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Daily runoff estimation in Musi river basin, India, from gridded rainfall using SWAT model

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Abstract: The main objective is to assess the spatial water availability in Musi river basin, India from gridded rainfall data and compare the results with the observed discharge data. Musi River passing through Hyderabad, India being one of the major sub basins of Krishna River and is catering various demands. In the recent past, it is suffering from severe spatial and temporal water availability problem. Thus, there is a need to quantify the spatial and temporal runoff availability in the Musi River for better water management. The spatial and temporal runoff has been estimated using Soil Water Assessment Tool (SWAT) model with the available data. The SWAT model has been developed and validated with India Meteorological Department (IMD) gridded rainfall data as one of the inputs and the daily runoff data observed at Dharmacherla (runoff data obtained from WRIS website of Central Water Commission (CWC)) as the model output. A rigorous calibration, sensitivity and uncertainty analyses are being carried out using SWAT-CUP. The obtained results are evaluated using performance measures such as Coefficient of determination (R^2), Nash-Sutcliff Efficiency (NSE), Mean Absolute Error (MAE), and Percent bias (PBias). It is found that the results obtained from SWAT model are satisfactory. Based on the present study it may be concluded that SWAT model can be used to generate spatial and temporal runoff from IMD gridded rainfall data in Musi River Basin.

Key words: IMD gridded rainfall, Musi River India, Soil Water Assessment Tool, Spatial and temporal water availability, SWAT-CUP

1. INTRODUCTION

Water is one of the most important natural resources which support the survival of living organisms on earth. Rainfall is a primary cause of water existence on the land surface and is also a major input in hydrological models to quantify surface flow. Soil and Water Assessment Tool (SWAT) developed by Arnold *et al*. (1998) is a widely used semi-distributed hydrological model for estimating surface flow at catchment level. SWAT model is applied at different geographical locations of the earth for quantifying daily surface flow (Hernandez *et al*. 2000; Saha *et al*. 2014; Gamvroudis *et al*. 2015; Szcześniak and Piniewski 2015; Uniyal *et al*. 2015; Yen *et al*. 2015; Kim *et al*. 2016). It is reported that rainfall is a spatially distributed phenomenon which may not be represented by traditional rain gauges because of its course spatial distribution at catchment level (Xu *et al*. 2014). Therefore, representation of rainfall data in a gridded format with high resolution is needed for modeling surface flow. Previous studies also show the use of gridded rainfall data to estimate surface flow using SWAT model (Vu *et al.* 2012). Hence, there is a need to understand the applicability of the SWAT model for the prediction of runoff with gridded rainfall data.

There are two ways to quantify surface flow using SWAT model, (i) with curve number (CN) method and (ii) with physically based Green and Ampt method (GA). Yang *et al*. (2016) showed that daily runoff estimation using GA method is better. But GA method needs sub-daily rainfall data for runoff estimation which is highly difficult to get at the catchment scale. Therefore, in the present study CN method is used to estimate daily surface flow. SWAT model is a comprehensive model and relies on several parameters varying widely while transforming rainfall into runoff. Calibration process becomes complex and computationally extensive since the number of parameters is substantial. However, with the help of sensitivity analysis, it is possible to reduce the number of parameters by not considering non-sensitive parameters for calibration, which in turn can give results relatively in shorter time. SWAT Calibration and Uncertainty Program (SWAT-CUP) is the calibration, validation and sensitivity analysis of SWAT model.

2. STUDY AREA

The study area Musi basin lies between 78^0 to 79^0 44´ east longitudes and 16^0 40´ to 17^0 50´ northern latitudes and has an area about 10,885 km^2. Musi River is a tributary of the Krishna River in the Deccan Plateau flowing through Telangana state in India. It originates in Anantagiri Hills near Vikarabad in Ranga Reddy district, 90 km to the west of Hyderabad and flows due east. It finally joins Krishna river after traveling a length of 240 km in Nalgonda district at Vadapally.

3. HYDROLOGICAL MODELLING OF MUSI SUB BASIN USING SWAT

SWAT model is used for hydrological modelling of Musi basin where watershed delineation and hydrological response unit definition are to be carried out. Digital Elevation Model (DEM), soil map, land use and land cover map, and slope map are given as inputs to the SWAT model. DEM is used to delineate the watershed. Soil map, land use/land cover map and also slope maps used to create Hydrological response units (HRU’s).

