engenharia agrícola
Journal of the Brazilian Association of Agricultural Engineering

Engenharia Agrícola

ISSN: 1809-4430 (on-line)
www.engenhariaagricola.org.br

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v38n1p55-63/2018

CALIBRATION AND VALIDATION OF THE SWAT HYDROLOGICAL MODEL FOR THE MUCURI RIVER BASIN

Rafael A. Almeida[1*], Silvio B. Pereira[2], Daniel B. F. Pinto[3]

[1*]Corresponding author. Universidade Federal dos Vales do Jequitinhonha e Mucuri/ Teófilo Otoni - MG, Brasil.
E-mail: rafael.almeida@ufvjm.edu.br

KEYWORDS

hydrological modeling, SWAT-CUP; flow rate.

ABSTRACT

Hydrological models are becoming more and more widespread, mainly due to their capacity to simulate the impact of environmental changes on water resources. In this way, the aim of this study was to calibrate and validate the SWAT model for the soil and climatic conditions of the Mucuri River Basin, located in the Northeast region of the States of Minas Gerais, Brazil. The SWAT-CUP software module SUFI2 was used to analyze the sensitivity, calibration and validation of the model. The calibration was performed in an intermediate fluviometric station and the validation in five other located: three upstream, one downstream and one independent from the calibration point. It was evidenced for the study area that the parameters referring to the basic flow processes were more sensitive. The model obtained a good adjustment with an overestimate tendency of 15%. In general, the SWAT model, using SWAT-CUP was good and adequate in terms of its calibration performance and validation of the flow simulation in the Mucuri River Basin by the determination coefficients, Nash-Suttclife efficiency and percentage of trend.

INTRODUCTION

Issues related to water resources are widely disseminated and discussed throughout the world, as it is an indispensable natural resource for life on the planet. Thus, studies to assess their distribution over time and space are of paramount importance. Hydrological models are fundamental mainly in regions with the greatest water scarcity, since they help simulate the impacts of human actions on water resources and assist in the planning and management of river basins (Tundisi & Tundisi, 2010).

The *Soil and Water Assessment Tool* (SWAT) was developed in the United States by the Agricultural Research Service and by Texas A & M University, and it is a conceptual mathematical base model semi-physical, semi-distributed, continuous time and that operates through daily data allowing the interconnection of different physical processes that occur in a watershed through the SIG environment (Andrade et al., 2013; Monteiro et al., 2015).

The model is structured on basic components of action, such as: hydrological, climate, sediments, nutrients, agricultural management, among others. A command structure is used to propagate superficial flow, sediments, and nutrients through the sub-basins. Although the model operates on a daily time step, it is efficient to simulate several years, being used to predict the long-term behavior of the basin (Arnold et al., 1998; Neitsch et al., 2005; Winchell et al., 2009).

The input data of the model are the main limitation for application under Brazilian conditions, since acquisition system data is out of date with faults and in smaller quantity than it should be. These factors contribute to the inefficiency of the application of more complex and precise models (Bressiani et al., 2015; Monteiro et al., 2015; Durães et al., 2011).

The SWAT establishes an operating sequence which is the steps of heating, sensitivity analysis, calibration of the model parameters, validation and simulation of future scenarios (Pinto et al., 2013).

The calibration process consists of adjusting the values of the model parameters so that the simulated values approximate those observed, thus representing better the simulated process. It is important to emphasize that the hydrological model does not know the initial conditions of simulation, conditions that can exert great impacts on the simulated process, and therefore needs a

---

[2] Universidade Federal de Viçosa/ Viçosa - MG, Brasil.
[3] Universidade Federal dos Vales do Jequitinhonha e Mucuri/ Teófilo Otoni - MG, Brasil.
Received in: 9-13-2016
Accepted in: 10-28-2017

warm-up time (Li et al., 2015; Ercan et al., 2014; Ajami et al., 2004).

The validation is based on the use of the model with calibrated parameters in an independent data mass so that the applicability of the model to the event can be evaluated through several tests (Pereira et al., 2014; Arnold et al., 2012). After the validation phases, if the model achieves a satisfactory performance, it becomes possible to perform model simulations according to different scenarios (Marek et al., 2016).

There are several advantages of hydrological modeling from issues related to planning and management of water resources to public safety in extreme events such as floods or droughts (Abbaspour et al., 2015; Meaurio et al., 2015; Awan & Ismaeel, 2014). In this context studies are convenient on the development of models to have a consistent database for the most diverse edaphoclimatic conditions existing in Brazil (Pinto et al., 2013, Pereira et al., 2014; Monteiro et al., Durães et al., 2011).

Based on this approach, the aim of this study was to calibrate and validate the SWAT model for edaphoclimatic conditions of the Mucuri River Basin located in Northeast region of Minas Gerais, Brazil as well as to test its performance.

MATERIAL AND METHODS

The Mucuri River Basin (BHRM) is part of the Eastern Atlantic Hydrographic Region, extending over 17 municipalities, comprising an area of about 15,400 km², with population of approximately 450,000 inhabitants. It has extensive mining activity, mainly in the city of Teófilo Otoni, besides the activities on agriculture, livestock and reforestation (IGAM, 2011). The predominant climate in the region is characterized as warm semi-humid tropical type Aw, according to Köppen classification (Kottek et al., 2006). Its location is shown in Figure 1.

