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Hydrological modeling in the Sono river basin, environmental protection region of the Jalapão, brazilian savanna

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A B S T R A C T

The Sono river basin (SRB) is an important ecological area located at the Cerrado biome, which encompasses several environmental protection units, highlighting the Jalapão State Parque. In order to assist the water resource management, this paper developed a hydrological simulation of the SRB, delineated at the Jatobá station (drainage area of 16,862 km²), using the SWAT model, and determined the spatial distribution of the mean, maximum, and minimum specific yields (REmlt, REmin, and REmax) in the basin. The performance of the model was evaluated using Nash-Sutcliffe efficiency (NSE) and percentage bias (PBIAS). For the monthly calibration and validation periods, respectively, NSE values of 0.55 and 0.56 and PBIAS values of 8.2% and -10.2% were obtained. For daily calibration and validation periods, respectively, NSE values of 0.40 and 0.41 and PBIAS values of 8.2% and -11.2% were obtained. These results indicate that the SWAT was able to model the monthly and daily streamflows of the SRB. In addition, the REmlt, REmin and REmax maps showed that the environmental protection areas are the biggest water producers compared with the other parts of the basin. Therefore, the results achieved in this study are fundamental tools for the water resources management at this important ecological region.
Keywords: soil and water assessment tool; Cerrado biome; Tocantins-Araguaia river basin.

Modelagem hidrológica na bacia do rio Sono, região de proteção ambiental do Jalapão, savana brasileira

R E S U M O

A bacia do rio Sono (SRB) é uma importante área ecológica localizada no Cerrado, a qual engloba diversas unidades de proteção ambiental, com destaque para o Parque Estadual do Jalapão. Visando auxiliar a gestão dos recursos hídricos, este trabalho desenvolveu uma simulação hidrológica da SRB, delineada na estação Jatobá (área de drenagem de 16.862 km²), utilizando o modelo SWAT, e determinou a distribuição espacial dos rendimentos específicos médio, máximo e mínimo (REmlt, REmin e REmax) na bacia. O desempenho do modelo foi avaliado por meio do coeficiente de Nash-Sutcliffe (NSE) e do percentual de viés (PBIAS). Para os períodos mensais de calibração e validação, respectivamente, foram obtidos valores de NSE de 0,55 e 0,56 e valores de PBIAS de 8,2% e -10,2%. Para os períodos diários de calibração e validação, respectivamente, foram obtidos valores de NSE de 0,40 e 0,41 e valores de PBIAS de 8,2% e -11,2%. Esses resultados indicam que o SWAT foi capaz de modelar as vazões mensais e diárias da SRB. Além disso, os mapas REmlt, REmin e REmax mostraram que as áreas de proteção ambiental são as maiores produtoras de água em comparação com as demais partes da bacia. Portanto, os resultados alcançados neste estudo são ferramentas fundamentais para a gestão dos recursos hídricos nesta importante região ecológica.
Palavras-chave: soil and water assessment tool; bioma Cerrado; bacia hidrográfica dos rios Tocantins-Araguaia.

Introduction

Understanding and representing the rainfall-runoff process in a basin through the use of hydrological model is essential for enhancing water resource management (Nkiaka et al., 2018), since it helps to estimate the availability and distribution of freshwater, to predict the streamflow and to evaluate the hydrological response due to changes in land use and climate change scenarios (Lucas-Borja et al., 2020).

Over the past decade, hydrologists have implemented models to investigate the hydrological processes in several basins in Brazil and worldwide (Viola et al., 2013, Fang et al., 2018, Alvarenga et al., 2018, Oliveira et al., 2019). In order to provide accurate streamflow simulations, these models must be calibrated from available measured data (Van Liew and Mittelstet, 2018). During a model calibration, the parameters are changed until a sufficient correspondence between the model outputs and actual measurements are obtained (Krishnan et al., 2018).

Among the several hydrological models, the Soil and Water Assessment Tool (SWAT) developed by the U.S. Department of Agriculture (USDA), has been widely applied and recognized worldwide as one of the most promising and efficient models to simulate the hydrology and the impacts of climate change and land management practices on water within a basin (Abbaspour et al., 2015, Pontes et al., 2016, Anand et al., 2018). The SWAT model can provide reliable information on the behavior of the system for estimation, planning and management of current and future water resources (Abbaspour et al., 2015, Anand et al., 2018). In addition, SWAT model uses a GIS interface which provides a user friendly data entry and editing environment for SWAT (Boyanova et al., 2016, Ndulue et al., 2018).

Despite the advance in the use of hydrological models in Brazil, few studies have been developed focusing on estimating streamflows in the Cerrado biome, even though it is the second most extensive biome in South America, one of the world's most biodiversity savannas and one of the 25 biodiversity hotspots (Myers et al., 2000, Silva et al., 2018, De Oliveira et al., 2019, Rodrigues et al., 2020). In addition, the Cerrado currently faces one of the greatest threats related to habitat loss in Brazil; an annual loss rate of 0.44% has been observed, with >51% of the biome having already been removed (De Oliveira et al., 2020). Thus, the implementation of models to investigate the hydrological dynamics in the Cerrado biome is crucial for water management in Brazil and South America (Amorim et al., 2020).

