Eco. Env. & Cons. 29 (2) : 2023; pp. (744-750)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i02.033

Sensitivity analysis, Calibration and Validation of SWAT model for the Lower Mahanadi River Basin

Mithlesh Kumar[1]*, A.P. Sahu[1], J. C. Paul[1] and Lokesh Kumar Tinde[2]

[1]College of Agricultural Engineering and Technology, Odisha University of Agriculture and Technology, Bhubaneswar 751 003, Odisha, India
[2]Department of Rural Technology and Social Development, Guru Ghasidas Vishwavidyalaya, Bilaspur 495 009, Bilaspur, India

(Received 6 October, 2022; Accepted 20 December, 2022)

ABSTRACT

Hydrological models are becoming a fundamental tool for natural resource planning and management; however, their application is hampered by a lack of data for calibration and validation. Therefore, the aim of this study is to calibrate and validate the SWAT model in the Lower Mahanadi river basin. The SWAT-CUP was used for sensitivity analysis, calibration and validation of the model. Based on the sensitivity analysis, twelve parameters were calibrated by the SWAT-CUP. The model performance indicators (R^2, NSE and PBIAS) showed satisfactory results with 0.76, 0.78 and 6.6 during calibration and 0.79, 0.74 and 7.8 during validation, respectively.

***Key words :** Hydrological model, SWAT, Calibration, Validation, Sensitivity analysis, SUFI-2*

Introduction

Water is in almost continuous motion in natural environment and the hydrological cycle changes its state from liquid to vapour or solid and vice-versa. Knowledge of the status and trends of water storage and movement within the hydrological cycle assists decision-makers, policymakers, and other stakeholders in quantifying various types of water scarcity threats and developing strategies for better utilization, allocation and long-term management of water resources (Verma and Verma, 2019).

The world's available water resources are constantly struggling to meet the rising agricultural water demand. Therefore, it is crucial to determine the amount of water needed at the local, regional, and global levels in order to achieve the sustainable and profitable yield. Many water resources authorities have developed policies for decision making in water resources management (Mwangi *et al.,* 2017). Further, in this context, hydrological models plays crucial role in effective water resources planning and decision making (Mwangi *et al.,* 2017). These models' temporal and spatial properties make them effective tools for managing urban and rural watersheds, managing water resources under different climatic conditions, and modelling groundwater (Thapa *et al.,* 2017).

Hydrological models are becoming more popular due to their ability to assess the impact of climate changes on natural resources (Mwangi *et al.,* 2017; Almeida *et al.,* 2018; Dakhlalla and Parajuli, 2019; Sane *et al.,* 2020). Further, these models are very effective in water scarcity regions because they simulates the impact of human activities on natural resources planning and management (Almeida *et al.,* 2018; Huo *et al.,* 2020). In recent years, the use of hydrological models has received a lot of attention for the simulation of rainfall-runoff relationships and flood forecasting (Nazari-sharabian *et al.,* 2019).

Hydrological models area valuable time saving and cost-effective tool for simulating the various hydrological processes (Musyoka *et al.,* 2021). The model highlights the dominant hydrologic system drivers, which improves our comprehension of the watershed and advances the development of hydrological management systems (Musyoka *et al.,* 2021). To address various hydrological issues at catchment scales, researchers have created a variety of models, including CREAMS, MIKE-SHE, VIC, ANSWERS, GLEAMS, HEC-HMS, and SWAT (Verma and Verma, 2019). The SWAT is one of the most well-liked and widely used hydrological models around the world for a variety of applications. Therefore, the aim of this study was to calibrate and validate the SWAT model in Lower Mahanadi river basin.

Materials and Method

Study area and input data

The Lower Mahanadi basin is situated between 20°03′40" and 20°47′45" N latitude and between 84°54′16" and 85°66′93" E longitude and covering a geographical area of 5971 km^2. The study area's elevation ranges from 64 m to 991 m above mean sea level. The Lower Mahanadi river basin has a humid subtropical climate with an average annual rainfall of 1421 mm. The location of the study area is shown in Fig. 1.