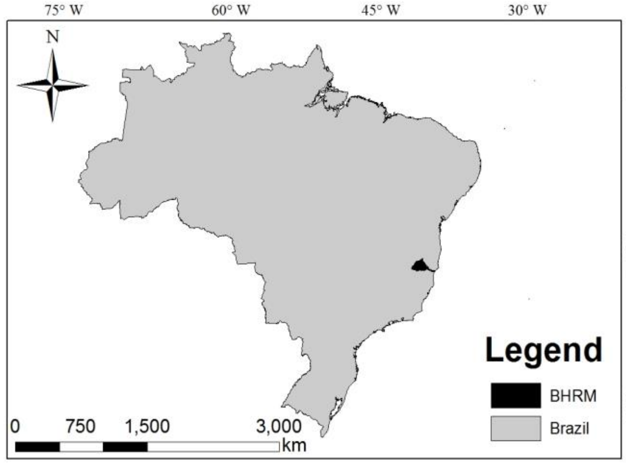

FIGURE 1. Location of BHRM.

The computational simulation was performed with the SWAT version 2012 (Arnold et al., 2012), through the interface with ARCGIS 10.x, called ARCSWAT.

The relief data were obtained from the Hydrographically Conditioned Digital Elevation Model (MDEHC), based on the altimeter data derived from SRTM (Shuttle Radar Topographic Mission), according to methodology proposed by Elesbon et al. (2011).

The MDEHC presents a variation from 1 to 1,238 meters, with the highest altitudes found on the headwater regions and the lowest at the river mouth, as expected. Its spatial distribution is represented in Figure 2. For the definition of the Hydrological Response Units (HRU's), based on the MDEHC, were used the slope classes proposed by EMBRAPA (1979).

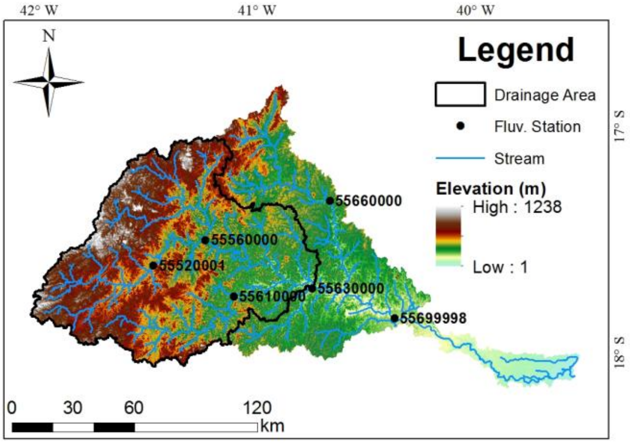

FIGURE 2. MDEHC of BHRM.

The soil map was adapted from a survey carried out by the Land Department of the Federal University of Viçosa which mapped the entire BHRM in the 1980s. The BHRM presents seven classes of soils: Inceptisols (0.5%), Gleyssols (0.5%), Oxisols (50.4%), Ultisols (45.6%), Mangrove soils (0.1%), Spodosols (0.3%) and Rock outcrops (2.6%). The spatial distribution of soils is shown in Figure 3.

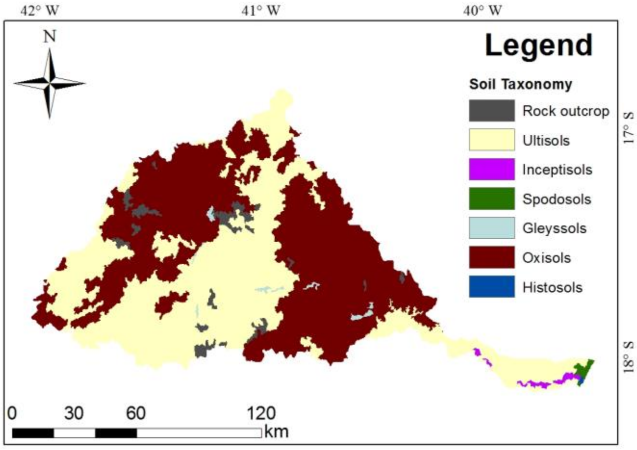

FIGURE 3. BHRM Soils.

The physical-hydrological attributes of the soils came from previous studies carried out in other hydrographic basins (Pinto, 2011; Lelis et al., 2012; Oliveira, 2014). For the use of the Rocky outcrop class the SWAT has specific attributes in its base, therefore, it was used the own base for this one.

The land use map was obtained using ArcGis version 10.0 by means of a supervised classification by maximum likelihood method, using 1,800 pixels of training sample per class of soil use and filtering of smaller areas than one hectare with the use of mosaic images LANDSAT 8 with spatial resolution of 30 meters in the years 2014 and 2015 (Figure 4).

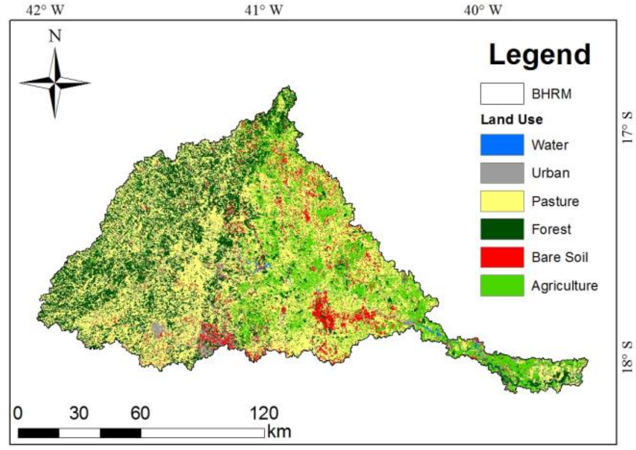

FIGURE 4. Land use and occupation at BHRM.

