Hydrologic Model of the Paracatu River Basin: calibration and validation

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Abstract

The Paracatu River Basin (PRB), with a drainage area of 45,600 km^2, is a tributary of the São Francisco River. The PRB is responsible for 24% of the flow of the São Francisco, with an average discharge between 200 and 1,000 m^3/s. The PRB land use is mainly savanna, which has decreased significantly during the last 30 years. Currently it is necessary to understand the impact of climate and land use change on PRB water resources. The objective of this study was to develop, calibrate and validate a hydrologic simulation model for the PRB. The model was developed using the SWAT (Soil Water Assessment Tool) hydrological model. SWAT is a physically based model, of which the major components are: climate, hydrology, soil properties and land use. Discharge data from the last gauge station before the outlet of the PRB (Porto Alegre station) was used. Calibration was performed manually, using daily gauged discharge data for the years of 1984 and 1985. The calibration result showed that there is a good agreement (NSE=0.66) between the simulated and gauged daily flows. Validation results for the years 1986 and 1987 indicated that the model has strong predictive capability (NSE=0.65), showing that the model parameters represent the processes occurring in the watershed and may be used to predict watershed response.

Index terms: water resources, Nash Sutcliffe, SWAT

Modelagem Hidrológica da Bacia do Rio Paracatu: calibração e validação

Resumo

A Bacia do Rio Paracatu é um afluente do Rio São Francisco com uma área total de drenagem de 45.600 km^2. O Rio Paracatu é responsável por 24% da vazão do rio São Francisco, com uma descarga média variando entre 200 m^3/s e 1.000 m^3/s. O uso do solo nessa bacia é predominantemente Cerrado, cuja área diminuiu significativamente nos últimos 30 anos. Atualmente faz-se necessário entender melhor quais serão os impactos nos recursos hídricos advindos das mudanças climáticas e no uso da terra nessa bacia. Esse artigo objetivou preparar, calibrar e validar um modelo de simulação hidrológica para simulação das vazões do rio Paracatu. Para isto, utilizou-se o modelo hidrológico SWAT, que é um modelo físico e distribuído, sendo o clima, a hidrologia, as propriedades do solo e de uso da terra seus principais componentes. Os dados de vazão da estação de Porto Alegre, última estação de medição antes do exutório da bacia, foram utilizados no estudo. A calibração foi feita manualmente utilizando dados diários de vazão para os anos de 1984 e 1985. A validação foi realizada para os anos de 1986 e 1987. O resultado da calibração mostrou que existe uma boa aderência (NSE = 0,66) entre vazões simuladas e medidas. A validação, com NSE = 0,65, indicou que o modelo tem boa capacidade de previsão, indicando que os parâmetros do modelo representam os processos que ocorrem na bacia e pode ser usado para prever a resposta da bacia hidrográfica.

Termos para indexação: recursos hídricos, Nash Sutcliffe, SWAT.

Introduction

Brazil holds 12% of world's fresh water. Irrigated agriculture is, like in most of the countries, the largest water user with nearly 70% of Brazilians water use (BRAGA et al., 2009). If the irrigated areas will expand, this water demand can get even higher and lead to conflicts with other water users. The reduction of precipitation can lead to water shortages during summer and thereby affect crops. Therefore, it is important to get a good picture of available water resources and the impacts that climate and land use change will have on them. This is also of great importance for the Paracatu River Basin (PRB), since irrigated agriculture is an important activity and will increase in future. Furthermore some tributaries of the PRB are already in an alert situation, looking at the ratio between water demand and water availability (BRAGA et al., 2009). In some parts of the PRB conflicts about water use have already occurred, between different users of irrigation systems and also between them and other water users (BILIBIO et al., 2011). Therefore a determination of the current surface water availability of the PRB is necessary. The objective of this study was to develop, calibrate and validate a hydrologic simulation model for the PRB.

Material and Methods

Study area

The Paracatu River Basin (PRB) is located in the Medium São-Francisco region of Brazil. It drains areas from the states of Minas Geiras, Goias and Federal District with a total drainage area of 45,600 km^2. The Paracatu River Basin is the second largest sub-basin of the São-Francisco River Basin. It is one of the most important tributaries of the São-Francisco River, being responsible for 24% of the flow. Currently, the water conflicts in the PRB have the tendency to increase.

Soil water assessment tool – SWAT

SWAT (NEITSCH et al., 2011) was the model used in this study. It can be used for different scales. Furthermore different hydrological processes can be simulated within SWAT, as well as the impact of climate and land use changes and different land management strategies. Within this research ArcSWAT was used, a graphical user interface of the SWAT model within ArcGIS. The major model components of SWAT are climate, hydrology, soil properties and land use.

Calibration and validation

To assess the performance of model calibration the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and the RMSE-observations standard deviation ratio (RSR) goodness-of-fit statistics methods were used. According to Moriasi et al. (2007) a model can be called satisfactory if the NSE > 0.5, the RSR < 0.7 and the PBIAS < 25%. The number of parameters SWAT needs as input is large, which makes the model parametrization and calibration more complicated. There are different approaches that can be used to calibrate SWAT model, like manual calibration methods, automated methods and SWAT-CUP which combines automated and manually calibration in one decision tool (ARNOLD et al., 2012). In this research, the model was calibrated manually, by using the "manual calibration helper" (WINCHELL et al., 2010) and the "SWAT Check" (WHITE et al., 2014). First all parameters inside the manual calibration were analyzed, based on their relevance for the research. Parameters regarding snow, water quality, etc. were left out in the calibration process. The remaining parameters and their definitions can be found in Table 1. The second step of the calibration process was a sensitivity analysis. Therefore, the sensitivity was tested with changing one parameter at the time. After changing each parameter once, it was analyzed which parameters had the biggest impact on the results. The third step was the calibration process itself. The calibration process consisted of several steps, which were repeated several times, until the result became acceptable. If the NSE became higher after the run, the new parameter value was adopted, if the result became worse, the parameter was set to the value it had before. SWAT was calibrated using historical streamflow data for 2 years (1984-1985). This period was chosen because for these years discharge data is available without gaps. The model was run for 8 year period of 1980-1987 but the first four years (1980-1983) were used for SWAT initialization and data for 1984-1985 was used for calibration purposes. Streamflow data of two years from 1986 to 1987 were used for validation. The three statistical model performance measures used in calibration procedure were also used to validate the model.

