Hydrologic Model of the Upper Preto River Basin: calibration and validation

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Abstract

The Distrito Federal is a region experiencing rapid changes due to population growth and urbanization. Irrigated agriculture is the main water user in the region, with high demands, especially during the dry season when demand among all sectors increases. In addition, climate change is expected to impact the water resources of the DF. Thus, it is important to better understand the hydrology of this region to propose mitigation and adaptation strategies. The objective of this study was to develop, calibrate and validate a hydrologic simulation model for the upper Peto River basin. The model was developed using the SWAT (Soil Water Assessment Tool) hydrological model. The Preto River is an important tributary of Paracatu, which is the main tributary of the São Francisco. The drainage area of the upper Preto river is about 3,300 km^2. At the outlet the river has an average discharge varying between 50 m^3/s and 200 m^3/s. The model was calibrated and validated using observed daily streamflow from the Fazenda Limeira station for the period of 1986 to 1994. The model performed satisfactorily with an NSE=0.73, PBIAS =-9.5% and RSR=0.5 goodness-of-fit between simulated streamflow and observed streamflow for the validation period.

Index terms: hydrological modelling, SWAT, nash sutcliffe, cerrados.

Modelagem Hidrológica do Alto Rio Preto: calibração e validação

Resumo

O Distrito Federal (DF) é uma região que vem experimentando mudanças rápidas devido ao crescimento populacional e urbanização. A agricultura irrigada é a principal usuária nessa região, apresentando demandas elevadas, principalmente durante a estação seca, quando a demanda de todos os setores aumenta. Assim, é importante compreender melhor a hidrologia da região para propor estratégias de mitigação e adaptação. O objetivo deste estudo foi desenvolver, calibrar e validar um modelo de simulação hidrológica para o alto rio Preto. Para isto, utilizou-se o modelo hidrológico SWAT. O rio Preto é um importante tributário do Paracatu, que, por sua vez, é o principal afluente do São Francisco. O alto rio Preto, modelado nesse estudo, tem uma área de drenagem de aproximadamente 3.300 km^2 e possui uma vazão média variando entre 50 m^3/s e 200 m^3/s. O modelo foi calibrado e validado utilizando dados diários de vazão da estação Fazenda Limeira para o período de 1986 a 1984. O modelo apresentou um desempenho satisfatório com NSE=0,73, PBIAS =-9,5% e RSR=0,5 para o período de validação.

Termos para indexação: modelagem hidrológica, SWAT, nash sutcliffe, cerrados.

Introduction

The Distrito Federal (DF) is a region of rapid urbanization and population growth (LORZ et al. 2012). In 1960 the population was ±24 thousand and currently the population is approximately 2.7 million in 2016 and expected to grow to 3.2 million in 2025 (LORZ et al., 2012). This rapid population growth due to urbanization around the DF leads to high water demand, which in this region is reaching the limits of water supply. Irrigated agriculture is the main water user in the region. Moreover climate change in this region is expected to reduce rainfall events, especially during the dry season, and thus reduce water resources (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2014). An important river, delineating the eastern border of the DF is the Preto river. It is important to understand how future land use change and climate change affects this important water resource in this rapidly developing region. Important decision support tools are numerical hydrologic models, which are able to perform scenario analysis to better understand watershed response to these rapid changes. Therefore the objective of this study was to develop, calibrate and validate a hydrologic simulation model for part of the Preto River that borders the DF.

Material and Methods

Study area

The Preto River is a tributary of the Paractu river and flows along the eastern border of the Distrito Federal (DF) southward into the Minas Gerais state. The model was built for an upstream catchment of the Preto River basin, because this part of the basin is mostly influenced by the agriculture in DF. The catchment is part of the Cerrados, Brazil's tropical savannah, which is typified by shrub vegetation and deep red oxisols with a high saturated hydraulic conductivity (DELVAUX; BRAHY, 2016).

Soil water assessment tool – SWAT

The SWAT model is a water balance model based on physical processes, operating at a daily time step. It is designed to predict the impact of environmental changes on water, sediment, and agricultural chemical yields (NEITSCH et al., 2009). The model requires input data about the spatial distribution of land use and soil properties and hydrological and meteorological data. The SWAT model was chosen because it is able to incorporate changes in land use and cover, climate change and it allows for basin delineation at various spatial scales. Moreover it is open source and has a large community of users, resulting from extensive efforts by the developers to make the model easily accessible.