In land classes distribution for soil use we found: 47.1% of the basin area for the pasture class; 23.2% for the forest class; 16.1% for agriculture, 6.7% for exposed soil; 6.4% for the urban class, and finally, 0.5% represents the water class.

The required data for the stations, on daily basis of the meteorological type were: precipitation (mm), maximum and minimum temperature (ºC), solar radiation (MJ m^{-2} s^{-2}), wind speed (m s^{-1}) and relative humidity (%).For rainfall stations precipitation is required (mm), and finally for the fluviometric station only the flow (m^3 s^{-1}).

The input of meteorological data for the model use was obtained by consulting with the HIDROWEB / ANA database and the INMET automatic station network. Eight rainfall stations, six fluviometric stations and two meteorological stations were used, all with a period from 01/01/2007 to 12/31/2014. The spatial distribution of the stations is shown in Figure 2. Other relevant information for the used stations is shown in Table 1.

TABLE 1. Available stations for the study area.

Code	Type	Name	County	Sponsor
55630000	F[1]	CARLOS CHAGAS	CARLOS CHAGAS	ANA
55560000	F	FAZENDA DIACUI	TEÓFILO OTONI	ANA
55610000	F	FRANCISCO SÁ	CARLOS CHAGAS	ANA
55660000	F	SÃO PEDRO DO PAMPÃ	UMBURATIBA	ANA
55699998	F	NANUQUE – Upstream	NANUQUE	ANA
55520001	F	MUCURI	TEÓFILO OTONI	ANA
OMM 86763	M[2]	SERRA DOS AIMORÉS	NANUQUE	INMET
OMM 86762	M	TEÓFILO OTONI	TEÓFILO OTONI	INMET
1740000	P[3]	CARLOS CHAGAS	CARLOS CHAGAS	ANA
1740001	P	NANUQUE – Upstream	NANUQUE	ANA
1740026	P	SÃO PEDRO DO PAMPÃ	UMBURATIBA	ANA
1740033	P	ÁGUAS FORMOSAS	ÁGUAS FORMOSAS	ANA
1741001	P	MUCURI	TEÓFIL O OTONI	ANA
1741007	P	PEDRO VERSIANI (EFBM)	TEÓFILO OTONI	ANA
1741009	P	FRANCISCO SÁ (EFBM)	CARLOS CHAGAS	ANA
1841008	P	ATALÉIA	ATALÉIA	ANA

[1]indicates fluviometric type Station; [2]indicates meteorological Station, and [3]indicates Pluviometric Station.

The model warm-up period was defined in two years (2007 and 2008). In order to analyze the sensitivity, calibration and validation of the SWAT model for the BHRM we used the SUFI2 module present in the SWAT-CUP software, version 5.1.6 (Abbaspour, 2007).

It was decided to define the 19 main parameters (Table 2) for the calibration of the basin flow. These parameters were defined as a function of their occurrence among the main calibration parameters for the variable flow rate (Blainski et al., 2011; Durães et al., 2011; Muleta & Nicklow, 2005; Neto, et al., 2014; Andrade et al., 2013; 2013, Pinto et al., 2013).

From the studies developed by Pinto et al. (2013), Lelis et al. (2012) and Pereira et al. (2016) which developed the application of the SWAT model for basins that are also inserted in the State of Minas Gerais, defined the methods of adjustment and initial intervals of the parameters that would be used in the SWAT application in the BHRM. The parameters related to the solid phase of the water were excluded, because the basin in question is under influence of tropical domain and does not count on such phenomena.

It is worth mentioning that several studies make use of these parameters for the initial configuration of the model for the flow variable (Andrade et al., 2013; Neto et al., 2014).

Based on the results of the last performed simulation a sensitivity ranking of the parameters defined through the analysis of the values of the "t-stat" and "p-value" indexes was presented according to methodology described by Singh et al. (2013).

TABLE 2. Parameters used from the SWAT model.

Parameter	Meaning
CN2	Number of the initial curve for the moisture condition AMCII (dimensionless)
ALPHA_BF	Baseline flow recession constant (days)
GW_DELAY	Time interval for recharge of the aquifer (days)
GWQMN	Water limit level in the shallow aquifer for the occurrence of base flow (mm)
CH_K2	Effective hydraulic conductivity of the channel (mm h^{-1})
SURLAG	Delay time of direct surface runoff (days)
SOL_K	Saturated soil hydraulic conductivity (mm h^{-1})
CH_N2	Manning coefficient for the main channel (s $m^{-0.33}$)
ESCO	Soil water evaporation compensation factor (dimensionless)
SLSOIL	Slope length for lateral subsurface flow (m)
CANMX	Maximum amount of water intercepted by vegetation (mm)
SOL_AWC	Soil water storage (mm mm^{-1})
SOL_Z	Depth of soil layer (mm)
GW_REVAP	Coefficient of water rise to saturation zone (dimensionless)
BIOMIX	Efficiency of soil biological mix (dimensionless)
SOL_ALB	Soil Albedo (dimensionless)
REVAPMN	Water depth in the aquifer for the occurrence of water rise to the unsaturated zone (mm)
EPCO	Factor of compensation of water consumption by plants (dimensionless)
SLSUBBSN	Average slope length (m)

From the definition of parameters' model, the calibration step started from 250 iterations by simulation until the objective function was reached (Abbaspour, 2007). The objective function was defined by the Nash-Suttclife efficiency coefficient developed by Nash & Suttclife (1970), opting for a value of 0.6 in order to seek good performance without causing bias to the model.