Table 1. Calibration parameters and their values before and after calibration.

Parameter	Description	Unit	Min and max parameter value suggested by Arnold et al.(2012)		Parameter value before (b) and after (a) calibration	
			Min.	Max.	b	a
SURLAG	Surface runoff lag time	days	1	24	4	4
ALPHA_BF	Baseflow alpha factor for deep aquifer	1/days	0	1	0.048	0.55
GW_DELAY	Groundwater delay	days	0	500	31	150
GW_REVAP	Groundwater "revap" coefficient	-	0.02	0.2	0.02	0.02
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	mm	0	5000	1000	700
RCHRG_DP	Deep aquifer percolation fraction	mm	0	1	0.05	0.1
REVAPMN	Threshold dept of water in the shallow aquifer for "revap" to occur	-	0	1000	750	750
CANMIX	Maximum canopy storage	-	0	100	0	0
EPCO	Plant uptake compensation factor	m/m	0.01	1	1	1
ESCO	Soil evaporation compensation factor	m	0.01	1	0.95	0.01
SLOPE	Average slope steepness	-	0	0.6	0.006-0.43	0.003-0.21
SLSUBBSN	Average slope length	m	10	150	9-121	9-121
CN2	SCS runoff curve number for moisture condition 2	-	35	98	60-92	45-69
CH_K2	Effective hydraulic conductivity in main channel alluvium	mm/h	0	500	0	0
CH_N2	Manning's "n" value for the main channel	-	0.01	0.3	0.014	0.09
SOL_ALB	Moist soil albedo	-	0	0.25	0.08	0.08
SOL_AWC	Available water capacity of the soil layer	mm/mm	0	1	0.13-0.21	0.13-0.21
SOL_K	Saturated hydraulic conductivity	mm/h	0	2000	100-1686	50-843
SOL_Z	Surface runoff lag time	mm	0	3500	800	3460

Results and Discussion

To calibrate the model nine parameters were changed. The initial values (before calibration) and the final values (after calibration) can be found in Table 1. The parameters indicated in grey were the one which have been changed. The most sensitive parameters within this research were GW_DELAY, GWQMN, RECHARGEDP and SLOPE.

SWAT was manually calibrated and simulated and observed daily streamflow at the Porto Alegre outlet were compared for the calibration (Figure 1A) and the validation (Figure 1B) periods. Minor discrepancies between the observed and simulated stream discharges can be observed. During the calibration period, the NSE on a daily scale was about 0.66, the PBIAS has a value of -26.19 and the RSR has a value of 0.58. Hence, according to the model evaluation guidelines proposed by Moriasi et al. (2007), SWAT fulfills two of the three criteria and simulation was satisfactory for the Paracatu River basin. For the validation run (Figure 1B), the value for the NSE is slightly lower than calibration, NSE = 0.65, the PBIAS = -29.04 and RSR = 0.59, both value slightly higher, but also here two of the three criteria are fulfilled. A range of NSE values has been reported in the literature. For example, Andrade et. al (2013) obtained values of 0.66 (calibration step) and 0.87 (validation step) for simulations of the watershed of the Ribeirão Jaguara River in Minas Gerais State. Simulation results indicate that SWAT represents well the discharge behavior, but overestimates the peak flow during heavy storm events in the Paracatu river basin.

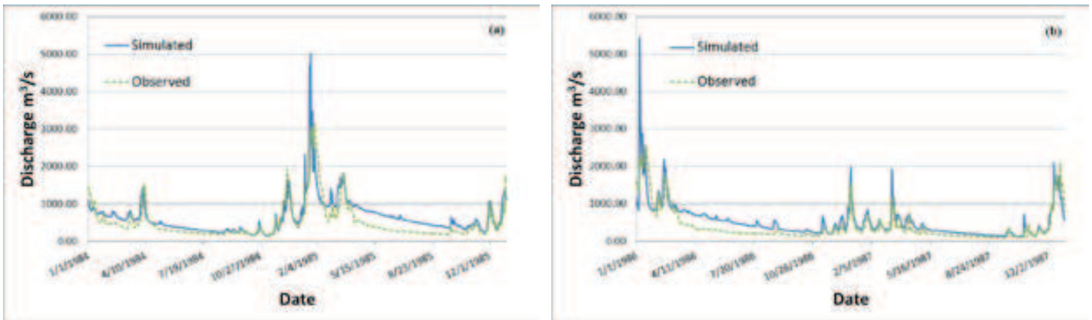

Figure 1. Observed and simulated daily streamflow at the Porto Alegre station watershed outlet during the calibration (a) and the validation (b) periods.

Conclusions

In the calibration procedure, the model provided a good fit between observed and simulated discharge data for the Paracatu river basin, with model performance evaluated as satisfactory.

The model performance for the validation run indicated that the set of parameters identified during the calibration process could satisfactorily represent the hydrological processes in the river basin.

This provides opportunities to evaluate the effect of changes in land use, climate and irrigation management on the Paracatu river discharge.

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