For execution of SWAT model, generally four input data are required: soil data, land use map, digital elevation model (DEM), and meteorological data. The CARTOSAT DEM of 30mx30m resolution (Fig. 2) and the LULC map of 1:50,000 scales (Fig. 3) were obtained from Bhuvan website (http://www.bhuvan.nrsc.gov.in/). The soil map of 1:5,000,000 scales was obtained from the world FAO soil database (Fig. 4). The climatic data was obtained from the India Meteorological Department, Bhubaneswar for the period of 12 years from 2001 to 2012. The available stream discharge data was collected from Naraj division, Cuttack for the same period.

Hydrological Model: SWAT

The SWAT is a catchment-scale, physically process-based model, developed to predict the impact of management practises on water and agricultural chemical yields on a basin scale (Arnold *et al.*, 1998). The model uses soil data, land use, DEM, and hydro-meteorological data for hydrological and climatologically modelling (Nilawar *et al.*, 2017; Baker and Miller, 2013). The major hydrological processes such as hydrology, sediments and nutrients transfer, vegetation growth, environmental and climatic change all can be simulated using SWAT model (Shahvari *et al.*, 2019; Breen *et al.*, 2020).

The model simulates the hydrological component using water balance equation as follows: (Nilawar *et al.*, 2017; Silva *et al.*, 2017; Swami and Kulkarni, 2017; Sane *et al.*, 2020).

$$SW_t = SW_o \, \Sigma_{i=1}^{t} (R_{day} - E_a - Q_{surf} - W_{seep} - Q_{gw}) \quad .. (1)$$

Where, SW_t (mm) and SW_o (mm) is the final and initial soil water content, R_{day}(mm) is the amount of precipitation, E_a(mm) is the amount of evapotranspiration, Q_{surf}(mm) is the amount of surface runoff, W_{seep}(mm) is the amount of percolation, Q_{gw}(mm) is the amount of return flow, and *t*(days) is the time.

Model set-up

Delineation of catchment is the first step in simulation procedure. The catchment area was delineated using the ArcSWAT interface. The definition of HRUs was continued after the process of catchment delineation was finished. Three types of spatial data such as soil, slope, and land use and land cover maps are required for the definition of HRUs. The HRU is the fundamental spatial unit, consisting of a unique combination of soil, land use, and slope characteristics (Winchell *et al.,* 2013). Using the weather generator tool, all of the necessary climatic input data was fed into the ArcSWAT interface. The SWAT simulation was started once the entire procedure was completed. A warming period of two years (2001-2002) was provided during the simulation. The total simulation period was set to run from 2003 to 2012 (10 years), excluding the warm-up period. The SWAT simulates the major water balance components on HRUs basis (Neitsch *et al.,* 2011; Arnold *et al.,* 2012).

Sensitivity analysis

Sensitivity analysis enables the testing of the model's efficacy by reducing the number of input parameters (Yu *et al.,* 2018). The SWAT-CUP along with the SUFI-2 algorithm was used to perform the sensitivity analysis of the model. The SWAT contains a huge number of parameters for different processes, and the calibration of all those parameters is tedious and time-consuming (Musyoka *et al.*, 2021). In order to enable modellers to calibrate only those parameters while minimising the number of parameters, sensitivity analysis was carried out to determine the parameters that contribute the most to the model's output variability owing to changes in input parameters (Musyoka *et al.*, 2021). Based on the different literatures, we used the parameters that are frequently used by many researchers (Sane *et al.*, 2020). A set of 12 parameters related to surface runoff, groundwater and percolation processes are usedto detect the most influential parameters. To prioritize the sensitive parameters, a global sensitivity procedure was followed. The parameter prioritization was carried out based on their t-stats and p-values.