Calibration and validation

The SWAT model incorporates a large amount of physical processes representing the hydrological cycle of a catchment. This results in a large number of input data and parameters, which complicates parameterization and calibration of the model. To overcome this difficulty there are a multitude of options to calibrate the model, such as manual methods, automated numerical methods and combined manual and automated methods, such as the SWAT-CUP tool. In this research a manual method was used assisted by the tools “manual calibration helper” (WINCHELL et al., 2010) and the “SWAT Check” screening tool (WHITE et al., 2014). In addition to these tools three goodness-of-fit statistics were used to assess the model performance; Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS) and the root mean square error-observations standard deviation ratio (RSR). According to Moriasi et al. (2007) model performance is satisfactory when NSE>0.5, the RSR ≤ 0.7 and the PBIAS ±25%. After determining the relevant parameters related to simulation of streamflow in this tropical region (i.e. parameter related to water quality or snowfall were discarded) a sensitivity analysis was performed using the Influence coefficient method (HELSEL; HIRSCH, 1992). This method calculates a sensitivity index value for each adjusted parameter based on the change exerted on the dependent variable, in this case simulated basefow and quickflow. In addition to this analysis, individual parameters were adjusted for each separate model run. The model output was then compared to observed values in order to assess the goodness-of-fit using the mentioned performance indicators. If the NSE value increased after parameter adjustment the parameter value is accepted, otherwise the value is returned to its original value. Observed streamflow data (m^3/s) for the calibration and validation process were collected from the catchment outlet over the period 1986 until 1994, of which the first four years were used for calibration and the last three years for validation. This period was selected, because after this period irrigated agriculture increased significantly and a hydropower dam was built in the Preto river.

Results and Discussion

Resulting from the sensitivity analysis and calibration process four parameters that have more influence in the simulation of streamflow were selected. The choice to adjust the limited amount of four parameters was too avoid overparametrization and overfitting of the model, which results from using too many parameters during calibration (ABBASPOUR, 2016; WHITTAKER et al., 2010). Table 1 shows the parameters used during the calibration process, with the adjusted parameters in grey.

Figure 1 shows the results of the monthly averaged simulations for the calibration (a.) and validation (b.) periods between 1986 and 1994 compared to the observed streamflow (m^3/s) values at the Fazenda Limeira observation station. After calibration simulation shows a NSE = 0.717, the PBIAS = 9.1% and the RSR = 0.6 for the calibration period from 1986 until 1991. As a NSE>0.5, the RSR ≤ 0.7 and the PBIAS ±25% as goodness-of-fit is considered satisfactory for simulation purposes, all performance indicators resulting from the calibration period suggest a satisfactory calibration. Moreover during the calibration period the model is able to simulate streamflow in dry periods, such as in 1987 as well as wet periods such as in 1989. The validation period model simulation show goodness-of-fit values of NSE = 0.734, PBIAS = -9.5%, indicating that the model performs satisfactory, although during periods of higher precipitation the model underestimates observed streamflow.

Table 1. Parameters used during sensitivity analysis and calibration. Figured are the parameter abbreviation, description, value ranges and values before and after calibration.

Parameter	Description	Unit	Range parameter values suggested by Arnold et al. (2012)		Parameter values before and after calibration	
			Min.	Max.	before	after
SOL_AWC	Available water capacity of the soil layer	mm/m	0	1	0.13-0.21	0.13-0.21
CN2	SCS runoff curve number for moisture condition 2	-	35	98	60-92*	45-69*
GW_REVAP	Groundwater "revap" coefficient	-	0.02	0.2	0.02	0.02
GW_DELAY	Groundwater delay	days	0	150	31	31
ESCO	Soil evaporative compensation factore	-	0.7	0.95	0.95	0.75
RCHRG_DP	Deep aquifer percolation fraction	-	0	1	0.05	0.8
EPCO	Plant uptake compensation factor	-	0.1	1	1	1
ALPHA_BF	Baseflow alpha factor for deep aquifer	-	0.05	0.8	0.048	0.048
SOL_K	Saturated hydraulic conductivity	mm/h	-	-	100-1686*	65-1096
SOL_Z	Soil layer depth	mm	-	-	800-3460*	800-3460

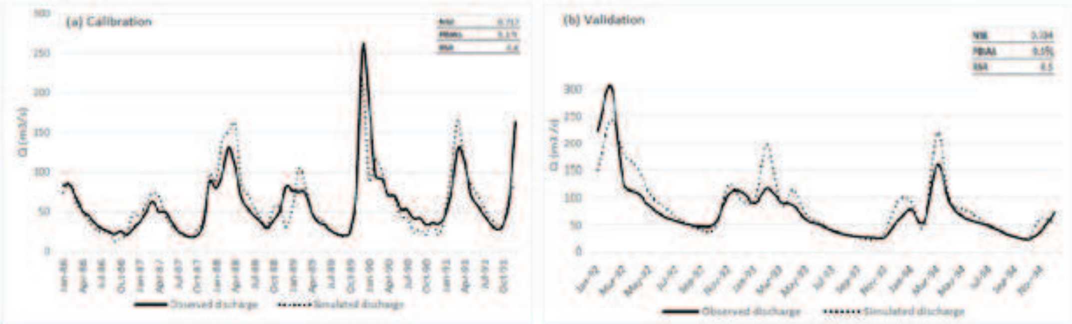

Figure 1. Observed and simulated streamflows at the Fazenda Limeira station watershed outlet during calibration (a) and the validation (b) periods.

Conclusion

After sensitivity analysis and the iterative manual calibration procedure the SWAT model was able to satisfactorily simulate streamflow, showing a goodness-of-fit with observed streamflow at the catchment outlet according to the three selected performance indicators. As the set of calibrated parameters was determined during a period where irrigation practices were limited in the catchment, the model is able to simulate the natural hydrological system of the river catchment, allowing for analysis of the Preto river watershed in response to climate and land-use change scenarios.

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