Figura 4 evidencia a flutuação de nível em relação à estações do ano.

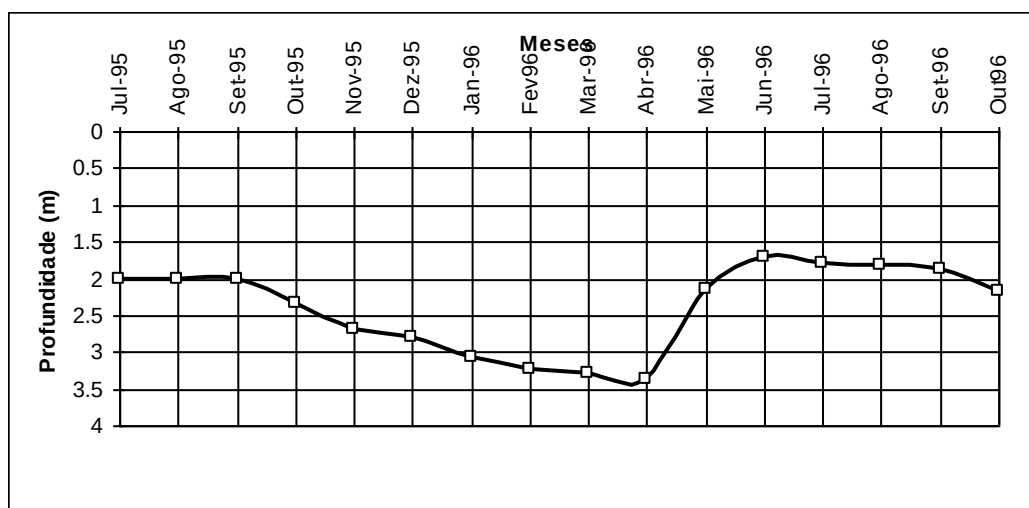


Figura 4 – Sazonalidade da profundidade média do freático nos piezômetros

A dinâmica discutida representa uma média da flutuação ocorrida em 80 piezômetros distribuídos na área, conforme pode ser visualizado na figura 2. Tais piezômetros foram instalados em Julho de 1995, pelos autores deste trabalho. Série piezométrica mais extensa está disponível para os cacimbões públicos P1, P2, P3 e P4, construídos pelo Governo do Estado de Pernambuco, através da extinta Cisagro, atualmente incorporada à Emater - Pe. A figura 5 exhibe tais séries.

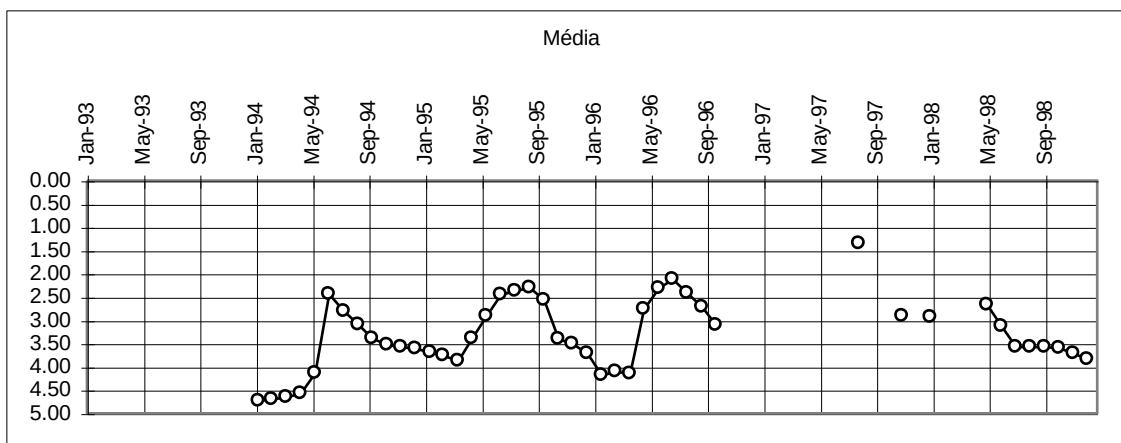


Figura 5. Flutuações médias nos piezômetros dos cacimboes P1, P2, P3 e P4

Devido a existência de falhas nos dados no ano de 1997, bem como ao ano atípico de 1998, com baixa pluviosidade, vamos concentrar a análise deste trabalho nos anos de 1995 e 1996. Tomando-se a taxa mensal de variação do nível do lençol e assumindo-se um coeficiente de armazenamento de 0,10 para a área (**Cisagro, 1991**), pode-se identificar os meses onde ocorreram recuperação geral da piezometria do aluvião. Tais recuperações estão situadas nos meses chuvosos, entre Maio e Julho, para o ano de 1996, e estão associadas a recargas pluviométricas. Como os piezômetros foram instalados em Julho de 1995, não houve registro de recargas em 1995. A figura 6 apresenta as lâminas mensais de precipitação e de recarga. Pode-se observar a importância da precipitação antecedente na geração de recarga.