Calibration and validation

To achieve satisfactory results, the model must be calibrated before being used in simulations of hydrological processes (Mengistu *et al.*, 2019). Calibration is a process to minimize the errors between the measured and simulated data before implementing the SWAT model successfully (Yu *et al.*, 2018; Breen *et al.*, 2020). Validation is the process of determining whether a result satisfies the goal and the model's credibility (Musyoka *et al.*, 2021). The calibration and validation are carried out using the SWAT-CUP software (Abbaspour *et al.*, 2007; Abbaspour, 2011). Calibration and validation process requires two sets of data: one for calibration and another for validation (Sane *et al.*, 2020). The first two years (2001–2002) were used as a warming period, and periods of six years (2003–2008) and four years (2009–2012) were taken for calibration and validation, respectively.

Model performance indices

Successful application of the SWAT model is heavily reliant on sensitivity analysis of model parameters (Moriasi *et al.*, 2007; Fereidoon *et al.*, 2019). The error between observed and simulated results is evaluated using graphical and statistical techniques. To evaluate the performance of model, three statistical indicators are used:the coefficient of correlation (R^2), the Nash-Sutcliffe efficiency (NSE), and the percent bias (PBIAS) (Dash *et al.*, 2021). The criteria for performance of hydrological model are presented in Table 1.

Results and Discussion

Sensitivity analysis

Table 2 contains a list of sensitivity parameters. The

Table 1. Criteria for evaluating the model'sperformance and their ranges (Ferraz *et al.*, 2021; Musyoka *et al.*, 2021)

Indicators	Performance criteria				
	Very good	Good	Satisfactory	Unsatisfactory	Ranges
R2	$R^2 > 0.85$	$0.75 < R^2 \leq 0.85$	$0.60 < R^2 \leq 0.75$	$R^2 \leq 0.60$	-1 to 1
NSE	NSE > 0.80	0.70 < NSE ≤ 0.80	0.50 < NSE ≤ 0.70	NSE ≤ 0.50	-∞ to 1
PBIAS	PBIAS < ±5	±5 ≤ PBIAS ≤ ±10	±10 ≤ PBIAS ≤ ±15	PBIAS ≤ ±15	-∞ to ∞

Table 2. Sensitivity parameters for stream flow simulation in the Lower Mahanadi river basin

Sl. No.	Parameters	*t*-stat	*p*-value	Description of abbreviation
1	CN2.mgt	5.89	0.00	SCS runoff curve number for moisture condition II
2	GW_DELAY.gw	3.14	0.00	Groundwater delay
3	GWQMN.gw	1.95	0.05	Threshold depth of base flow produced by shallow aquifer
4	EPCO.hru	1.57	0.12	Plant uptake compensation factor
5	ESCO.hru	1.56	0.12	Soil evaporation compensation parameter
6	CANMX.hru	1.34	0.18	Maximum canopy storage
7	SURLAG.bsn	1.17	0.24	Surface runoff lag time
8	SOL_AWC.sol	0.84	0.40	Available soil water parameter
9	GW_REVAP.gw	0.74	0.46	Groundwater "revap" coefficient
10.	SOL_K.sol	0.67	0.50	Saturated hydraulic conductivity, mm/hr
11.	SLSUBBSN.hru	0.44	0.66	Average slope length
12.	ALPHA_BF.gw	0.33	0.74	Baseflow subsided parameter