The model calibration was done for a fluviometric station and the validation carried out in the other basin stations. This technique is justified on the premise of modeling which the model must be able to respond to the entire hydrological process that occurs in the basin for the calibration conditions. The chosen fluviometric station for the calibration stage was Carlos Chagas (55630000). This choice was justified by the existence of three upstream stations (Mucuri (55520001), Fazenda Diacuí (55560000) and Francisco Sá (55610000)), one downstream (Nanuque Upstream (55699998)), and another totally independent (São Pedro do Pampã (55660000)) which, although in a same basin, present very different characteristics. Figure 2 represents the spatial distribution of the fluviometric stations.

The Nanuque Upstream station (55699998) contains all others in its drainage area, therefore, chosen for downstream validation. The São Pedro do Pampã station (55660000) has no drainage area in common with the calibration station. This fact becomes interesting to visualize the applicability of the model to the whole basin.
The coefficients of determination (R2) and Nash-Suttclife (E_{NS}) efficiency were used to analyze the adjustment of the values predicted by the model to the observed data, and to evaluate the magnitude of the error was used the Percentage of Trend (P_{BIAS}) (Abbaspour , 2007).

Moriasi et al. (2007) defined values of E_{NS}, P_{BIAS} and R^2 for the evaluation models. Van Liew et al. (2003) and Fernandez et al. (2005) also proposed some limits for the classification of these statistical indices. Table 3 shows the used limits of the statistical indices.

TABLE 3. Classification of statistical indices.

E_{NS}	P_{BIAS}	R²	Classification
$0.75 < E_{NS} \leq 1.00$	$P_{BIAS} \leq \pm 10$	$0.75 < R^2 \leq 1.00$	Very good
$0.60 < E_{NS} \leq 0.75$	$\pm 10 < P_{BIAS} \leq \pm 15$	$0.60 < R^2 \leq 0.75$	Good
$0.36 < E_{NS} \leq 0.60$	$\pm 15 < P_{BIAS} \leq \pm 25$	$0.50 < R^2 \leq 0.60$	Satisfactory
$0.00 < E_{NS} \leq 0.36$	$\pm 25 < P_{BIAS} \leq \pm 50$	$0.25 < R^2 \leq 0.50$	Bad
$E_{NS} \leq 0.00$	$\pm 50 \leq P_{BIAS}$	$R^2 \leq 0.25$	Inappropriate

Source: Adapted from Moriasi et al. (2007), Van Liew et al. (2003) and Fernandez et al. (2005).

RESULTS AND DISCUSSION

From the definition of the parameters to be calibrated and the subsequent calibration, SWAT-CUP defines the parameters most sensitive to calibration using the Latin Hypercube (LH) and one-factor-a-time (OAT) methods, using this information for the next iteration, if any. The ranking of the parameters based on the "t-stat" and "p-value" indexes, after five simulations with 250 iterations each, is presented in Figure 5.

The most sensitive parameters in the calibration step are presented at the top of the rankings, that is, the highest value of the t-stat index module which represents the ratio of the parameter coefficient by the standard error; and the lower value of the "p-value" which is related to the rejection of the hypothesis that an addition in the value of the parameter provides a significant increase in the variable response (Abbaspour, 2007).

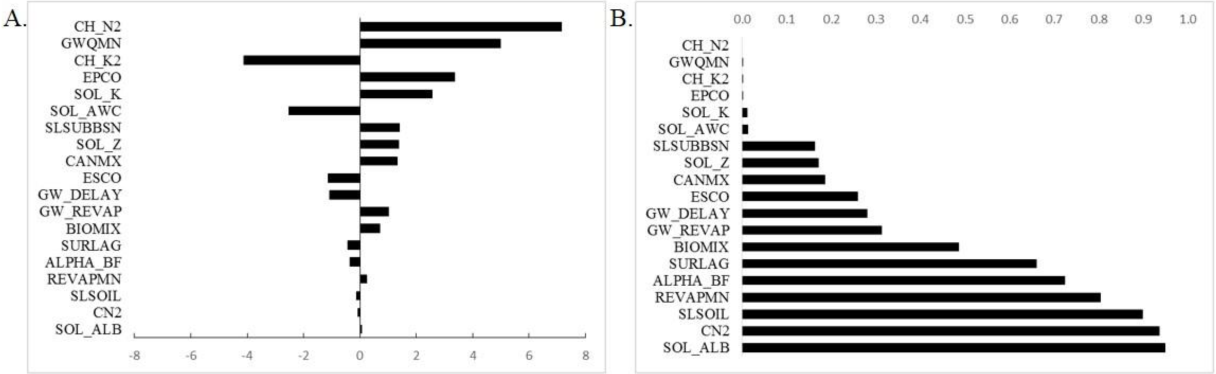

FIGURE 5. Graph of statistical index values: a) "t-stat"; and b) "p-value" *versus* calibrated parameters.

The most sensitive parameters were CH_N2, GWQMN, CH_K2, EPCO, SOL_K and SOL_AWC (Table 2), ranked according to the highest sensitivity tested at a significance level of 5%. These parameters are related to the flow in the channel (CH_N2 and CH_K2), water in the soil (GWQMN, SOL_K and SOL_AWC) and the vegetation water consumption factor (EPCO). It is interesting to note that the CN2 parameter did not show the expected sensitivity, since it is related to direct surface flow however; it was shown to be one of the least sensitive. This fact may be related to the characteristic of the relief, being this more flat in great extent of the basin; as well as by the predominant soil (Oxisol) have great permeability, and, thus, favor the component related to water infiltration in the soil and consequently, the formation of the flow from the base flows.