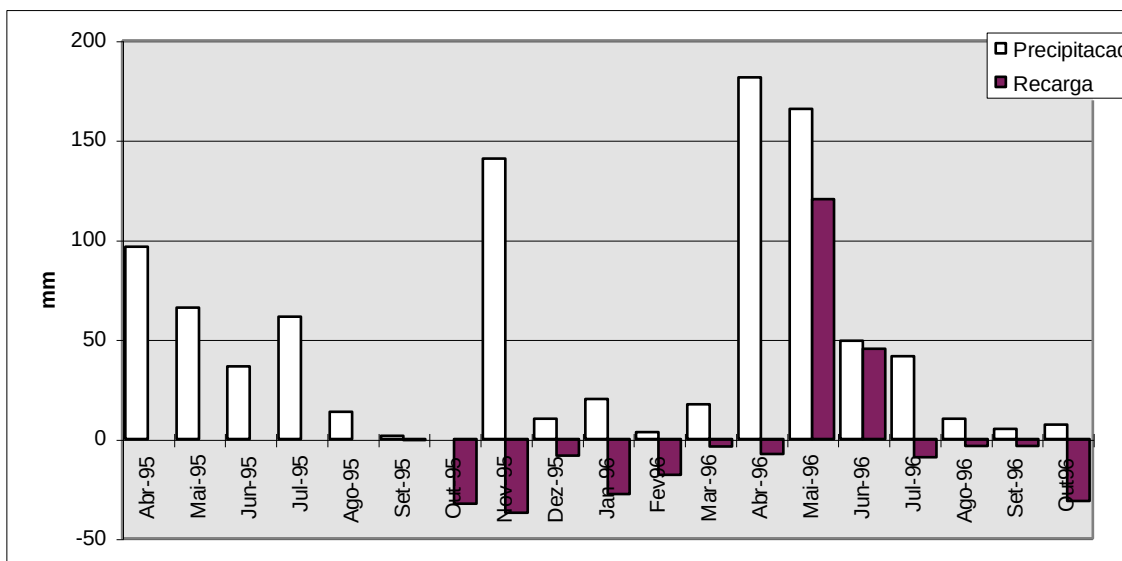


Figura 6- Dinâmica de recarga média de origem pluviométrica nos piezômetros.

Tomando-se agora como referência as taxas variação mensais do nível do lençol dos quatro cacimbões públicos, é possível estender o período de análise para os anos de 1994 e 1995. Embora esta série possua o inconveniente de integrar tanto os efeitos de recarga de origem pluviométrica, quanto a recuperação do nível devido à redução do bombeamento nos meses chuvosos, pode-se observar comportamento semelhante àquele representado na figura 6. Integrando-se os eventos de recarga para os cacimbões, assim como a precipitação, é possível avaliar a contribuição da pluviometria no armazenamento subterrâneo do aluvião. A figura 7 evidencia tal contribuição para os anos de 1994 a 1996, assumindo-se que a recuperação dos níveis dos cacimbões se dá primordialmente pela pluviometria. Esta última hipótese parece

aceitável, principalmente quando de inclui, na análise, a recarga acumulada avaliada a partir da sazonalidade média de todos os piezômetros da área (figura 7). Parece existir alguma superestimação da recarga quando se considera as séries dos cacimbões, o que poderia, em parte, ser explicado considerando-se as texturas mais arenosas nas vizinhanças dos cacimbões.

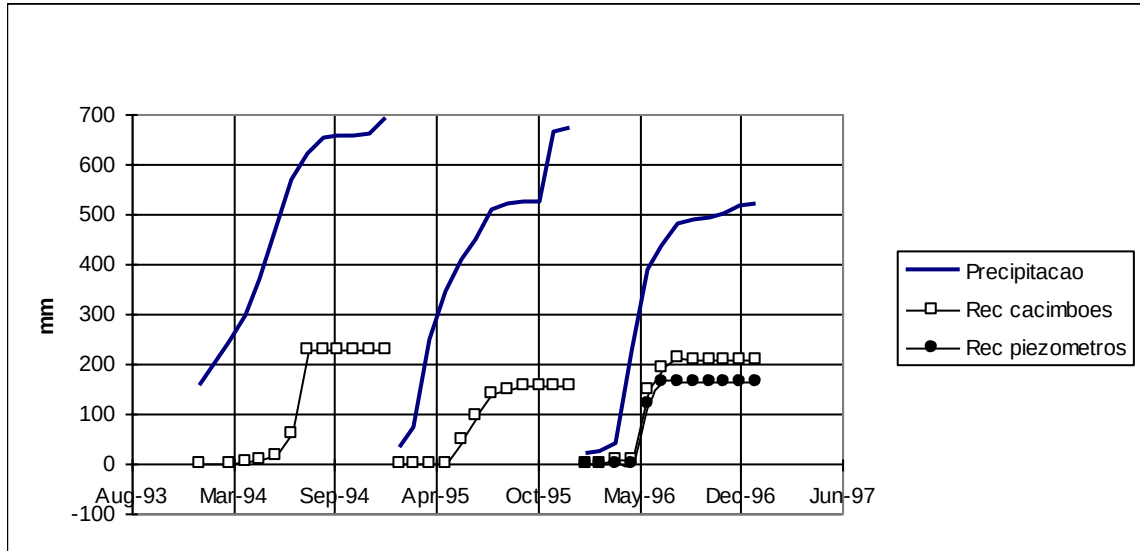


Figura 7- Precipitação e recarga acumuladas anuais.

SIMULAÇÕES DE FLUXO E TRANSPORTE DE SAIS

Utilizando-se dados hidráulicos do solo e do aquífero, dados climáticos locais, simulou-se dinâmica de sais no aluvião para um período de quatro anos. Calendário agrícola sugerido por **CISAGRO(1991)** foi adotado, com cultivo de beterraba de Setembro a Novembro. Para previsão de componentes hídricos e de sais, foi utilizado o modelo PARADIGM (**Mackay, 1993**), desenvolvido na Universidade de Newcastle- Inglaterra, integrado a um modelo simplificado, discutido por **Montenegro (1997b)** e por **Montenegro e Montenegro(1998)**. A figura 8 apresenta a dinâmica de sais simulada por trimestre, para um período de quatro anos. Durante a estação chuvosa (períodos 2, 6, 10 e 14), grandes quantidades de sais são lixiviadas para a zona saturada. Em particular, a transferência de massa por lixiviação sob os lotes irrigados é maior que o total de sais removidos das águas subterrâneas por bombeamento. Por outro lado, durante os períodos secos onde a irrigação se realiza (períodos 4, 8, 12 e 16), a perda capilar domina nos lotes não-irrigados, e parte dos sais bombeados e aplicados nas áreas irrigadas permanece na zona não-saturada, até o próximo período chuvoso.