Figure 1 shows that the Musi basin is divided into 98 sub-basins by using stream network and outlet point present in Dharmacherla. SWAT model was simulated to generate runoff by using gridded weather data obtained from India Meteorological Department (IMD). The simulated data is calibrated using manual calibration helper followed by SWAT-CUP by adjusting the parameters.

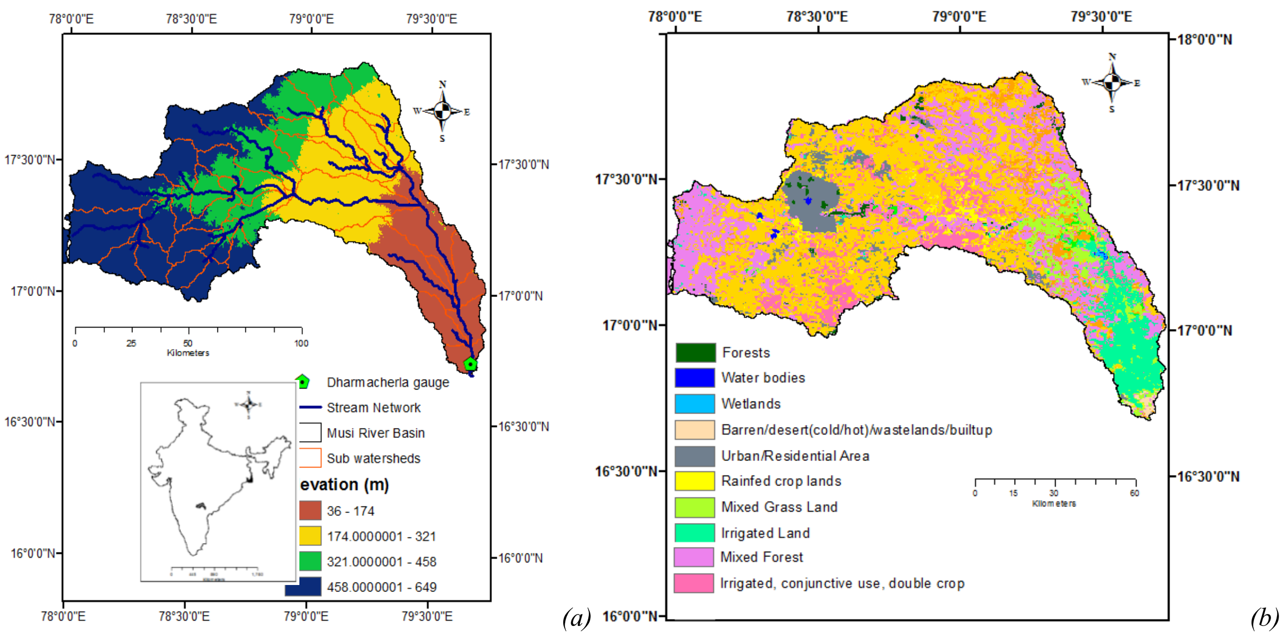

Figure 1. Location (a) and land use (b) maps of Musi basin

3.1 Database preparation

SWAT model primarily requires the following input data for the hydrologic simulation of runoff.

3.1.1 Climate data

SWAT requires climate data in daily time step for weather generation. The climate data includes information on the location of the weather station (latitude and longitude), daily values of precipitation (mm), maximum and minimum air temperature (^oC). India Meteorological Department (IMD) gridded precipitation data of $0.25^0x0.25^0$ resolution and temperature data of 1x1 degree resolution has been used.

3.1.2 Runoff data

The stream gauge measured by Central Water Commission (CWC) department located at Dharmacherla at the basin outlet is used for SWAT model calibration. The daily runoff time series has been collected from India-WRIS portal (*www.india-wris.nrsc.gov.in/wris.html*) for a period from 01 January 2001 to 31 May 2012 and the observed runoff is shown in the Figure 2(a). There seems to be one outlier which is 5 times of the nest maximum. Figure 2(b) shows the observed runoff after excluding that outlier. This data has been used in the further SWAT model.