The Sono River Basin (SRB) is one of the main hydrological units entirely within the Cerrado biome, since it comprises several areas of environmental protection, including the Jalapão State Parque (JSP) and the Environmental Protection Region of the Jalapão (EPRJ). The Jalapão region forms the largest protected area of Cerrado, has a very diversified flora, with species that are not found in other Cerrado regions and is under serious threat of large-scale deforestation, mostly due to the MATOPIBA agricultural development plan (BRASIL, 2015), which included the region as part of an expanding agricultural frontier (Silva and Bates, 2002, Silva et al., 2018, Antar and Sano, 2019, Eloy et al., 2019). Therefore, the Jalapão region is in critical need for tools to support its hydrological management.

In order to contribute for future water resource management of the Cerrado biome and Jalapão region, this paper aims to calibrate and validate the Soil and Water Assessment Tool (SWAT) model to estimate the daily and monthly streamflows of the Sono River Basin, and to determine the spatial distribution of the mean, maximum, and minimum specific yields (REmlt, REmin, and REmax) in the basin.

Material and methods

Study Area

The Sono River Basin (SRB), delimited from the Jatoba streamflow station located in the headwater of the SRB, has a drainage area of 16,862 km². It is located in the Tocantins state, Northern Brazil, and in the Hydrographic Region of the Tocantins-Araguaia river basin (TARB). The Parque Estadual do Jalapão (PEJ), a full protection environmental unit (FPEU), and the Área de Preservação Ambiental do Jalapão (APAJ), an environmental unit for sustainable use (EUSU), are totaly inseted at SRB. Also, there are partially inserted two FPEU: Parque Nacional das Nascentes do Rio Parnaíba (PNNRP) e Estação Ecológica Serra Geral do Tocantins (EESGT) (Figure 1).

According to Thornthwaite's climate classification, the climate type is C1A’w2a’, dry subhumid, megathermal, with large summer water surplus, and a temperature efficiency regime normal to megathermal (Sousa et al., 2019). According to Köppen's classification, the climate is tropical with predominant rains in summer and dry winter (Aw) (Alvares et al., 2013). The average annual precipitation varies from 804 mm in the eastern to 1,675 mm in the western. The mean monthly temperature ranges from 23,4 ºC in July to 28,5 ºC in September.

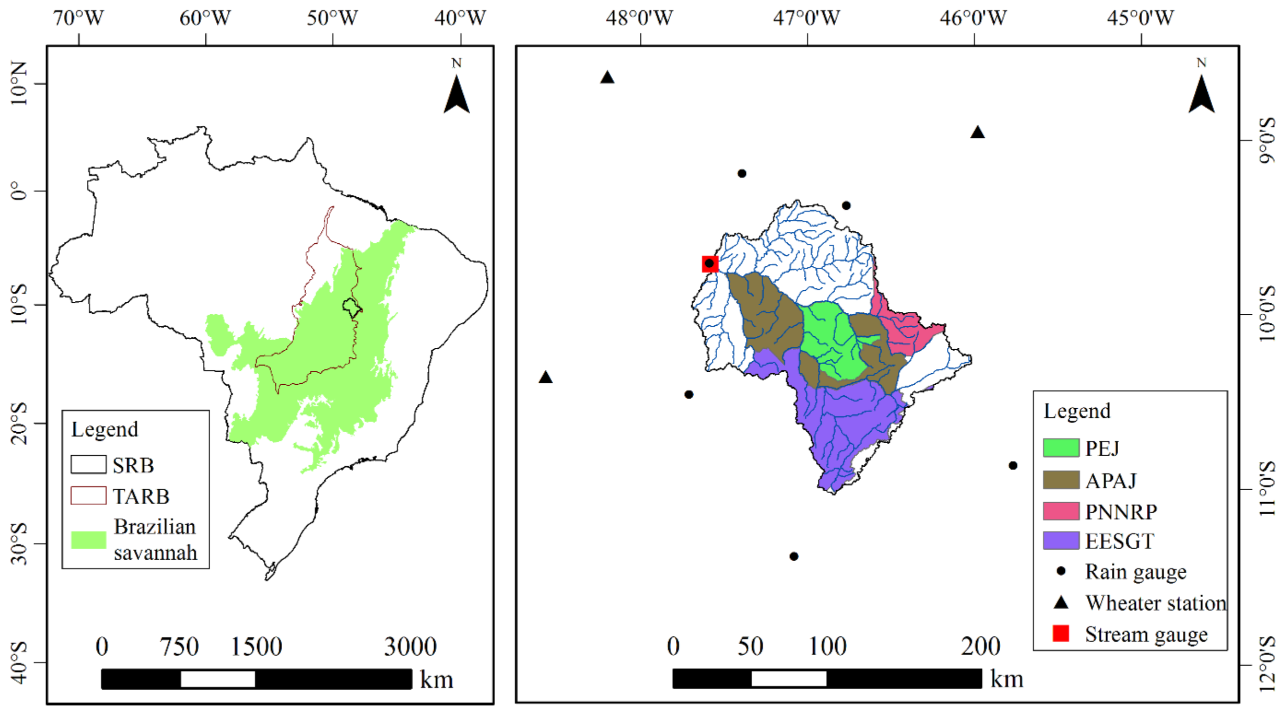

Figure 1. Location of the Sono River basin (SRB) in the context of the Tocantins-Araguaia river basin (TARB) and Brazilian savanna (left), gauge stations, and environmental units (right).