Pinto et al. (2013) describe the CH_K2 parameter as one of the most sensitive for the characteristics of the study region, and other parameters presented differing degrees of sensitivity. Neto et al. (2014) found results similar to those of Pinto (2011), but with the GWQMN factor as one of the most sensitive for the region in question. This fact can be evidenced by the fact that these basins are closer to each other, both in the Alto Rio Grande region. Due to the proximity they are in regions with similar characteristics of soil occupation, besides the topographic ones being close (regions with high slopes), consequently, they are submitted to hydrological processes strongly influenced by direct surface runoff.

Other studies have shown several parameters to be more sensitive to the most diverse watersheds in the world, such as: SOL_AWC (Schmalz & Fohrer, 2009; Lelis et al., 2012; Santosh et al., 2010), SOL_K (Cibin et al., 2010), EPCO (Jha, 2009; Jeong et al., 2010), SOL_K (Cibin et al., 2010).

Table 4 shows the used method for the calibration; the limits for the calibration interval of the parameters (Pinto et al., 2013, Pereira et al., 2016; Lelis et al., 2012) and the calibrated value for each parameter.

TABLE 4. Methods, initial adjustment intervals and calibrated value for each parameter.

Parameter	Method	Initial Minimum value	Initial Maximum value	Calibrated value
CH_N2	Absolute	0.01	0.059	0.116929
GWQMN	Absolute	-500	1000	1365.775
CH_K2	Absolute	0	25	8.948516
EPCO	Absolute	0	1	-0.16168
SOL_K	Relative	-0.9	0.9	-0.40892
SOL_AWC	Relative	-0.25	0.25	-0.21873
SLSUBBSN	Relative	-0.25	0.25	0.059871
SOL_Z	Relative	-0.25	0.25	0.164637
CANMX	Absolute	0	10	14.94177
ESCO	Absolute	0	1	0.786809
GW_DELAY	Absolute	10	120	82.0119
GW_REVAP	Absolute	0,02	0.2	0.33627
BIOMIX	Absolute	0	1	0.687435
SURLAG	Absolute	0.5	10	1.664087
ALPHA_BF	Relativo	0	0.048	0.004285
REVAPMN	Absolute	-50	100	40.74179
SLSOIL	Relative	-0.5	0,5	-0.59382
CN2	Relative	-0.3	0.3	-0.65569
SOL_ALB	Relative	-0.25	0.25	-0.15716

After each simulation the SWAT-CUP suggests new values of intervals, always aiming at the statistical optimization of precision. Due to this characteristic the calibrated value for each parameter can appear outside the initial intervals, since were performed five simulations. These calibrated values were adjusted from Carlos Chagas station. The simulated and observed hydrograms as well as the precipitation at the station are shown in Figure 6A.

By the analysis of Figure 6A, the observed and simulated values were close, with discrepancies in the regions of peak flow which the SWAT calibrated model for the basin had more difficulty in simulating. There is still a tendency to overestimate the model in the recession phase immediately after the highest flow peaks, especially in the beginning periods of each year.

The efficiency coefficient of Nash-Suttclife (E_{NS}) presented a value of 0.63, being considered Good, as well as the correlation coefficient (R^2) which presented value of 0.65. Finally, the percentage of trend (P_{BIAS}) was -15, that is, a general tendency of an overestimate of 15% which is close to the limit between the Good and Satisfactory classification (Table 3).

In order to validate the SWAT model in the BHRM were used other available fluviometric stations. The daily arrangement of simulate and observe flows as well as precipitation are shown in the sequence.