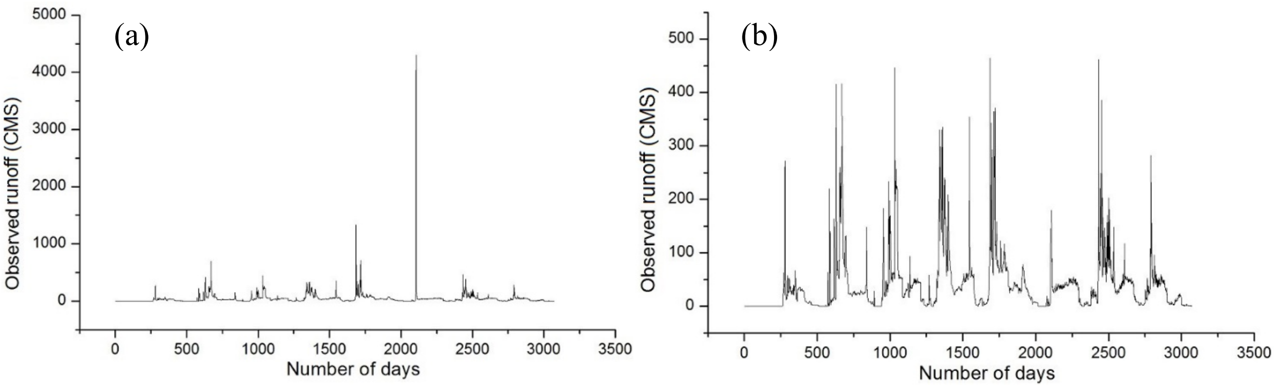

Figure 2. Time series for observed runoff a) original data, b) excluding peak runoff

3.1.3 Digital Elevation Model (DEM)

A 30m resolution digital elevation model has been downloaded from Bhuvan website (*http://bhuvan.nrsc.gov.in/data/download/index.php*). Different elevation bands can be seen from Figure 1. The high values are the locations of higher elevations located in Western Ghats and is shown in Figure 1.

3.1.4 Land Use and Soil map

Land use land cover map has been downloaded from the website *www.swat.tamu.edu* which is of 1km x 1km resolution for Indian data sets and has been used in this study. From the map (Figure 1b), it can be observed that there are around 10 classes of Land use. The types of land cover present in the watershed are shown in the Figure 1(b). Soil map of the Musi river basin has been downloaded in raster format from the website *www.swat.tamu.edu*. The Musi river consists of three different soil classes namely, silty loam, rocky/sandy loam, and fine sandy loam, however majority of the basin lies in rocky/sandy load type of soil.

3.1.5 HRU map

Hydrological response units (HRU) are the regions with homogenous land use, soil and topographical characteristics. SWAT requires the land use map, soil map and slope classification map for creating HRU. From SWAT overlay analysis nearly 341 HRU's were generated.

4. RESULTS AND DISCUSSION

The above collected, analysed and generated data has been used to simulate the runoff from Musi basin using SWAT model. As an initial step a sensitivity analysis has been carried out.

4.1 Sensitivity analysis

Sensitivity analysis is performed using the SUFI-2 algorithm of SWAT-CUP. The parameter producing the highest average percentage change in the objective function value is ranked as most sensitive.

SWAT-CUP uses the SWAT input files and runs the SWAT simulations by modifying the given parameters. Model calibration and validation are challenging and to a certain degree it is a subjective step in a complex hydrological model. SWAT model of Musi watershed was calibrated and validated using measured daily river discharge available at Dharmacherla.

The optimized parameters of the Musi watershed will be very important in representing the entire watershed and analyzing the water distribution under natural conditions. The Dharmacherla has the discharge data for the period 2001-2012 and the same has been used in the SWAT simulation. The first three years were used as a warm-up period to mitigate the effect of unknown initial conditions, which were subsequently excluded from the analysis. Hence, we divide the discharge data into two periods: a calibration (2004–2009) and a validation period (2010–2012). Based on the built in sensitivity analysis tool in SWAT (Neitsch *et al., 2002*), nine most sensitive parameters were identified. Nevertheless, it is concluded that other parameters are also considered to be important for SWAT simulation in the Musi watershed. After performing rigorous manual calibration, we feed initial values to SWAT-CUP after which sensitivity analysis is performed to get the best fitted values of the parameters. The Table 1 shows the parameter values prior to the usage of the SWAT-CUP and final values of the parameters after incorporating the sensitivised value obtained from the SWAT-CUP sensitivity analysis. The 14 parameters sensitivity analysis results are shown in Table 1. They represent the minimum and maximum values between which the parameters are changed in a SWAT-CUP sensitivity analysis to get the best fitted value of the parameters.