SWAT model

SWAT is a semi-distributed and continuous hydrological model that can be used in simulations in daily, monthly and annual time steps (Arnold et al., 2012). One of its main characteristics is the discretization of the basin into sub-basins and later into hydrological response units (HRUs), which are the result of the unique combination of land use, soil type and slope class.

The rainfall-streamflow hydrological modeling in SWAT is based on measuring the water balance for each HRU and aggregation of these results to the basin scale by applying a weighted average to the HRU results. Equation 1 describes the water balance adopted by the SWAT model.

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where: SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), R_{day} is the amount rainfall on day i (mm), Q_{surf} is the amount of surface runoff on day i (mm), E_a is the amount of evapotranspiration on day i (mm), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Q_{gw} is the amount of base flow on day i (mm).

SWAT input data

The SWAT model requires weather data such as rainfall, maximum and minimum air temperature, solar radiation, wind speed, air relative humidity, topography, and soil and land use data as input to simulate the hydrological processes in a basin. To select the rainfall and weather stations with influence on the study area, the Thiessen polygon method was used (Gao and Li, 2018). Thus, six rain gauge stations and three weather stations were selected from Hydrological Information System platform (Hidroweb) of the Brazilian National Water Agency (ANA) and Meteorological Database for Education and Research (BDMEP) of the Brazilian Weather Bureau (INMET), respectively. In addition, daily streamflow series of the Jatobá streamflow station used to calibrate and validate the SWAT model was obtained from the HidroWeb platform for a 24 year (1995–2018). Figure 1 shows the location of these stations.

The base maps required by the SWAT model are the Digital Elevation Model (DEM), and land use and soil maps. The DEM of the SRB was derived from the satellite images with a spatial resolution of 30 meters of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), which were acquired from the United States Geological Survey (USGS) (Figure 2a). The land use map of the SRB was obtained from Tocantins Planning and

Budget Secretariat (SEPLAN, 2012). Eight land use classes are present in the studied basin as follows: Cerrado (Cer, 80.43 %), riparian forest (RF, 9.83 %), forest (Frst, 6.84 %), pasture (Past, 2.59 %), agriculture (Agr, 0.15 %), water bodies (WB, 0.12 %), bare soil (BS, 0.02 %), and urban area (Urb, 0.02 %) (Figure 2b). The soil map was obtained from the Brazilian Agricultural Research Corporation (EMBRAPA, 2011) on a scale of 1:5,000,000. Five soil classes are present in the SRB: Quartzarenic Neosol (RQ, 70.8%), Yellow Latosol (LA, 11.4%), Red-Yellow Argisol (PVA, 7.1%), Petric Plinthosol (FF, 6%), and Litholic Neosol (RL, 4.8%) (Figure 2c). The land use and soil physical parametrization required by the SWAT model were conducted according to Rodrigues et al. (2020).

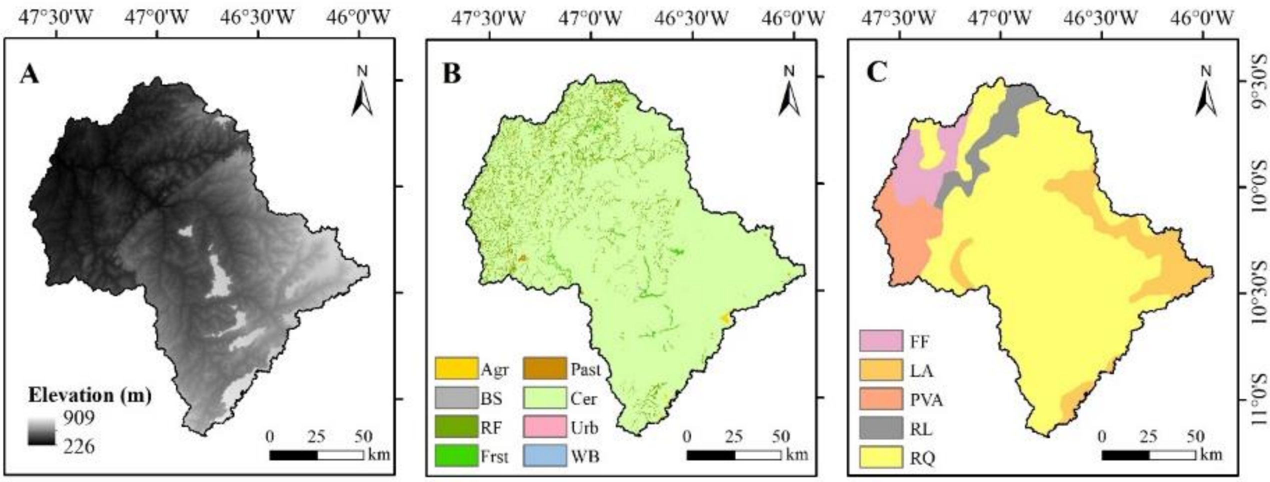

Figure 2. DEM (A), land use map (B), and soil map (C) of the SRB headwater.