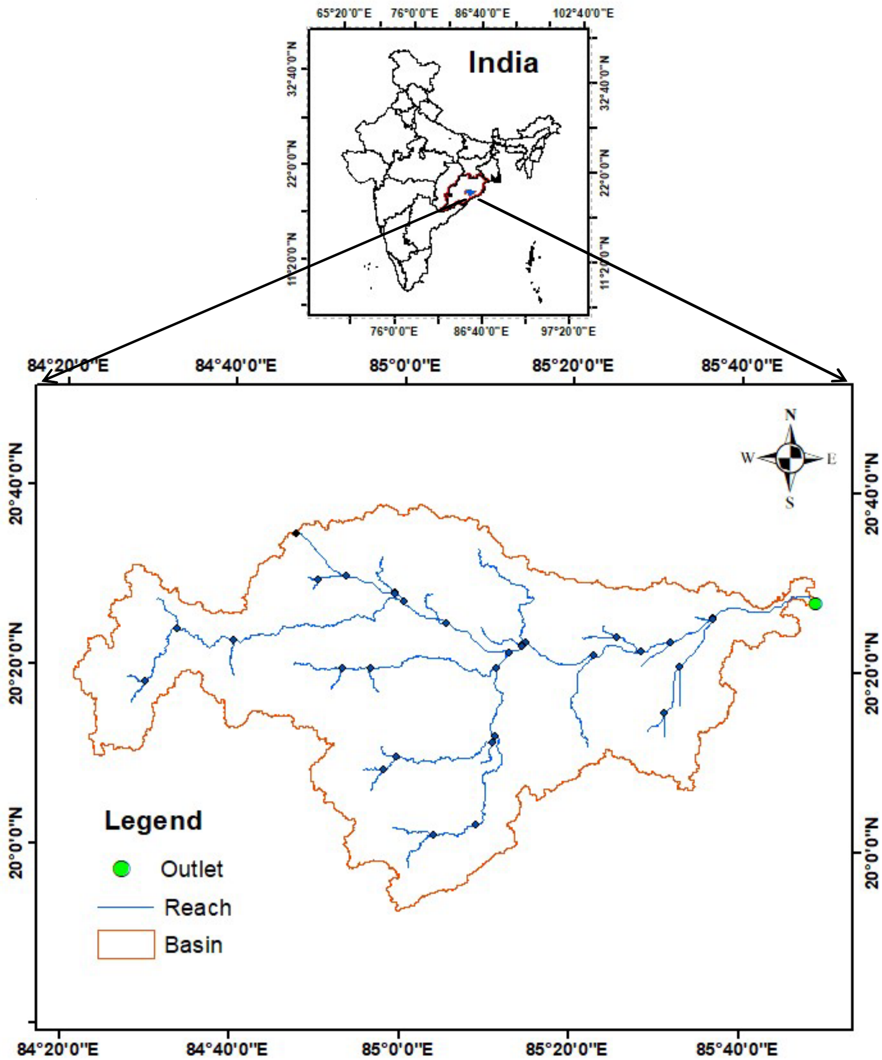

Fig. 1. The location of Lower Mahanadi river basin

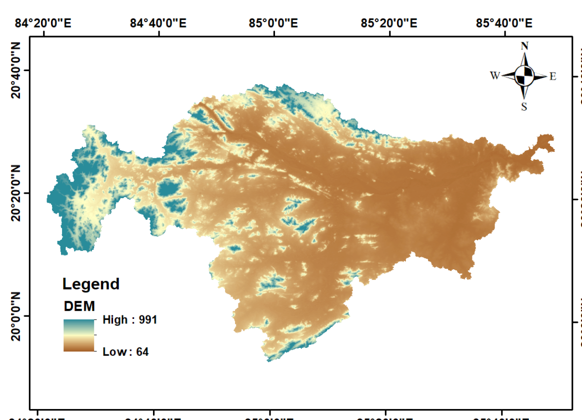

Fig. 2. DEM of Lower Mahanadi river basin

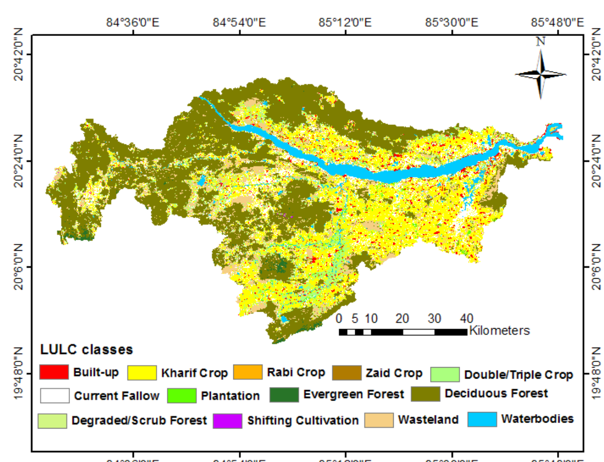

Fig. 3. LULC map of Lower Mahanadi river basin

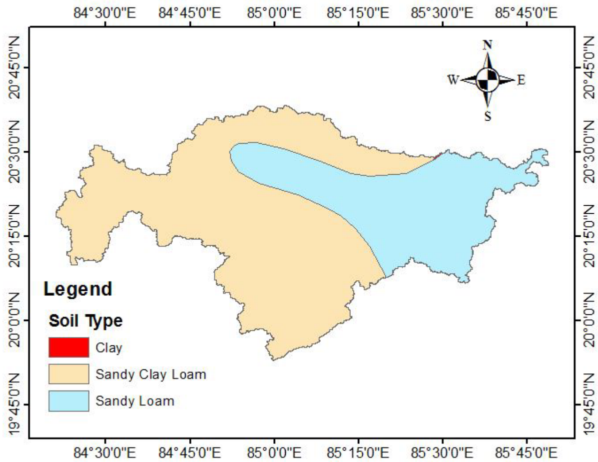

Fig. 4. Major soil types in Lower Mahanadi river basin

parameters are listed in order of sensitivity level as analyzed by SUFI-2 algorithm of SWAT-CUP. The result showed that CN2 was the most sensitivity parameters, followed by GW_DELAY, GWQMN, EPCO, ESCO, CANMX, SURLAG, SOL_AWC, GW_REVAP, SOL_K, SLSUBBSN andALPHA_BF, respectively.

SWAT model calibration and validation

The sensitivity analysis produced the list of sensitive parameters. Using the SUFI-2 algorithm, these parameters in SWAT-CUP are calibrated on a monthly time step.The calibrated parameters, change methods and final calibrated values are presented in Table 3. Fig. 5 shows the graphical comparison of simulated and observed streamflow data at the Lower Mahanadi river basin. The results showed that simulated discharge