Table 1. Comparison of initial and final values of the parameters used in SWAT-CUP

Parameter Name	Parameter Description	Initial values	Final values	Minimum value	Maximum value
A__CH_K2.rte	Effective channel hydraulic conductivity, mm/hr	0.0000	55.16	55.0	65.0
R__CN2.mgt	Curve Number	77.000	76.81	76	82
V__OV_N.hru	Manning's N	0.1500	3.59	3.50	4.5
V_SURLAG.bsn	Surface runoff lag coefficient, mm/hour	4.0000	20.36	19.0	21.0
V__ESCO.bsn	Soil evaporation compensation factor	0.9500	0.67	0.63	0.68
V__RCHRG_DP.gw	Groundwater recharge	0.0500	0.18	0.0	0.2
R__SOL_K (...).sol	Saturated hydraulic conductivity	3.6634	-0.006	-0.04	0.0
V__GW_DELAY.gw	Ground water delay, days	31.000	57.50	55.0	60.0
A__GWQMN.gw	Threshold depth for ground water flow to occur, mm	1000.0	927.7	920.0	930.0
V__GW_REVAP.gw	Ground water evaporation coefficient	0.0200	0.082	0.08	0.11
V__EPCO.bsn	Plant uptake compensation factor	1.0000	0.89	0.85	0.9
V__ALPHA_BF.gw	Base flow recession factor, days	0.0480	0.08	0.08	0.09
R__SOL_AWC (...).sol	Available water capacity, m/m	0.1211	0.47	0.47	0.49
V__SOL_BD (...).sol	Moist bulk density (Mg/ m3)	1.5090	1.21	1.20	1.4

Table 2. Performance measures

Performance measure	Calibration	Validation
R^2	0.50	0.48
NSE	43 %	44 %
MAE (m^3/sec)	21.39	15.238
Pbias (m^3/sec)	-4.40	12.5