Calibration, validation, and sensitivity analysis of the SWAT

Parameter sensitivity analysis was performed through SWAT-CUP software with the Sequential Uncertainty Fitting version 2 (SUFI2) algorithm and the Latin Hypercube One-factor- At-a-Time sensitivity analysis (LH-OAT) method (Abbaspour et al., 2015). This method consists of keeping all parameters constant and changing only one within a certain range. Thus, it allows to identify the individual influence of each parameter in the hydrological simulation, where the greater the variation of the hydrograph the greater the sensitivity of the parameter. Sixteen parameters (Table 1) were considered for the sensitivity analysis in this study, as they are considered as the most sensitive by the literature (De Oliveira et al., 2019, Rodrigues et al., 2020).

Hydrological modeling was carried out in a daily and monthly time step in the period between 1992 and 2018. The period of 1992 to 1994 was utilized to warm up the SWAT model in order to stabilize the initial conditions of soil water content (Aragão et al., 2013). Calibration and validation were performed for the periods 1995-2006 and 2007-2018, respectively.

The calibration was carried out with the SUFI2 algorithm within the SWAT-CUP software, seeking to maximize Nash-Sutcliffe efficiency (NSE) (Equation 2). Additionally, the percentage of bias (PBIAS) was calculated to evaluate the results (Equation 3).

$$\text{NSE}=1-\frac{\sum_{i=1}^{N}(Q_{obs_i}-Q_{sim_i})^2}{\sum_{i=1}^{N}(Q_{obs_i}-\overline{Q_{obs}})^2} \quad (2)$$

$$\text{PBIAS}=\frac{\sum_{i=1}^{N}(Q_{obs_i}-Q_{sim_i})}{\sum_{i=1}^{N}(Q_{obs_i})}.100 \quad (3)$$

Where: Q_{obs} is the observed streamflow, $m^3.s^{-1}$, Q_{sim} is the simulated streamflow, $m^3.s^{-1}$, $\overline{Q_{obs}}$ is the observed mean streamflow, $m^3.s^{-1}$, and n is the number of data points.

To evaluate the monthly model performance based on NSE and PBIAS coefficients, Moriasi et al. (2007) classifications were adopted. NSE is a measure that shows model effectiveness in simulating flood flows. According to Moriasi et al. (2007), NSE = 1 means perfect fit data simulated by the model; NSE > 0.75 (model is very good); 0.75 > NSE > 0.65 (model is good); 0.65 > NSE > 0.5 (model is satisfactory) and NSE < 0.5 (model is unsatisfactory). PBIAS is a measure that shows the trend of the average simulated streamflow being higher or lower than the observed. According to Moriasi et al. (2007), |PBIAS| < 10% (very good); 10% < |PBIAS| < 15% (good); 15% < |PBIAS| < 25% (satisfactory); and |PBIAS| ≥ 25% (unsatisfactory). In the daily step, the classifications proposed by Green et al. (2006) and Van Liew et al. (2007) were adopted. According to Green et al. (2006), daily simulations with NSE greater than 0.4 are classified as satisfactory. According to Van Liew et al. (2007), the classification for PBIAS in a daily time step is the same as the monthly PBIAS classification presented by Moriasi et al. (2007).

Table 1. Parameters used for the sensitivity analysis and their initial range values.

Parameter	Parameter description	Initial range
V_ESCO	Soil evaporation compensation coefficient	0.5 – 0.95
R_CN2	Initial SCS runoff curve number for moisture condition II	- 0.1 – 0.1
V_ALPHA_BF	Baseflow recession constant (days)	0 – 1
A_GW_DELAY	Groundwater delay time (days)	- 30 – 60
A_GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	- 1000 – 1000
V_CANMX	Maximum canopy storage (mm)	0 – 30
V_CH_K2	Effective hydraulic conductivity in main channel ($mm.h^{-1}$)	0 – 10
V_CH_K1	Effective hydraulic conductivity of the tributary channel ($mm.h^{-1}$)	0 – 5
V_CH_N2	Manning's "n" value for the main channel	- 0.01 – 0.2
V_CH_N1	Manning's "n" value for the tributary channels	0.01 – 0.3
V_GW_REVAP	Groundwater "revap" coefficient	0.02 – 0.2
A_REVAPMN	Threshold depth of water in the shallow aquifer for 'revap' or percolation to the deep aquifer to occur (mm)	- 1000 – 1000
R_SOL_AWC	Soil available water capacity ($mm_{água}.mm_{solo}^{-1}$)	- 0.1 – 0.1
R_SOL_K	Saturated hydraulic conductivity ($mm.h^{-1}$)	- 0.2 – 0.2
V_SLSOIL	Slope length (m)	0 – 150
V_SURLAG	Surface runoff lag coefficient (days)	0.01 – 24

Note: The parameter prefixes V, R and A indicate the calibration operations replace, relative and add, respectively.