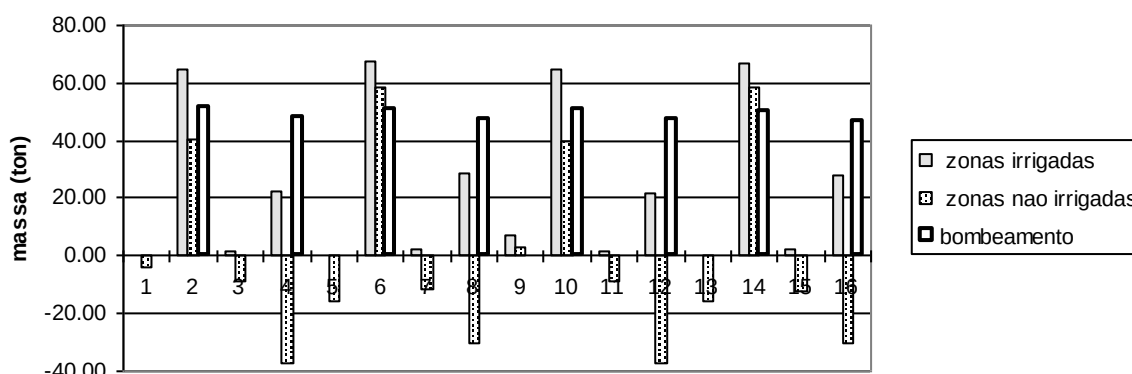


Figura 8- Transferência de massa entre a zona saturada e não-saturada, simulada por trimestre.

CONCLUSÕES:

Conforme discutido, o reservatório aluvionar em estudo apresenta alto potencial em captar e armazenar a água da chuva. Estimativa média para os anos de 1994 a 1996 indicam que, para um total de cerca de 670mm precipitados no ano, aproximadamente 180 mm foram armazenados no aluvião. Estas recargas dependem das precipitações atual e precedente, e lixiviam os sais da zona radicular, que são evacuados através da circulação subterrânea. Embora baseado em série hidrológica curta e a nível mensal, este trabalho permite avaliação de totais armazenados no aluvião, anualmente, a partir das lâminas pluviométricas.

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A Simulation Model of Flood Runoff Utilization in Taiwan

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Abstract

Watershed data are being gathered in Taiwan that includes soil, topography, hydrology, and land use. These information along with the AGNPS model are used to assess watershed conditions and objectively evaluate storm-related generation and transport of non-point source pollution. The main objective of this pilot study is to simulate storm water collection using retention ponds and infiltration enhancement through tree planting. Runoff volume results from various storm sizes may provide adequate information for a follow-up on-site study to optimize flood runoff utilization in Taiwan.

INTRODUCTION

About two-thirds of the island of Taiwan is covered with rugged mountains. The central mountain range runs from North to South. Torrential typhoon rains, steep topography, young and weak geologic formations, and erodible soils are unfavorable natural factors contributing to rapid rates of geologic erosion and runoff. In addition to these natural conditions, population pressure, diversified cropping, small size of individual farms, abusive cultivation on steep slopeland, and socio-economic pressure for more land have accelerated the rate of soil erosion and runoff causing irreversible damages. A detailed assessment of the natural environment along with accurate estimation of the potential erosion and runoff hazard would reduce major on-site and off-site damages.

Many erosion and runoff models have been developed for predicting fluvial soil erosion, runoff and sediment yield. The "AGNPS" (Agricultural Non-Point Source Pollution) model has the capabilities of evaluating non-point source pollution and predicting site-specific sedimentation within a catchment. With proper modifications of the Universal Soil Loss Equation (USLE) factors, excellent agreements between the simulated and measured sediment yields have been obtained for a few reservoir watersheds in Taiwan (Lo, 1995).

The objective of this study is to integrate the powerful tools of GIS and AGNPS, to simulate soil erosion, runoff and sediment yield resulting from various storm sizes, and to optimize the design of storm runoff utilization in the Shuili River Basin, Taiwan.

AGNPS MODEL

The AGNPS model was developed by the USDA's Agricultural Research Service in co-operation with the Minnesota Pollution Control Agency and the Soil Conservation Service (Young et al., 1987). The model subdivides the catchment watershed into uniform grid squares called "cells". Potential pollutants are routed through cells in a stepwise manner, proceeding from the headwaters of the watershed to the outlet. This allows flow as well as water quality parameters to be examined at any point. All characteristics of the watershed are expressed at the cell level.

AGNPS is an event-based model. The basic model components include

hydrology, erosion, and sediment and chemical transport. In the hydrology component, runoff volume and peak concentrated flow are calculated. The erosion portion computes total upland erosion, total channel erosion, and a breakdown of these sources into five particle size classes (clay, silt, sand, small aggregates, and large aggregates). Upland erosion is routed through the watershed. Sediment transport is also calculated for the five particle classes as well as the total. The chemical transport portion is separated into one part handling soluble pollutants and another part handling sediment-attached pollutants.