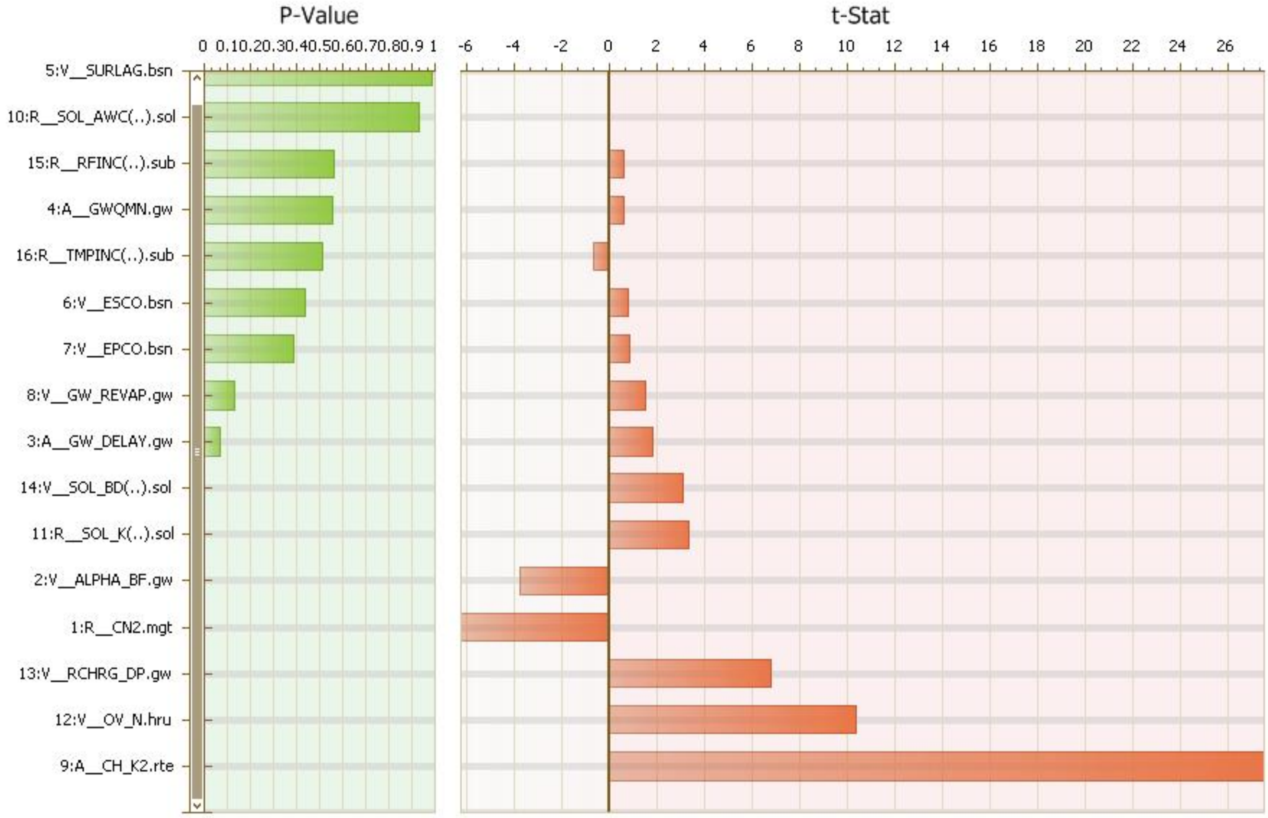

Figure 3. Sensitivity analysis of the SWAT model parameters used in Musi basin

4.2 Global sensitivity analysis

The sensitivities given above are resulted estimates of the average changes in the objective function. This gives relative sensitivities based on linear approximations and, hence, only provides partial t-stat value (larger in absolute values are more sensitive). P-values determined the significance of the sensitivity. A value close to zero has more significance. In Figure 3, it can be seen that the most sensitive parameters are CH_K2, OV_N, RCHRG_DP, CN2, ALPHA_BF, SOL_K and SOL_BD.

4.3 Calibration and Validation of Musi basin using SWAT-CUP

The SWAT hydrologic model was calibrated using observed inflow at Dharmacherla. The calibration procedure involved the adjustment of the SWAT parameters by using SWAT-CUP such that the resulting stream flows matched the observed inflows at Dharmacherla between the period 2004 and 2009 and validation was carried out between the period 2010 and 2012.

Before going to calibration of the model, there is a need to perform uncertainty analysis and sensitivity analysis. This has been carried out by using 14 parameters as shown in Table 1. All parameters except Surface Runoff Lag Coefficient (SURLAG) and Soil Available Water Capacity (SOL_AWC) are observed to be most sensitive parameters. The SWAT model was again simulated with these sensitivised parameters to obtain the daily discharge. The time series and scatter plot of observed and SWAT resulted runoff during calibration and testing period at basin outlet (Dharmacherla) are shown in Figures 4 and 5, respectively.

The performance of SWAT model has been analyzed based on the graphical representation as well as on the basis of various statistical parameters such as Nash Sutcliff Efficiency (NSE) and regression coefficient (R^2). The value of NSE ranges between $-\infty$ and 1, values between 0.4 and 1.0

are viewed as acceptable levels of performance. The regression coefficient (R^2) describes the proportion of the total variance in the observed data that can be explained by the model. The closer the value of R^2 to 1, the higher is the agreement between the simulated and the measured flow. The statistical performance during calibration period is R^2=0.5, NSE=43%; and during validation R^2 and NSE values are 0.48 and 44% respectively, this shows that the resulted runoff statistics are in acceptable range for daily simulation. The performance measures of SWAT model during calibration and validation are given in Table 2. The performance measures R^2 and NSE have been discussed in detailed above. Mean Absolute Error (MAE) value obtained is not very high considering the number points that are considered for the analysis. Pbias shows that the simulated flow is over estimated in case of calibration and under estimation in case of validation. However, for a daily catchment area based runoff, the results are seems to be in acceptable range.