Results and Discussion

Sensitivity analysis

Based on the results of the LH-OAT method, 8 and 12 parameters presented sensitivity regarding the monthly and daily streamflows simulations, respectively, for the SRB headwater. The parameters ESCO, CN2, ALPHA_BF, CANMX, CH_N2, GW_REVAP, CH_N1, and CH_K2 were sensitive in both time steps, while the parameters CH_K1, GW_DELAY, GWQMN and SLSOIL showed sensitivity only in the daily time step. The most sensitive parameters in the present work refer to groundwater, vegetation management, and transmission network. The greatest influence in the streamflow modeling of parameters related to groundwater was also found by Abe (2017), by González-Ramírez and Parés-Sierra (2019) and by Nkiaka et al. (2018). Rodrigues et al. (2020), which applied the SWAT model to monthly streamflow simulation near the SRB outlet with a control section in Porto Real (drainage area of 45,042 km²), identified 11 sensitive parameters, of which seven are coincident with this study: ESCO, CN2, ALPHA_BF, CANMX, CH_N2, GW_REVAP, and CH_K2. Similar results were also found in Rodrigues et al. (2021), which applied the SWAT model for the simulation of daily streamflow in Manuel Alves da Natividade River Basin (MRB) (drainage area of 14,344 km²), adjacent to the SRB. The authors identified 14 sensitive parameters, of which eleven are coincident with this study, and the GWQMN did not show sensitivity in the MRB. The parameterization of SWAT model may vary among different basins due to the environmental and size variation (Paz et al., 2018). Thus, to reduce errors in the streamflow simulation, one can highlight the importance this sensitivity analysis.

SWAT calibration and validation

Based on the parameters obtained in the sensitivity analysis, the SWAT model was calibrated from 1995 to 2006 and validated from 2007 to 2018 using the daily and monthly streamflow data from the Jatoba streamflow station, which delimits the SRB headwater. Tables 2 and 3 show, respectively, the final calibrated parameters and the results from statistical performance of SWAT model in the calibration and validation periods, in daily and monthly streamflows simulation, for the SRB headwater. NSE values calculated from daily results were 0.40 and 0.41, while the monthly data produced values of 0.55 and 0.56 for the calibration and validation periods, respectively. These values suggest a satisfactory model performance for daily (Green et al., 2006) and monthly (Moriasi et al., 2007) estimates. Regarding the PBIAS, the SWAT model underestimated by 8.2% the daily and monthly observations during the calibration period, and overestimated by 10.2% and 11.2% the monthly and daily observations, respectively, during the validation period. From these values, the model can be classified as very good and good in the calibration and validation periods, respectively, according to classifications suggested by Van Liew et al. (2007) and by Moriasi et al. (2007). These results demonstrate that the SWAT model is able to adequately predict the daily and monthly streamflows of the SRB headwater.

In other Brazilian studies using the SWAT, statistical indices were also used to evaluate the performance of the simulations. Santos et al. (2018) evaluated the performance of the SWAT model in daily and monthly streamflows simulation in the Paraguaçu watershed, in northeastern Brazil, and obtained daily results with NSE of 0.49 and 0.42 and PBIAS of 10.4 and 6.0%, and monthly results with NSE of 0.82 and 0.76 and PBIAS of 9.86 and 3.41%, respectively, for calibration and validation periods. Rodrigues et al. (2020) evaluated the SWAT model for monthly streamflow simulation in the SRB with a control section in Porto Real (drainage area of 45,042 km²), and in the Manuel Alves da Natividade and Palma basins, and obtained NSE values ranging from 0.56 to 0.84 and 0.70 to 0.81 and PBIAS values ranging from −4.7 to −24.3% and −18.4 to −24.7%, respectively, for calibration and validation periods. Dos Santos et al. (2020) applied the SWAT model in daily and monthly streamflow simulation in the Atibaia and Jacaré-Guaçu watersheds, and obtained, respectively, for the calibration and validation periods, daily results with NSE ranging from 0.15 to 0.27 and -0.74 to 0.49 and PBIAS ranging from −6.77 to −1.31% and −10.88 to 3.15%, and monthly results with NSE ranging from 0.30 to 0.55 and 0.35 to 0.81 and PBIAS ranging from −6.65 to −1.75% and −10.83 to 10.3%. Martins et al. (2020) applied the SWAT model for monthly streamflow simulation in the Ribeirão do Pinhal watershed, Limeira - São Paulo, and obtained NSE of 0.64 and 0.58 and PBIAS of 15.2 and -2.8%, respectively, for calibration and validation periods. Rodrigues et al. (2021) evaluated the performance of the SWAT model in daily streamflow simulation in the Manuel Alves da Natividade River Basin (MRB), adjacent to the SRB, and obtained NSE values of 0.67 and 0.61, respectively, for calibration and validation periods.