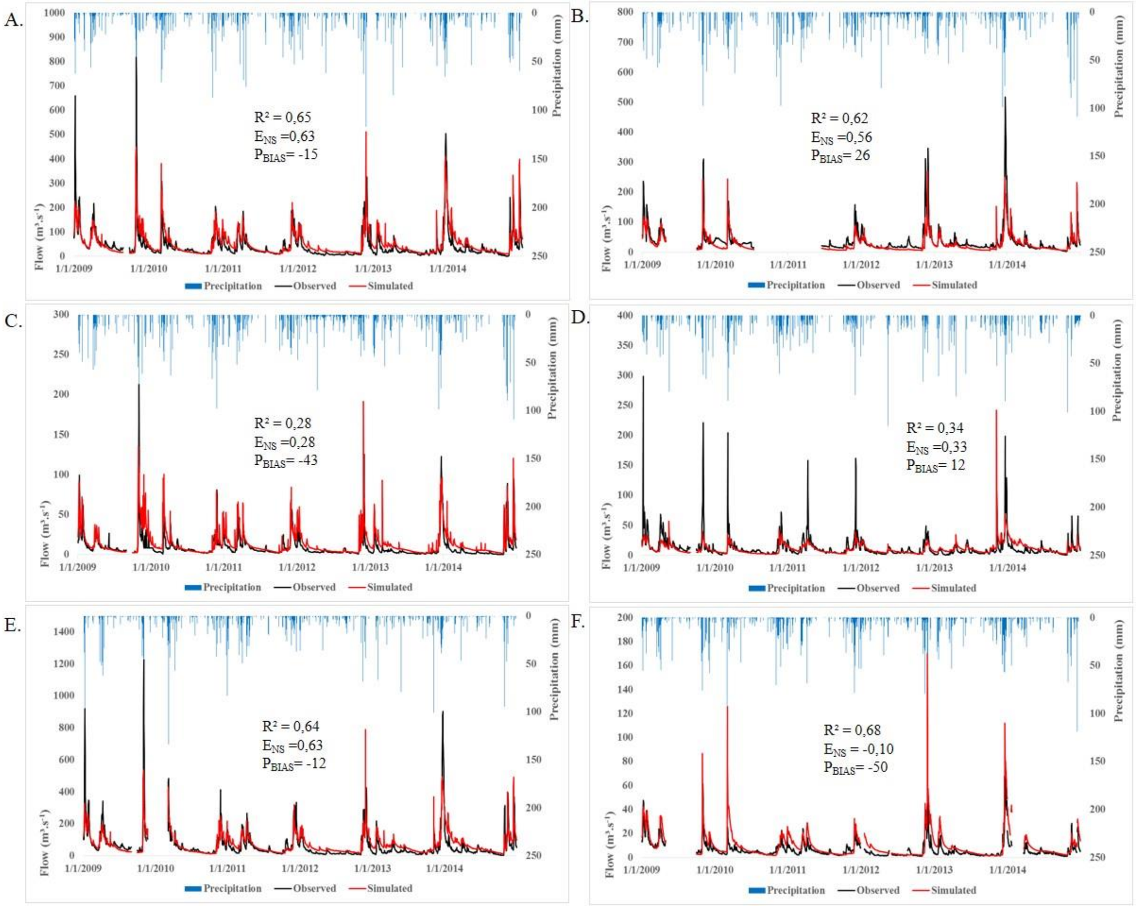

FIGURE 6. Hydrograms observed, simulated and precipitations for the stations in the BHRM, being: a) Carlos Chagas (calibration); b) Diacui farm (validation); c) Francisco Sá (validation); d) São Pedro do Pampã (validation); e) Nanuque Upstream (validation); and f) Mucuri (validation).

For the Diacui Farm station, Figure 6B, it was verified the presence of two major faults in the data period, being part of the middle of the year 2009 and end of 2010 until the middle of 2011. It is a station that presents values with lower mean flow that is $100 m^3 s^{-1}$, but there is a peak of 516 $m^3 s^{-1}$ in December 2013. In general, it is possible to observe the presence of underestimation model, especially in the large flow peaks, which are hydrologically influenced by phenomena related to direct surface runoff.

The Francisco Sá station (Figure 6C) had practically no flaws, except for the month of September in 2009. The overall behavior of the simulated series was visually superior to the observed series, except for the peak event at the end of 2010 and beginning of 2014. It can be observed that the values at the station were much lower than 50 $m^3 s^{-1}$, except in the rainy periods.

For the São Pedro do Pampã station it was verified that the simulated series showed very little sensitivity to the flow peaks (Figure 6D). The behavior presented is close to the expected behavior of the base flow. The observed values at the station were below 25 $m^3 s^{-1}$ most of the time, exceeding this limit during some extreme events, generally associated with daily rainfall greater than 50 mm.

The Nanuque Upstream station (Figure 6E) presented a fault in the period from November 2009 to March 2010. The overall behavior of the simulated series was visually above the observed series, except for peak events. It was observed that the values at the station were close to the average of 100 $m^3 s^{-1}$ with maximum observed value of 1,226 m³ s^{-1}. The flow of this station was superior to the others because it is the closest station to the mouth of the basin.

The simulated Hydrogram of Mucuri station presented a behavior that was noticeably higher than that observed (Figure 6F). The station presented values lower than 10 m³ s^{-1} most of the time. There are several flaws in the series being the major one in the middle of 2009.

The statistical accuracy indices results (E_{NS}, P_{BIAS} and R²) and their classification according to Table 3 for the fluviometric stations are in Table 5.

TABLE 5. Accuracy statistical indexes of SWAT adjustment for the various stations.

Station	Name	Fase	E_{NS}	Clas.[1]	P_{BIAS}	Clas.	R²	Clas.
55630000	Carlos Chagas	Calibration	0.63	B[2]	-15	B	0,65	B
55560000	Diacui Farm	Validation	0.56	S[3]	26	R	0,62	B
55610000	Francisco Sá	Validation	0.28	R[4]	-43	R	0,28	R
55660000	São Pedro do Pampã	Validation	0.33	R	12	B	0,34	R
55699998	Nanuque Upstream	Validation	0.63	B	-12	B	0,64	B
55520001	Mucuri	Validation	-0.10	I[5]	-50	I	0,68	B

[1]Classification; [2]Good; [3]Satisfactory; [4]Bad; [5]Inappropriate.

The statistical accuracy indexes E_{NS}, P_{BIAS} and R^2 for Carlos Chagas station (calibration stage) indicate that the model had a good adjustment.

In the validation stage it is possible to observe different performances of the evaluated statistical indices. According to the E_{NS} index the use of model at the Nanuque Upstream station was good; at the Diacui Farm station was satisfactory; at the Francisco Sá and São Pedro do Pampã stations was bad, and at the Mucuri station was inadequate according to values suggested by Moriasi et al. (2007).

By the analysis of the P_{BIAS} index the trend was not the same as the one observed in the E_{NS} index, since in São Pedro do Pampã and Nanuque Upstream station the classification was good, in Diacui Farm and Francisco Sá station was bad and for the Mucuri station inadequate. However, R² index in Diacui Farm, Nanuque Upstream and Mucuri stations was considered good, and in the others as bad (Van Liew et al., 2003; Fernandez et al., 2005).

As for the results of the statistical indices it is possible to infer that in the Francisco Sá, São Pedro do Pampã and Mucuri stations the model presented inferior performance basically due to stations being located in regions with the use and occupation of the soil differentiated from the average calibration station. In the drainage area of Francisco Sá station there is a great presence of regions with urban spots and exposed soil, and in the drainage areas of São Pedro do Pampã and Mucuri station are regions with greater percentage of forest and agriculture, respectively. Durães et al. (2011) reported variation in flow rate due to changes in land use and occupation, corroborating with results obtained under different land use domains.