followed the same trends as observed discharge. The values of R^2, NSE, and PBIAS are 0.76, 0.78, and 6.6 during calibration and 0.79, 0.74, and 7.8 during validation, respectively. The model's performance results showed that the values of all performance indicators were within reasonable limits.

Conclusion

The SWAT-CUP was used in the Lower Mahanadi river basin to calibrate and validate the SWAT

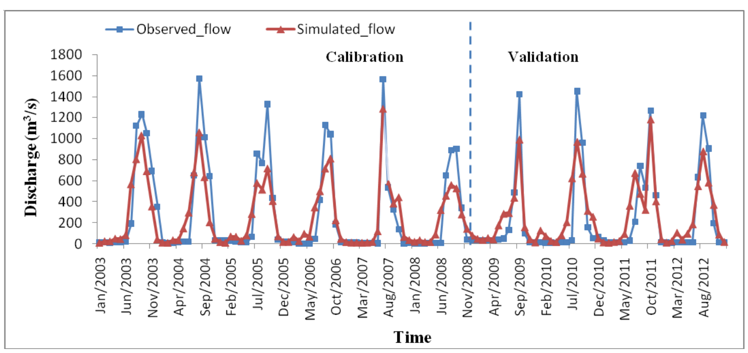

Fig. 5. Comparison of observed and simulated monthly streamflow

Table 3. Description and initial ranges of stream flow parameters

Sl. No.	Parameters name	Method of change	Minimumvalue	Maximum value	Calibrated value
1	R__CN2.mgt	Relative	-0.2	0.2	0.19
2	V__GW_DELAY.gw	Replace	30	450	417
3	V__GWQMN.gw	Replace	1	4500	512
4	V__EPCO.hru	Relative	0.01	1	0.53
5	V__ESCO.hru	Replace	0.01	1	0.75
6	V__CANMX.hru	Replace	0	25	1.18
7	V__SURLAG.bsn	Replace	0	24	23
8	R__SOL_AWC.sol	Relative	-0.15	0.15	-0.07
9	V__GW_REVAP.gw	Replace	0.02	0.18	0.09
10.	R__SOL_K.sol	Relative	-0.15	0.15	0.07
11.	R__SLSUBBSN.hru	Relative	-0.10	0.10	0.02
12.	V__ALPHA_BF.gw	Replace	0.01	1	0.23