Figures 3 and 4 show for the monthly and daily time steps, respectively, the simulated and observed hydrographs for calibration (a) and validation (b) periods along with the corresponding observed hyetographs for the SRB headwater. During the calibration period, the model underestimated the mean streamflow, in the daily time step the simulated mean streamflow was 260.59 m^3/s, and in the monthly time step the simulated mean streamflow was 261.02 m^3/s, while the observed was 284.29 m^3/s. On the other hand, during the validation period, the model overestimated the mean streamflow, in the daily time step the simulated mean streamflow was 259.35 m^3/s, and in the monthly time step the simulated mean streamflow was 257.83 m^3/s, while the observed was 233.89 m^3/s. Despite the differences, a good general fit is observed for the streamflows simulated by the SWAT model compared to those observed, with adequate representation of the maximum and the recession periods, which highlight the satisfactory performance obtained from the precision statistics. Thus, the SWAT model could be considered fit for improving management of streamflow in the SRB headwater.

Table 2. Results of the parameter calibration in the daily and monthly time step for SRB headwater.

Parameter	Calibrated Value	
	Monthly	Daily
V_ESCO	0.500	0.500
R_CN2	-0.100	-0.100
V_ALPHA_BF	0.001	0.0005
V_CANMX	30	30
V_CH_N2	0.200	0.200
V_GW_REVAP	0.070	0.085
V_CH_N1	0.200	0.300
V_CH_K2	7	0.500
V_CH_K1	-	5
A_GW_DELAY	-	-30
A_GWQMN	-	50
V_SLSOIL	-	150

Table 3. Performance of SWAT model in the calibration and validation periods, at both daily and

monthly time steps, for the headwater region of the Sono River Basin.

Time step	Calibration		Validation	
	NSE	PBIAS	NSE	PBIAS
Monthly	0.55	8.2	0.56	-10.2
Daily	0.40	8.2	0.41	-11.2

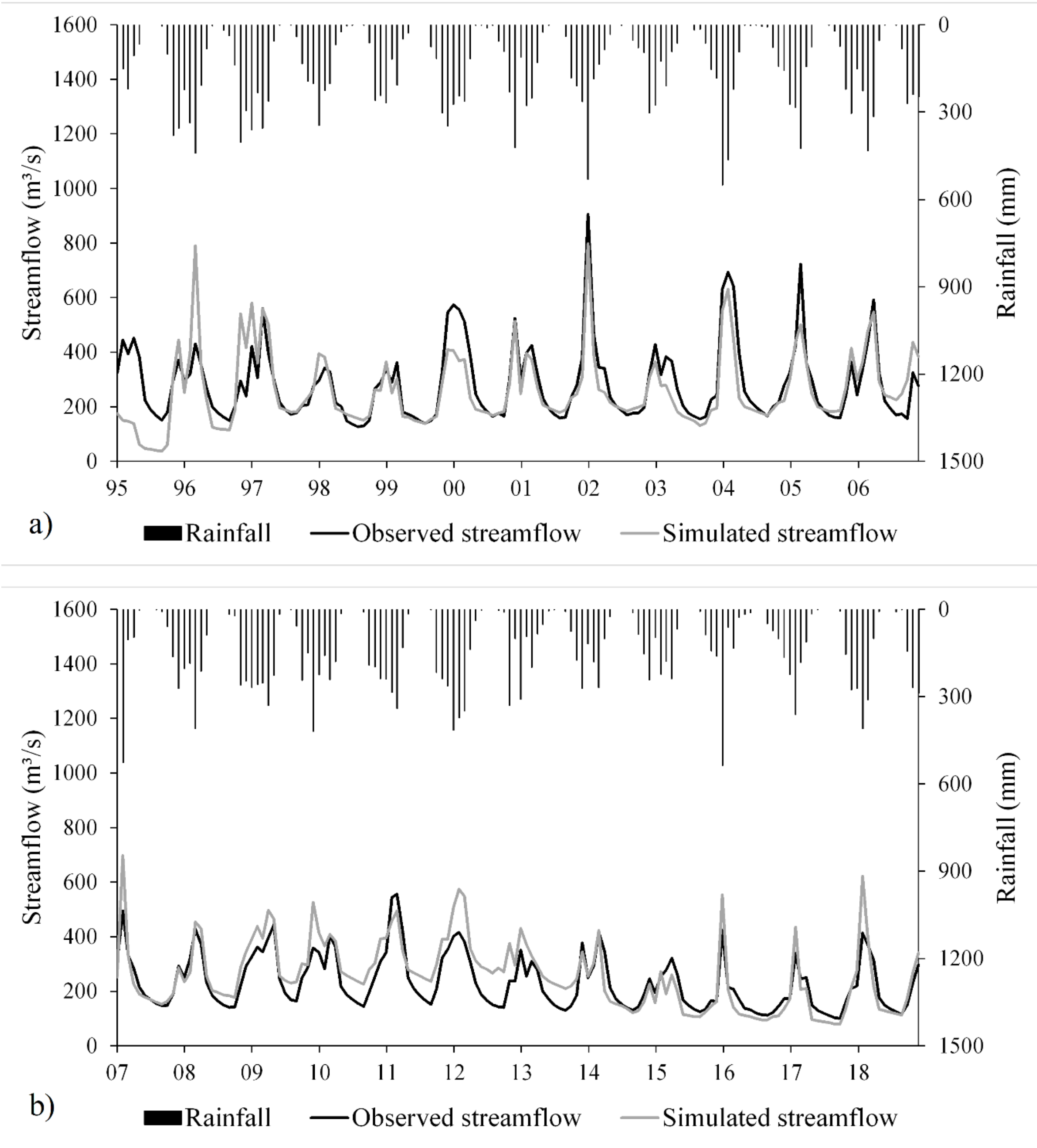

Figure 3. Observed and simulated monthly streamflow and their monthly observed hyetographs during the calibration (a) and validation (b) periods for the headwater region of the Sono River Basin with a control section in Jatobá.