DESCRIPTION OF STUDY AREA

The Shuili River is located in Nantou County (Figure 1). It is one of the tributaries of the Choshui River. There are two sub-watersheds within the Shuili River Basin, namely Mingtan and Minghu. The total area is about 57 km². The prevailing slope of this watershed is towards the south, with many undulating streams and hills, as well as high mountains. The average annual temperature is around 19.5°C, higher during August and lower in January. The average annual rainfall is about 2,400 mm. Major rainfall comes between April and September. December and January are the driest months.

Most land within the watershed is government-owned (75%). About 20% are privately owned land. The remaining is owned by the Land Bank. Land use in the study area often differs largely as a result of variability in topographic setting, soil property, climate, and the farmers' cultural preference. About 69% of the land area are covered with forest. Betel nut farms comprise about 23% of the watershed area. Other land use includes tea, orchard, rice paddy, and other crops.

STUDY METHODS

The ARC/INFO GIS computer software was employed to process and analyze the necessary input data. The ARC/INFO software is preferred over the others because of its ability to accept, store, manage, retrieve, and display both raster and vector data types, as well as its ability to convert from one form to the other.

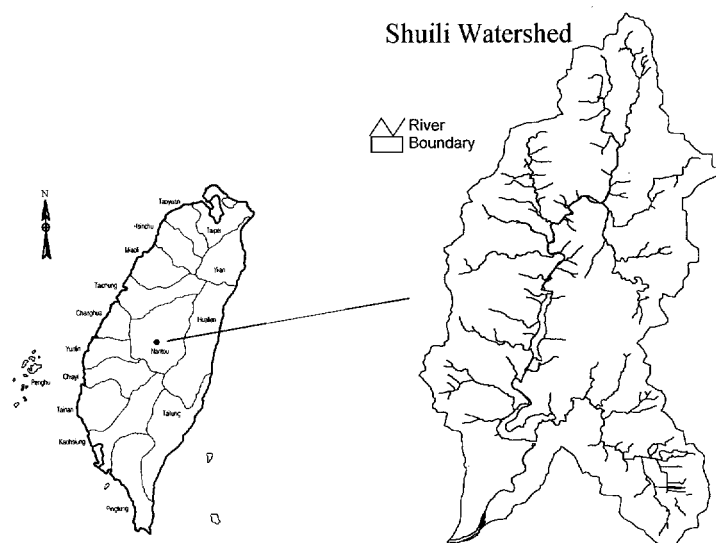


Figure 1. Location map of the Shuili River Basin.

Extremely accurate digitized vector data were first converted to raster form for direct input and creation of AGNPS model data file. Data layers consist of:

1. The Ministry of the Interior 1/25,000 topographic maps,
2. The Central Geologic Survey Institute 1/50,000 geologic maps, and
3. The Soil and Water Conservation Bureau 1/25,000 soil maps.

The available natural resources theme maps for the study area include climate, hydrology, geology, soil, elevation, slope steepness, aspect, land use, and vegetation.

To form the input data file needed to operate the model, the Shuili River Basin was first divided into 679 uniform cells. Each cell occupied approximately 9 ha in area. The drainage direction of each cell, defined as the direction of flow leaving the cell, was estimated based on its shape and topographic setting.

RESULTS AND DISCUSSIONS

Model Output

The erosion and runoff potential of the Shuili River Basin was first determined with a rainstorm of 200 mm and a rainfall erosivity index of 80. The soil erosion at the basin outlet (cell no. 677) is estimated to be about 1.25 t/ha. The sediment yield is about 509.2 t. The total runoff volume is about 87 mm. Among all the cells, the highest values for runoff, erosion, and sediment are 200 mm, 20.6 t/ha, and 1305.8 t, respectively. The lowest values for runoff, erosion, and sediment are 2.8 mm, 0.0 t/ha, and 0.0 t, respectively. Erosion vulnerable area is located in an area with steep topography, poor surface cover, and intensely cultivated farmland. The high sediment yielding area is concentrated at or near the stream channel. Therefore, high priority countermeasures should be provided for these cells. Timely remedial works may prevent sediment removal and erosion problems, further enhancing effective watershed management policies and farm development plans.

B. Selection of Collection Sites

Storm runoff water can be collected in a trench dug in the ground or stored in a small retention pond. Such a system can open up new prospects for land and water management. Rainwater collected can be used for irrigation, livestock husbandry, aquaculture, recreation, and reclamation of wasteland and/or introduction of high yielding cash crops. The collection and utilization of runoff may increase the availability of water resources. It also provides other indirect benefits that include depressing flood peaks, diminishing soil erosion, providing large sediment storage space, and improving the operation of reservoirs and channels.

The ideal siting of dugouts and farm ponds should satisfy the following design criteria: (1) upper reaches of the watershed; (2) maximum runoff interception; (3) minimum sediment load. Therefore, the drainage pattern of the watershed (Figure 2), in addition to the runoff and sediment analyses provided by the AGNPS model for each cell should be adequate in determining the best locations to construct dugouts and farm ponds.