Another factor that may be related is the relief, since Francisco Sá, São Pedro do Pampã and Mucuri stations are located in the headwater regions of BHRM, consequently, with high slopes. Due to the calibration occurring in a station with less rugged relief average the predominant hydrological processes are different. The headwater regions generally have the flow formation predominantly associated with the components of the direct surface runoff. Pinto et al. (2013) studying the application of SWAT model in the headwater region of Rio Grande Basin observed that the most sensitive parameters of the model are related to direct surface runoff components.

For the downstream regions, its flow formation process is predominantly associated with the components of the base flow. This analysis is confirmed by the low sensitivity of the parameters associated with the direct surface runoff in the sensitivity analysis phase of the model (Lelis et al., 2012).

CONCLUSIONS

The SWAT model presented a good performance in the calibration stage and in the validation stage it was adequate in most stations for the edaphoclimatic conditions of the BHRM. The SWAT-CUP module was an important tool for sensitivity analysis, calibration and validation of the model. SWAT, based on its performance, demonstrates the ability to use alternative scenarios simulations and their impacts on the hydrological cycle in future investigations.

REFERENCES

Abbaspour KC (2007) SWAT-CUP, SWAT Calibration and Uncertainty Programs. A user manual. Zurich, Swiss Federal Institute for Aquatic Science and Technology, 84p.

Abbaspour KC, Rouholahnejad E, Vaghefi S, Srinivasan R, Yang H, Kløve B (2015) A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology 524(1):733-752. DOI: http://dx.doi.org/10.1016/j.jhydrol.2015.03.027

Ajami NK, Gupta H, Wagener T, Sorooshian S (2004) Calibration of a semi-distributed hydrologic model for streamflow estimation along a river system. Journal of hydrology 298(1):112-135. DOI: http://dx.doi.org/10.1016/j.jhydrol.2004.03.033

Andrade MA, Mello CR, Beskow S (2013) Simulação hidrológica em uma bacia hidrográfica representativa dos Latossolos na região Alto Rio Grande, MG. Revista brasileira de engenharia agrícola e ambiental 17(1):69-76. http://dx.doi.org/10.1590/S1415-43662013000100010

Arnold JG, Moriasi DN, Gassman PW, Abbaspour KC, White MJ, Srinivasan R, Santhi C, Harmel RD, Van Griensven A, Van Liew MW, Kannan N, Jha MK (2012) SWAT: model use, calibration, and validation. Transactions of the ASABE 55(4):1491-1508.

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development. Journal of the American Water Resources Association 34(1):73-89. DOI: http://dx.doi.org/10.1111/j.1752-1688.1998.tb05961.x

Awan UK, Ismaeel A (2014) A new technique to map groundwater recharge in irrigated areas using a SWAT model under changing climate. Journal of Hydrology 519(1):1368-1382. DOI: http://dx.doi.org/10.1016/j.jhydrol.2014.08.049

Blainski E, Silviera FA, Conceição G, Garbossa LHP, Vianna LF (2011) Simulação de cenários de uso do solo na bacia hidrográfica do rio Araranguá utilizando a técnica da modelagem hidrológica. Revista Agropecuária Catarinense 24(1):65-70.

Bressiani DA, Gassman PW, Fernandes JG, Garbossa LHP, Srinivasan R, Bonumá NB, Mendiondo EM (2015) Review of Soil and Water Assessment tool (SWAT) applications in Brazil: challenges and prospects. International Journal of Agricultural and Biological Engineering 8(3):9-35. DOI: http://dx.doi.org/10.3965/j.ijabe.20150803.1765

Cibin R, Sudheer KP, Chaubey I (2010) Sensitivity and identifiability of stream flow generation parameters of the SWAT model. Hydrological Processes 24(9):1133-1148. DOI: http://dx.doi.org/10.1002/hyp.7568

Durães MF, Mello CR, Naghettini M (2011) Applicability of the SWAT model for hydrologic simulation in Paraopeba river basin, MG. Cerne 17(4):481-488. DOI: http://dx.doi.org/10.1590/S0104-77602011000400006

Elesbon AAA, Guedes HAS, Silva DD, Oliveira IC (2011) Uso de dados SRTM e plataforma SIG na caracterização morfométrica da bacia hidrográfica do Braço Norte do Rio São Mateus - Brasil. Revista Escola de Minas 64(3):281-288. DOI: http://dx.doi.org/10.1590/S0370-44672011000300005

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária (1979) Serviço Nacional de Levantamento e Conservação de Solos. Súmula da 10 Reunião Técnica de Levantamento de Solos. EMBRAPA-SNLCS. 83p. (Micelânea, 1)

Ercan MB, Goodall JL, Castronova AM, Humphrey M, Beekwilder N (2014) Calibration of SWAT models using the cloud. Environmental Modelling & Software 62(1):188-196. DOI: http://dx.doi.org/10.1016/j.envsoft.2014.09.002

Fernandez GP, Chescheir GM, Skaggs RW, Amatya DM (2005) Development and testing of watershed-scale models for poorly drained soils. Transactions of the ASAE 48(2):639-652.

IGAM - Instituto Mineiro de Gestão das Águas (2011) Plano estadual de recursos hídricos. IGAM, 192p.

Jha M (2009) Hydrologic simulations of the Maquoketa River Watershed Using SWAT. Ames, Center for Agricultural and Rural Development. 24p.