model. A sensitivity analysis was done prior to calibration in order to determine which parameters were the most sensitive. The parameter CN2 was the most sensitive, followed by GW_DELAY, CH_N2, GWQMN, SOL_Z, and EPCO, respectively. The model was calibrated and validated for the period of 2003 to 2008 and 2009 to 2012, respectively. The two years (2001-2002) were kept as a warm-up period, which is required for proper adjustment of the hydrological parameters. The model's performance was assessed using NSE, R^2, and PBIAS, with values of 0.78, 0.76, and 6.6 during calibration and 0.74, 0.79, and 7.8 during validation. The study revealed that all the performance indicators showed satisfactory results.

Acknowledgement

This study was conducted at the College of Agricultural Engineering and Technology, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha.

Conflict of Interest

The author declares that there is no conflict of interest.

References

Abbaspour, K.C., Vejdani, M., Haghighat, S. and Yang, J. 2007. SWAT-CUP calibration and uncertainty programs for SWAT *Fourth International SWAT Conference 1596–1602*. *Adv Water Resour.* 54: 11–21.

Abbaspour, K. 2011. SWAT-CUP2: SWAT Calibration and Uncertainty Programs Manual Version 2. Eawag.Swiss Federal Institute of Aquatic Science and Technology, Department of Systems Analysis. *Integrated Assessment and Modeling (SIAM), Duebendorf, Switzerland*, *106*.

Almeida, R.A., Pereira, S.B. and Pinto, D.B. 2018. Calibration and validation of the SWAT hydrological model for the Mucuri river basin. *Engenharia Agrícola.* 38: 55-63.

Arnold, J.G., Moriasi, D.N., Gassman, P.W., Abbaspour, K.C., White, M.J., Srinivasan, R., Santhi, C., Harmel, D., van Griensven, A., Van L., Michael, W., Kannan, N. and Jha, M.K. 2012. SWAT: Model use, calibration, and validation. *Transactions of the ASABE*. 55(4): 1491-1508.

Arnold, J.G., Srinivasan, R., Muttiah, R.S. and Williams, J.R. 1998. Large area hydrologic modeling and assessment part I: model development. *J. Am. Water Res. Assoc.* 34 : 73–89, http://dx.doi.org/10.1111/j.1752-1688

Baker, T.J. and Miller, S.N. 2013. Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. *Journal of Hydrology.* 486: 100–111.

Breen, K.H., James, S.C., White, J.D., Allen, P.M. and Arnold, J.G. 2020. A Hybrid Artificial Neural Network to Estimate Soil Moisture Using SWAT+ and SMAP Data. *Machine Learning and Knowledge Extraction*. 2 : 283–306.doi: 10.3390/make2030016

Dakhlalla, A.O. and Parajuli, P.B. 2018. Assessing model parameters sensitivity and uncertainty of streamflow, sediment, and nutrient transport using SWAT. *Information Processing in Agriculture*, https://doi.org/10.1016/j.inpa.2018.08.007

Dash, S.S., Sahoo, B. and Raghuwanshi, N.S. 2021. How reliable are the evapotranspiration estimates by Soil and Water Assessment Tool (SWAT) and Variable Infiltration Capacity (VIC) models for catchment-scale drought assessment and irrigation planning? *Journal of Hydrology*. 592 : 125838.

Fereidoon, M., Koch, M. and Brocca, L. 2019. Predicting rainfall and runoff through satellite soil moisture data and SWAT modelling for a poorly gauged basin in Iran. *Water.* 11(3) : 594.

Ferraz, L.L., Sousa, L.F., Silva, L.S., Silva, J.O., Tagliaferre, C., Santos, C.A.S. and Rocha, F.A. 2021. Calibration and validation of the SWAT model for hydrological simulation in a basin in Western Bahia. *RevistaIbero Americana de Ciências Ambientais.* 12 (1): 276-285. DOI: http://doi.org/10.6008/CBPC2179-6858.2021.001.0023

Huo, A., Huang, Z., Cheng, Y. and Liew, M. W. V. 2020. Comparison of two different approaches for sensitivity analysis in Heihe River basin (China). *Water Supply*, IWA Publishing, 20; 1.