A total of 12 sites were selected. They are located at cell number 39, 68, 113, 193, 273, 354, 386, 401, 440, 499, 644, and 674. Most are situated at the upper northeastern and southwestern parts of the watershed. The surface runoff pattern at these sites is characterized by runoff volume entering the collecting cell from three or more above cells, and thus, greatly inflated the total collected runoff volume. However, further examination of the sediment load at the receiving cell indicates that out of 5 cells (67, 131, 440, 640, and 674) while runoff volume is great, at the same time the sediment delivered is also large. This will adversely affect the rainwater storage capacity of the dugouts and farm ponds. The prevailing land use type at these

5 cells is betel nut farming. As a remedial measure, an attempt was made to convert this land use type to natural forest through model simulation. This was accomplished by modifying the current curve number, cover and management factor, and surface condition constant parameters to the appropriate values for forestland use. Although the generated runoff volume decreases only about 52 to 58% with forest conversion, the sediment reduction is quite significant, reaching above 95%. This result indicates that in order to optimize rainwater utilization using dugout and farm pond collection, proper land use and soil conservation measure are necessary to ensure maximum runoff interception and minimum sediment load.

C. Runoff Collection with Different Storm Sizes

Calculation of total runoff collected consists of one part runoff entering the receiving cell from above and another part from within the cell. Based on this computation procedure, total runoff volume collected with a 200-mm storm for the 12

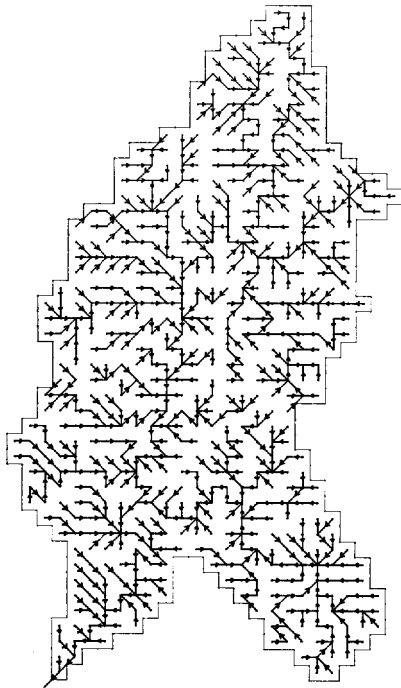


Figure 2. Drainage pattern of the watershed.

selected sites are listed in Table 1. The volume ranges from 20,060 to 47,352 m³, which is quite substantial considering it is coming from one storm only. However, a storm of this magnitude occurs only once or twice a year in this area, according to the long-term climatic statistics. The sediment generated is also listed in Table 1. The total sediment load (above + within) may amount to as much as 13.2 t. This shows that, on one hand, storm runoff collection at the upper watershed may indeed reduce a large amount of sediment delivered downstream. But, on the other hand, adequate and effective soil conservation measures such as in-situ check dam and stilling basin may be needed to store this large sediment load, in order to maximize rainwater collection in dugouts and farm ponds.

Table 1. Total runoff collected and sediment generated with a 200-mm storm.

Cell number	Runoff collected (m ³)	Sediment generated (t)	
		Above	Within

39	23624.1	6.18	4.63
68	23624.1	4.84	2.78
113	47352.4	7.62	0.03
193	23454.4	5.47	3.71
273	20059.7	6.81	3.71
354	20059.7	6.86	6.49
386	28578.2	4.94	2.04
401	27255.1	3.56	3.71
440	27255.1	1.87	7.42
499	20059.7	4.48	3.71
644	20059.7	4.60	4.08
674	27255.1	2.81	4.08

The model is also used repeatedly to simulate runoff output for other smaller size storms. With a 100-mm storm, the runoff collected at the selected sites range from 3,789 to 14,507 m³. The total sediment load becomes much smaller. The highest load occurs also in cell number 354 with a value of about 5.8 t. The total runoff collected ranges from 74 to 3,707 m³ with a small rainstorm of only 50 mm. The total sediment generated is less than 2 t. On the basis of a drainage area of over 9 ha, this sedimentation rate is not significantly high at all.

According to long-term climatic statistics, Shuili River Basin, on the average, will receive about two 200-mm storms, five 100-mm storms, and twenty 50-mm storms a year. Based on these statistics and ignoring evaporation and seepage loss, the annual runoff volume collected at the 12 selected sites will range between 60,550 and 241,394 m³. This large volume of water source should provide a wide range of benefits starting from the basic water supply for irrigation purposes to the far-fledged water supply for recreational purposes.

CONCLUSIONS

In a rainfall-abundant watershed with steep terrain, torrential rainstorm may result in accelerated soil erosion and runoff causing irreversible damages downstream. Flood runoff collection should increase the availability of water resources and include other side-benefits such as flood peak depression, soil erosion reduction, sediment storage, reservoir and channel operation improvement.

The AGNPS model is a computer simulation model capable of evaluating non-point source pollution at any point within a watershed. It is also capable of identifying areas within the watershed with high runoff and erosion. This provides a useful guide for selecting the best sites to install dugouts and farm ponds. The model output can be used to compute the total rainwater collected from each storm at the selected sites. Runoff volume results from various storm sizes simulation may provide adequate information for a follow-up on-site study to optimize flood runoff utilization in Taiwan.