Jeong J, Kannan N, Arnold J, Glick R, Gosselink L, Srinivasan R (2010) Development and integration of sub-hourly rainfall-runoff modeling capability within a watershed model. Water Resources Management 24(15):4505-4527. DOI: http://dx.doi.org 10.1007/s11269-010-9670-4

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15(3):259-263. DOI: http://dx.doi.org 10.1127/0941-2948/2006/0130

Lelis TA, Calijuri ML, Santiago AF, Lima DC, Rocha EO (2012) Análise de sensibilidade e calibração do modelo SWAT aplicado em bacia hidrográfica da região sudeste do Brasil. Revista Brasileira de Ciência do Solo 36(2):623-634. DOI: http://dx.doi.org/10.1590/S0100-06832012000200031

Li Q, Chen X, Luo Y, Lu Z, Wang Y (2015) A new parallel framework of distributed SWAT calibration. Journal of Arid Land 7(1):122-131. DOI: http://dx.doi.org 10.1007/s40333-014-0041-5

Marek GW, Gowda PH, Evett SR, Baumhardt L, Brauer DK, Howell TA, Marek TH, Srinivasan R (2016) Calibration and validation of SWAT model for prediciting daily ET over irrigated crops in Texas high plains using lysimetric data. Transactions of the ASABE 59(2):611-622.

Meaurio M, Zabaleta A, Uriarte J, Srinivasan R, Antigüedad I (2015) Evaluation of SWAT models performance to simulate streamflow spatial origin. The case of a small forested watershed. Journal of Hydrology 525(1):326-334. DOI: http://dx.doi.org/10.1016/j.jhydrol.2015.03.050

Monteiro JAF, Strauch M, Srinivasan R, Abbaspour K, Gucker B (2015) Accuracy of grid precipitation data for Brazil: application in river discharge modelling of the Tocantins catchment. Hydrological processes 30(1):1419-1430. DOI: http://dx.doi.org/10.1002/hyp.10708

Moriasi DN, Arnold JG, Van Liew MW, Binger RL, Harmel RD, Veith TL (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50(1):885-900.

Muleta MK, Nicklow JW (2005) Sensitivity and uncertainty analysis coupled with automatic calibration for a distributed watershed model. Journal of Hydrology 306(1):127-145. DOI: http://dx.doi.org/10.1016/j.jhydrol.2004.09.005

Nash JE, Suttclife JE (1970) River flow forecasting through conceptual model: Part I: a discussion of principles. Journal of Hydrology 10(3):282-290. DOI: http://dx.doi.org/10.1016/0022-1694(70)90255-6

Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R, Williams JR (2005) Soil and water assessment tool input/output file documentation version 2005. Available: http://www.brc.tamus.edu/swat/downloads/doc/swat2005/SWAT%202005%20io.pdf. Accessed: Apr 11, 2015.

Neto JOM, Silva AA, Mello CR, Júnior AVM (2014) Simulação Hidrológica escalar com o modelo SWAT. Revista Brasileira de Recursos Hídricos 19(1):177-188. DOI: http://dx.doi.org/10.21168/rbrh.v19n1.p177-188

Oliveira LT (2014) Aplicação do modelo SWAT para simular vazões em uma bacia hidrográfica em Aracruz, ES. Dissertação Mestrado, Vitória, Universidade Federal do Espírito Santo.

Pereira DR, Martinez MA, Almeida AQ, Pruski FF, Silva DD, Zonta JH (2014) Hydrological simulation using SWAT model in headwater basin in southeast Brazil. Engenharia Agrícola 34(4):789-799. DOI: http://dx.doi.org/10.1590/S0100-69162014000400018

Pereira DR, Martinez MA, Pruski FF, Silva DD (2016) Hydrological simulation in a basin of typical tropical climate and soil using the SWAT model part I: Calibration and validation tests. Journal of Hydrology 7(1):14-37. DOI: http://dx.doi.org/10.1016/j.ejrh.2015.11.008

Pinto DBF (2011) Aplicação do modelo SWAT (Soil and Water Assessment Tool) na simulação hidrossedimentológica em bacia hidrográfica da Serra da Mantiqueira, MG. Tese, Lavras, Universidade Federal de Lavras.

Pinto DBF, Silva AM, Beskow S, Mello CR, Coelho G (2013) Application of the soil and water assessment tool (SWAT) for sediment transport simulation at a headwater watershed in Minas Gerais state, Brazil. Transactions of the ASABE 56(2):697-709.

Santosh T, Kolladi R, Surya T (2010) Influence of Scale on SWAT Model Calibration for Streamflow in a River Basin in the Humid Tropics. Water Resources Management 24(1):4567-4578. DOI: http://dx.doi.org/10.1007/s11269-010-9676-y

Singh V, Bankar N, Salunkhe SS, Bera AK, Sharma JR (2013) Hydrological stream flow modelling on Tungabhadra catchment: parameterization and uncertainty analysis using SWAT CUP. Current Science 40(9):1187-1199.

Schmalz B, Fohrer N (2009) Comparing model sensitivities of different landscapes using the ecohydrological SWAT model. Advanced Geoscience 21(1):91-98.

Tundisi JG, Tundisi TM (2010) Impactos potenciais das alterações do código florestal nos recursos hídricos. Biota Neotropica 10(4):67-76.

Van Liew MW, Arnold JG, Garbrecht JD (2003) Hydrologic simulation on agricultural watersheds: Choosing between two models. Transactions of the ASAE 46(6):1539-1551.

Winchell M, Srinivasan R, Di Luzio M, Arnold J (2009) ArcSWAT 2.3.4 interface for SWAT2005 - user’s guide. Available: http://www.brc.tamus.edu/swat/downloads/doc/swat2005/SWAT%202005%20io.pdf. Accessed: Sep 8, 2013.