Mengistu, A. G., van Rensburg, L. D. and Woyessa, Y.E. 2019. Techniques for calibration and validation of SWAT model in data scarce arid and semi-arid catchments in South Africa. *Journal of Hydrology: Regional Studies.* 25 : 100621.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Binger, R.L., Harmel, R.D. and Veith. T. 2007: Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Trans ASABE.* 50(3): 885–900.

Musyoka, F.K., Strauss, P., Zhao, G., Srinivasan, R. and Klik, A. 2021. Multi-Step Calibration Approach for SWAT Model Using Soil Moisture and Crop Yields in a Small Agricultural Catchment. *Water.* 13: 2238. https://doi.org/10.3390/w13162238

Mwangi, W., Nyandega, I. and Kýthiia, S. 2017. Application of hydrological models in poorly gauged watersheds: A review of the usage of the Soil and Water Assessment Tool (SWAT) In Kenya.

Nazari-Sharabian, M., Taheriyoun, M. and Karakouzian,

M. 2019. Sensitivity analysis of the DEM resolution and effective parameters of runoff yield in the SWAT model: a case study. *Journal of Water Supply: Research and Technology-AQUA*. 1-16.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. 2011. Soil and Water Assessment Tool: Theoretical Documentation, Version 2009. Texas Water Resources Institute Technical Report No. 406. Texas A&M University, Texas, USA.

Nilawar, A.P., Calderella, C.P., Lakhankar, T.Y., Waikar, M.L. and Munoz, J. 2017. Satellite soil moisture validation using hydrological SWAT model: A case study of Puerto Rico, USA. *Hydrology.* 4(4): 45.

Sane, M.L., Sambou, S., Leye, I., Ndione, D.M., Diatta, S., Ndiaye, I., Badji, M.L. and Kane, S. 2020. Calibration and Validation of the SWAT Model on the Watershed of Bafing River, Main Upstream Tributary of Senegal River: Checking for the Influence of the Period of Study. *Open Journal of Modern Hydrology.* 10: 81-104. https://doi.org/10.4236/ojmh.2020.104006

Shahvari, N., Khalilian, S., Mosavi, S.H. and Mortazavi, S.A. 2019. Assessing climate change impacts on water resources and crop yield: a case study of Varamin plain basin, Iran. *Environ Monit Assess.* 191: 134. https://doi.org/10.1007/s10661-019-7266-x

Silva, V.P.R., Silva, M.T. and Souza, E.P. 2016. Influence of land use change on sediment yield: A case study of the sub-middle of the São Francisco river basin. *Journal of the Brazilian Association of Agricultural Engineering.* 36 (6): 1005-1015.

Swami, V. and Kulkarni, S. 2017. Application of SWAT model to investigate soil loss in Kaneriwatershed. *International Journal of Earth Sciences and Engineering,* 10 (2): 207-213.

Thapa, B.R., Ishidaira, H., Pandey, V.P. and Shakya, N.M. 2017. A multi-model approach for analyzing water balance dynamics in Kathmandu Valley, Nepal. *Journal of Hydrology: Regional Studies.* 9: 149–162.

Verma, M.K. and Verma, M.K. 2019. Calibration of a hydrological model and sensitivity analysis of its parameters: a case study of Seonath river basin. *Int. J. Hydrology Science and Technology.* 9(6): 640-656.

Winchell, M.F., Srinivasan, R., Di Luzio, M. and Arnold, J. 2013. ArcSWAT Interface for SWAT 2012 Users Guide. Black land Research and Extension Centre, Temple, Texas, USA P. 464.

Yu, D., Xie, P., Dong, X., Hu, X., Liu, J., Li, Y., Peng, T., Ma, H., Wang, K. and Xu, S. 2018. Improvement of the SWAT model for event-based flood simulation on a sub-daily timescale. *Hydrol. Earth Syst. Sci.* 22: 5001–5019, https://doi.org/10.5194/hess-22-5001-2018.