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Aplicação Prática da Pedologia Para Estimar o Escoamento Superficial de Água em Regiões Semi-áridas

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Resumo

A avaliação do escoamento das bacias hidrográficas através dos métodos tradicionais torna-se bastante difícil, face aos elevados custos e ao longo período necessário à sua realização. Este trabalho apresenta um método prático e seguro, elaborado a partir do cálculo do L_{600} de uma bacia hidrográfica, considerando o comportamento hidrológico dos solos da zona semi-árida do Nordeste do Brasil. O coeficiente L_{600} corresponde a uma lâmina fictícia que escoaria sobre uma superfície ocupada por uma classe de solo ou por uma unidade de mapeamento, que recebesse uma precipitação média anual de 600 mm, na zona climática do sertão. O método ora apresentado, fornece rapidamente uma avaliação dos recursos de água das pequenas bacias hidrográficas nas zonas semi-áridas do Nordeste com precipitações médias inferiores a 1.000mm. Seu princípio consiste em determinar a lâmina escoada padrão (L_{600}) a partir das classes de solos ou unidades de mapeamento que ocorrem na bacia hidrográfica de drenagem. Foram tabelados os valores centrais propostos para a L_{600} padrão das classes de solo de maior representatividade dessa Região, considerando-se as condições naturais médias. O cálculo da (L_{600}) entretanto, exige correções quanto a influência da cobertura vegetal, de outros açudes a montante do local de medição do escoamento e da influência de fatores como a geologia do subsolo, o clima e o relevo. A avaliação dos valores de correção devem ser definidas por pedólogos experientes na aplicação desta metodologia, haja visto que, o valor central da L_{600} dos Planossolos que foi fixado em 70mm, pode variar de 10 a 125mm considerando a variação da espessura de seu horizonte superficial (A). Essa diminuição é também agravada quando os Planossolos mais espessos e susceptíveis de maior interceptação de água, encontram-se na parte mais baixa da toposequência.

Introdução

A exploração dos recursos hídricos superficiais na zona semi-árida do Nordeste do Brasil (que alcança cerca de 900 mil km²) manifestou-se desde a colonização, tornando-se mais intensa a partir do meados deste século. Caracterizava-se pela implantação de sistemas de captação de água (barragens, açudes, barreiros, etc.) com a finalidade de atender, exclusivamente, o abastecimento d'água do rebanho e da população. A tomada de decisão para a localização desses sistemas, geralmente, levava em consideração um local aparentemente adequado para a sua construção, sem levar em conta, com o devido conhecimento, os recursos naturais envolvidos, tais como geologia, solo, relevo e clima; o que ocasionou o fracasso de vários empreendimentos.

Com base nas características próprias de cada solo e de outros fatores do ambiente, dispõe-se de importantes definições para um grande número de pequenas bacias hidrográficas.

O conhecimento do escoamento das bacias hidrográficas através dos métodos tradicionais de monitoramento torna-se bastante difícil, face aos elevados custos e ao longo período necessário à realização dos estudos que devem ser efetuados antes da instalação de qualquer obra para contenção de água, como barragens e açudes.

Portanto, revela-se como oportuna a praticidade da utilização de métodos simples e seguros que avaliem as características hidrológicas e que considerem os aspectos ambientais (solo, relevo, clima, vegetação, etc.).

Cadier (1984) propôs uma metodologia designada “cálculo do L_{600} de uma Bacia Hidrográfica”, para avaliação do escoamento superficial. Tal metodologia foi desenvolvida a partir de resultados obtidos através dos estudos de 30 bacias hidrográficas representativas da região semi-árida, em vários estados do Nordeste. O coeficiente L_{600} corresponde a uma lâmina fictícia que escoaria, sobre uma superfície ocupada por uma classe de solo ou por uma unidade de mapeamento, que recebesse uma precipitação média anual de 600 mm, na zona climática do sertão.

Uma nova proposta de estimativa do escoamento superficial em bacias hidrográficas, tomando-se por base a pedologia da bacia hidrográfica foi apresentada por Silva (1989).

O presente trabalho desenvolve um método prático e objetivo, elaborado a partir do cálculo do L_{600} de uma Bacia Hidrográfica, considerando o comportamento hidrólogo dos solos da zona semi-árida nordestina.

Tomou por base os aspectos pedoclimáticos verificados nos Levantamentos Exploratório-Reconhecimento de Solos dos Estados da Região Nordeste (Jacomine *et al*, 1971, 1972, 1973, 1975, 1976, 1977, 1979, 1986, 1986b; Silva *et al*, 1989).

Nos estudos desta proposta, foram correlacionados dados de lâminas de água escoadas, medidas em 15 bacias hidrográficas com superfície superior a 100 km², com os coeficientes de escoamento atribuídos para cada classe de solo e relevo. Tais coeficientes foram obtidos através de uma análise dos dados de bacias representativas e experimentais da SUDENE e de estudos em parcelas de erosão. A correlação entre esses dados foi altamente significativa ($r = 0,96$) o que mostra que essa técnica, é bastante promissora na classificação hidropedológica de bacias com superfície superior a 100 km².

O método ora apresentado permite fornecer rapidamente uma avaliação dos recursos de água das pequenas bacias hidrográficas nas zonas semi-áridas do Nordeste, com precipitações médias inferiores a 1.000 mm. Seu princípio consiste em determinar a lâmina escoada padrão (L_{600}) a partir das Classes de Solos (CS) ou Unidades de Mapeamento (UMP) que ocorrem na Bacia Hidrográfica de Drenagem (BHD).

A precisão dos resultados fornecidos por este método indireto é, certamente, inferior a de um estudo hidrólogo clássico e completo da bacia. Entretanto, deve-se levar em consideração o custo e a demanda de tempo (vários anos de observações) que o estudo clássico exige; especialmente quando necessitamos de informações em tempo hábil para pequenos aproveitamentos hidráulicos.