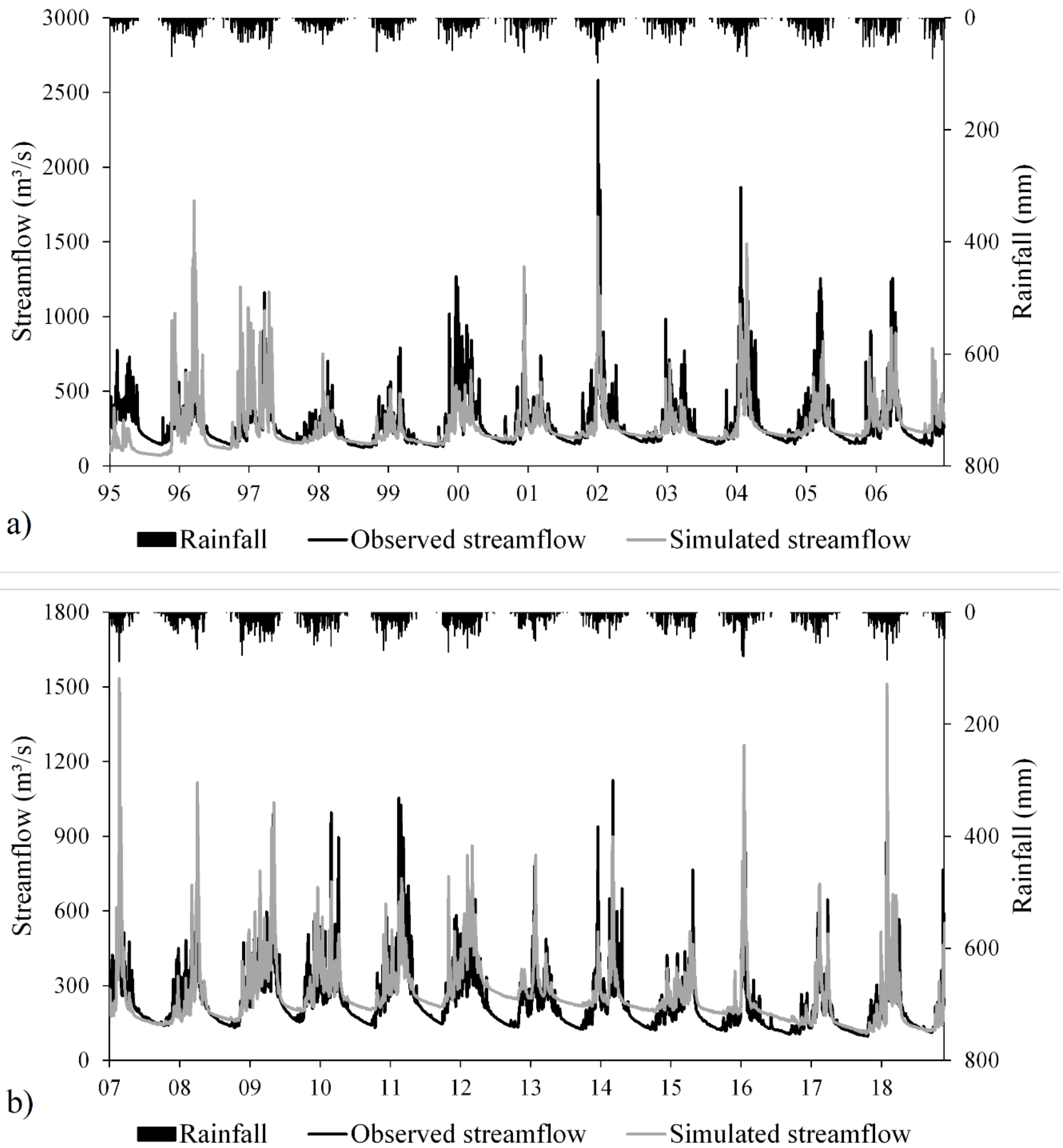

Figure 4. Observed and simulated daily streamflow and their daily observed hyetographs during the calibration (a) and validation (b) periods for the headwater region of the Sono River Basin with a control section in Jatobá.

In order to improve the management of water resources in the SRB headwater, spatial distribution maps of the mean, maximum and minimum water productions were developed (Figure 5). These water productions are represented by specific yields, and were calculated according to Mello and Silva (2013), for each sub-basin, based on the mean, maximum and minimum streamflows predicted by the SWAT model in the period from 1995 to 2018.