Os levantamentos de solos indicam, especialmente, a distribuição das classes de solos, em bases cartográficas, onde também são localizados acidentes geográficos, como a rede de drenagem, estradas e zonas urbanas. As manchas que aparecem nos mapas de solos, denominadas unidades de mapeamento, raramente tem limites rígidos. É muito freqüente que uma unidade de solo passe gradualmente para outra, sendo mais comum haver uma faixa do que uma linha de transição abrupta. Por outro lado, em alguns casos, não é possível a delimitação nos mapas, de manchas constituídas de uma única classe, já que os solos ocorrem em um padrão tão complexo, que se torna praticamente impossível separá-los nos mapas. Nesses casos, a unidade de mapeamento é constituída de uma associação de classes de solos. Nos relatórios são apresentadas as descrições das classes de solos, dando também indicação sobre a posição topográfica que cada componente ocupa na paisagem, o uso agrícola e a proporção de cada componente.

A base da presente classificação hidropedológica usa o solo como fator preponderante. As características hidrodinâmicas dos solos constituem o principal fator usado na classificação das bacias hidrográficas de drenagem. A zona semi-árida é especialmente apropriada para aplicação

dessa classificação pelas seguintes razões: a vegetação menos densa permite um comportamento mais direto no escoamento e na infiltração da água; e todos os estados do Nordeste dispõem de mapas pedológicos, cujas escalas variam entre 1:400.000 e 1:1.000.000, além de outros levantamentos mais pormenorizados. A Tabela 1 relaciona as lâminas escoadas de todas as classes de solos dos Relatórios dos Levantamentos Exploratórios de Solos de cada Estado do Nordeste.

Dentre as características intrínsecas dos solos que permitem estabelecer distinções entre componentes da mesma classe, alterando o escoamento superficial, destacam-se: profundidade, cor, mosqueado (manchas de cores diferentes da coloração principal), textura, estrutura, consistência, transição entre horizontes, presença de camadas de impedimento nos perfis, adensamento, coesão, tipo de argila, presença de sais, fertilidade natural e tipo de horizonte superficial. Outros fatores, como pedregosidade superficial e interna, rochiosidade, erosão, encrostamento, etc. definem alterações na infiltração de água no solo e, portanto, no escoamento superficial.

Na zona semi-árida, os solos rasos e pouco profundos - mais susceptíveis de erosão - permitem um maior escoamento superficial. Também elevações com exposição de afloramentos rochosos, bastante comuns na área, oferecem um escoamento quase total (Fotos 1, 2, 3 e 4).

Neste trabalho, para o cálculo do escoamento superficial utilizou-se o método proposto por Cadier (1984) ou método L_{600} para medição do escoamento superficial em bacias hidrográficas.

Para aplicação desse método, torna-se necessário reunir a documentação cartográfica relativa a bacia hidrográfica de drenagem em estudo e ao local de medição (mapas topográficos, hidrogeológicos, pedológicos, geológicos, de isoietas, fotografias aéreas, imagens de satélite). São ainda necessários resultados de análises hidroquímicas dos solos e da água visando avaliar os riscos de salinização. É indispensável a avaliação do total anual das precipitações na área da bacia hidrográfica de drenagem.

No campo, torna-se necessário: a) confirmar o local previsto para o estudo e plotá-lo nos mapas e nas fotografias aéreas, especialmente quando a bacia em estudo for muito pequena; b) confirmar informações sobre solo, drenagem, vegetação, uso atual, etc., para aplicação dos eventuais fatores corretivos da classificação; c) inspecionar açudes situados a montante do local previsto para medição, avaliar suas dimensões e os riscos de arrombamento; e d) avaliar a viabilidade de construção de açudes e sua futura utilização.

TABELA 1 - Valores do Coeficiente L_{600} dos solos da Região Nordeste Semi-Árido.

Classe de Solo (CS)	Características Adicionais	L_{600} Padrão (mm)
Bruno Não Cálcico (NC)	Típico	37
	Vértico ou Planossólico	25
Afloramentos de Rocha (AR)		90
Solos Litólicos (R)		37
Brunizem (B)		37
Redzina (RZ)		37
Podzólicos (PE, PV e PA)	Textura média a arenosa ou média ou textura média a arenosa plântico	15
	Textura média a argilosa ou média plântico	25
	Textura média a argilosa plântico	30
	Textura argilosa ou raso	37
	Erodido (Truncado)	60

	Solódico	125
Podzólico Acinzentado (PZ)		25
Terra Roxa (TR)	Típica	25
	Erodido (Truncado)	60
Vertissolo (V)		25
Solos Aluviais (A)	textura arenosa a média	10
	Textura média ou indiscriminada ou textura média a argilosa	25
	Textura argilosa	70
	Solódico	125
Cambissolo (C)	Textura média a arenosa	5
	Textura média a argilosa ou média	15
	Textura argilosa ou raso	37
	Erodido raso ou Textura argilosa erodido	60
	Vértico	25
Solonetz Solodizado (SS)		125
Laterita Hidromórfica (LH)		125
Solonchak (SK)		125
Solos Halomórficos (SH)		125
Planossolo (PL)	Típico (PL)	25
	Solódico Típico (PLs)	70
	Solódico com A espesso (PLs)	15
Plintossolo (PT)	Típico	50
	Erodido (Truncado)	70
	Solódico	125
Gleissolo (G)	Tipico	25
	Com impedimento	70
Areia Quartzosa (AQ)		0
Regossolo (RE)	Típico	3
	Com fragipã	5
Latossolo (LR, LE, LV e LA)	Textura média	5
	Textura média a argilosa	10
	Textura argilosa	15
Dunas (D)		0



Para avaliação da superfície de uma bacia hidrográfica de drenagem (BHD) são necessários os procedimentos descritos abaixo.

- 1) Definir o local do estudo, definir a linha de contorno da BHD e calcular a superfície (S). Para áreas com menos de 5 km^2 , utiliza-se fotografias aéreas ou mapa preciso (escala 1:50.000 ou 1:25.000). Áreas com 5 a 25 km^2 , utiliza-se mapas ou fotografias, conforme a nitidez do relevo nos documentos disponíveis. Para áreas com mais de 25 km^2 pode-se usar mapas planialtimétricos na escala de 1:100.000, cuja precisão é suficiente, em todos os casos.
- 2) Localizar os açudes existentes dentro da BHD e avaliar suas respectivas áreas de drenagem.
- 3) Calcular a superfície ativa (S_a) da bacia estudada, que corresponde à superfície total (S), diminuída da superfície controlada pelos açudes. A avaliação dessa superfície é fundamental. Ela permitirá o cálculo dos volumes escoados a partir das lâminas escoadas.

A classificação hidrológica das bacias hidrográficas de cada uma das unidades de solo existentes na BHD, se constitui, juntamente com a avaliação da superfície de drenagem e das precipitações, os três elementos fundamentais que permitem o cálculo dos volumes hídricos disponíveis. A classificação é feita, estimando-se o valor central do L_{600} padrão de cada classe de solos (CS) ou da unidade de mapeamento (UMP).

Os valores centrais propostos para cada L_{600} padrão das classes de solo mais representativos da Região Nordeste (Tabela 1), foram determinados considerando-se as condições médias existentes atualmente no sertão nordestino, para os principais fatores que também influenciam o escoamento, tais como cobertura vegetal, número de açudes, relevo e a densidade de drenagem.

A Tabela 1 pode ser melhor utilizada quando se dispõe de levantamentos de solos mais detalhados onde os solos foram mapeados sob a forma de classes simples (CS) e não de unidades de mapeamento (UMP), proporcionando assim, maior segurança dos limites e dos tipos de solos que ocorrem numa determinada bacia. Para Bacias Hidrográficas de Drenagem de superfície inferior a 10 km² é sempre necessário determinar a proporção das classes de solo efetivamente presentes.

O cálculo da L₆₀₀ da bacia é feito utilizando uma das seguintes equações:

$$L_{600} \text{ da BHD} = \sum (L_{600} \text{ de cada CS} \times \% \text{ de ocorrência da CS})$$

$$L_{600} \text{ da BHD} = \sum (L_{600} \text{ de cada UMP} \times \% \text{ de ocorrência da UMP})$$

De posse da L₆₀₀ padrão, deve-se proceder correções necessárias devido a influência da cobertura vegetal, de outros açudes a montante do local de medição do escoamento, e de outros fatores tais como natureza geológica do subsolo, influência do clima e do relevo. As correções da L₆₀₀ padrão só deverão ser realizadas quando forem detectadas anomalias nos fatores corretivos, em função de critérios de apreciação mais subjetivos que na etapa anterior e requererão uma visita ao campo e uma certa experiência para a avaliação do peso real a ser atribuído a cada fator corretivo.

Os fatores de correção para o estado da cobertura vegetal (CV), devem-se aos estudos realizados por Silva et al. (1989), e estudos realizados nas Bacias Experimentais de Sumé/PB e Tauá/CE. A tabela 2 resume os fatores de correção da L₆₀₀ quanto a cobertura vegetal.

Tabela 2 - Fatores de correção (CV) da L₆₀₀ quanto a cobertura vegetal

Estado da cobertura vegetal	Fator de correção (CV)
Extremamente conservado	de 0,50 a (0,75)
Bem conservado	de 0,75 a (0,88)
Ocupação normal	1,00
Muito degradado	de 1,25 a (1,50)
Extremamente degradado	de (1,50) a 2,00

Valores entre parênteses são os mais indicados.

Os valores de L₆₀₀ propostos foram estabelecidos para as condições atuais das grandes bacias estudadas, onde pode-se considerar que os açudes existentes a montante já controlam, em média, 30 a 50% da superfície das bacias, com um volume total de armazenamento da ordem de 25 a 50% do volume natural médio escoado. Nesse caso, não se deve efetuar correções. A tabela 3 apresenta os valores de correção (CA), obtidos em estudos realizados em bacias hidrográficas na Região Nordeste.

Tabela 3 - Fatores de correção (CA) da L₆₀₀ quanto a influência de açudes a montante

Densidade de açudes	Fator de correção (ca)
Muito forte, superior a 0,5 açudes/km ² * ou presença de açude muito grande	< 1,00
Normal **	1,00
Nula	1,50

* Necessidade de realizar um estudo específico

** Volume total dos açudes da ordem de 40% do volume anual escoado; densidade entre 0,25 e 0,50 açude/km².

É imperiosa a necessidade de multiplicar por 1,50 as lâminas L(P) calculadas para pequenas bacias perto das cabeceiras e desprovidas de açudes.

As correções no cálculo do L_{600} por classe de solo, devido a fatores de natureza geológica do subsolo, influência do clima e do relevo, só deverão ser realizadas no caso de anomalias visíveis ou em solos susceptíveis a muitas variações. A avaliação dos valores de correção devem ser definidas por pedólogos experientes na aplicação desta metodologia.

O valor da lâmina L_{600} corrigida (em mm) de toda BHD é obtida através da seguinte equação:

$$L_{600} \text{ corrigida} = L_{600} \text{ da Bacia} \times CV \times CA \times CL$$

De posse da L_{600} corrigida, aplica-se a equação proposta por Cadier (1984) para o cálculo do volume escoado.

A definição de uma política de armazenamento de água na zona semi-árida do Nordeste é um fator sócio-econômico da maior relevância. A definição da L_{600} em solos de bacias hidrográficas representa um passo importante para o planejamento do armazenamento de água no campo.

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