Figure 5a shows the mean specific yield at the sub-basin level of the SRB headwater, which ranged from 9.5 to 26.3 L s^{-1} km^{-2}, with an average of 15.7 L s^{-1} km^{-2}. It can be observed that the environmental protection areas are greater water producers than the other parts of basin, they represent 55% of the total area of the basin and have an average of REmlt of 17 L s^{-1} km^{-2}. SRB headwater REmlt is high when compared to others obtained for Cerrado biome basins such as by Rodrigues et al. (2016) in the Manuel Alves da Natividade river basin, neighboring to the SRB, which obtained an average REmlt equal to 13.8 L s^{-1} km^{-2}, and by Junqueira et al. (2020) in the Pandeiros river basin, located in the Minas Gerais State, which obtained an average REmlt equal to 6.46 L s^{-1} km^{-2}. Although they are in the same biome, the higher REmlt values obtained in SRB headwater are associated with greater environmental protection in this basin.

Figure 5b shows the minimum specific yield at the sub-basin level of the SRB headwater, which ranged from 0.2 to 8.9 L s^{-1} km^{-2}, with an average of 4.4 L s^{-1} km^{-2}. It can be observed that the environmental protection areas have a high minimum water production, showed an average of REmin of 4.95 L s^{-1} km^{-2} while the other parts of basin showed an average of REmin of 3.85 L s^{-1} km^{-2}. Junqueira et al. (2020) found an average of REmin equal to 3.6 L s^{-1} km-^{2} for the Pandeiros river basin, also located in the Cerrado biome, which highlight the importance of environmental protection areas in maintaining the higher REmin value obtained in SRB headwater.

Figure 5c shows the maximum specific yield at the sub-basin level of the SRB headwater, which ranged from 66.6 to 436.4 L s^{-1} km^{-2}, with an average of 152.4 L s^{-1} km^{-2}. Rodrigues et al. (2016) found average of REmax equal to 97.7 L s^{-1} km^{-2} for the Manuel Alves da Natividade river basin. These basins, despite being neighbors, present considerable differences in specific yields, which emphasizes the importance of spatial analysis of specific yields for a better management of water resources.

The overlap between the spatial distributions of specific yields showed that the middle and southern parts of the SRB headwater are greater streamflow producers than the other parts of basin. This evidences the contribution of water from the mountains to the valley (Brouziyne et al., 2018; Näschen et al., 2018) and the great role of the conservation areas, which favors the formation of the underground runoff and supports the production of water in the SRB headwater.

It is expected that the SWAT model and the specific yield maps developed in this study can help the state government in the sustainable management of water resources in the SRB headwater and contribute to the management in the Brazilian Cerrado biome.

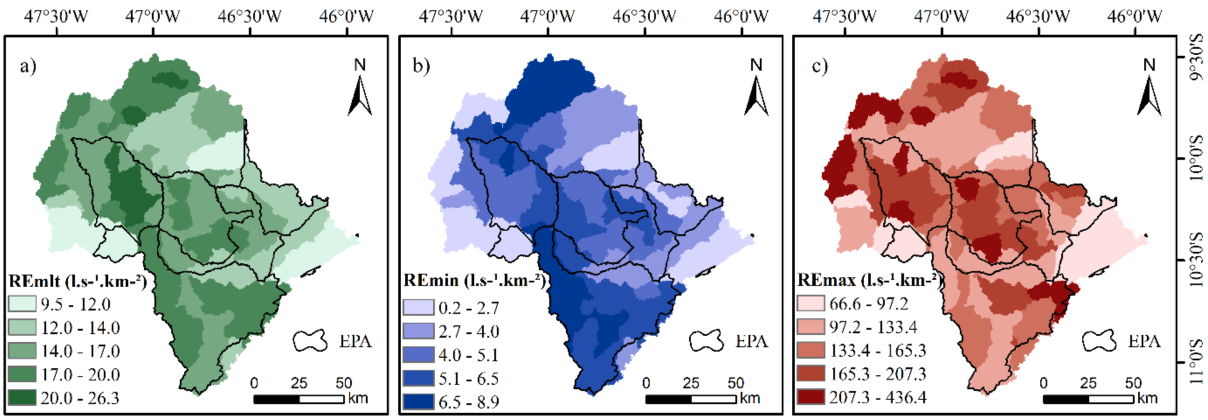

Figure 5. Long-term mean (REmlt) (a), minimum (REmin) (b) and maximum (REmax) (c) specific yield maps, in L s^{-1} km^{-2}, for the SRB headwater, and location of the Environmental Protection Areas (EPA).

Conclusions

The SWAT model was able to reproduce the monthly and daily streamflows in the Sono River Basin headwater. The statistical performance resulted in NSE values higher than 0.4 and 0.55 for daily and monthly streamflow, respectively, indicating a satisfactory performance at the daily and monthly scales. Likewise, mean, maximum and minimum specific yield maps were developed at the sub-basin level, with potential use in hydrological studies and water management plans. These maps showed that the Environmental Protection Region of the Jalapão are the biggest water producers compared with the other parts of the basin. Environmental protection areas favor the formation of the underground runoff and thus produce more water. Therefore, it is highlighted the great importance of the preservation of these region for the production of water in the Cerrado. In addition, the model properly calibrated and validated in this study is configured as an important tool for the planning and management of water resources in this basin.

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