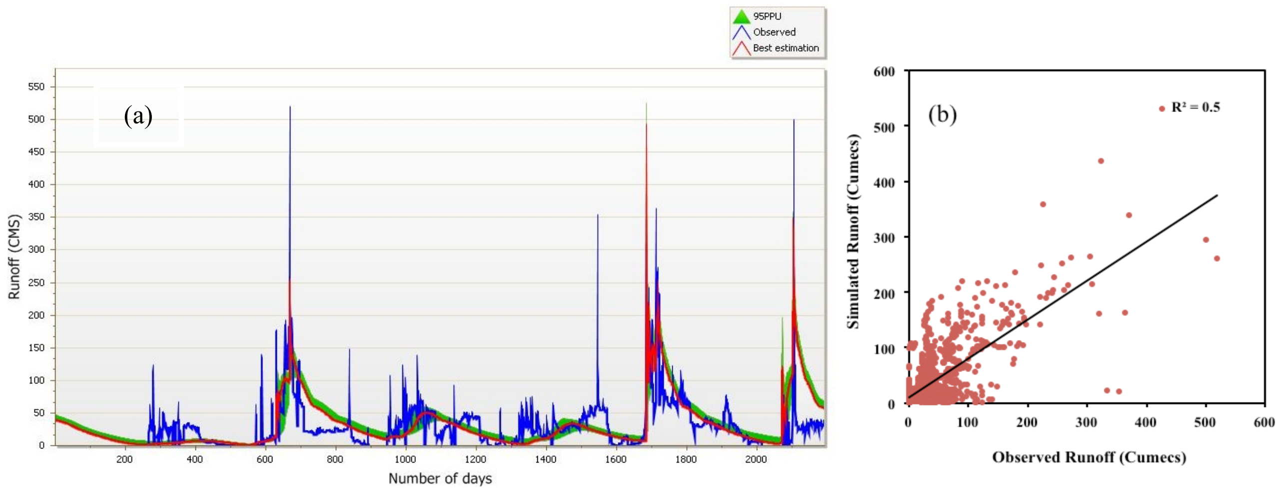

Figure 4. a) Time series and b) scatter plot of observed and SWAT simulated runoff during calibration period

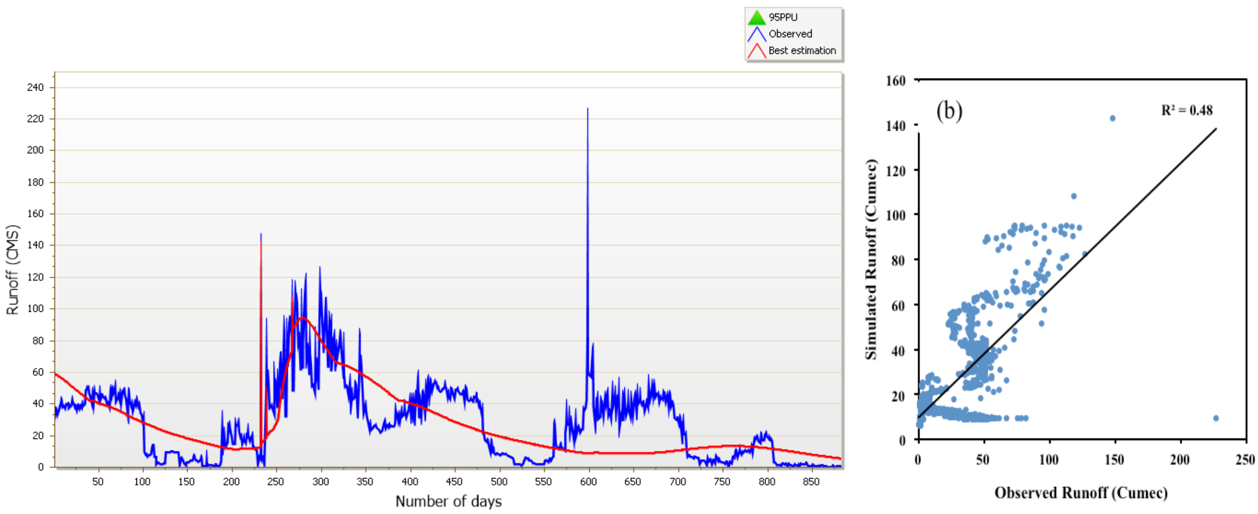

Figure 5. a) Time series and b) scatter plot of observed and SWAT simulated runoff during validation period

5. CONCLUSION

In the present study, a physical process based SWAT model has been developed for the Musi river basin. The Arc SWAT interface of SWAT model has been successfully used for exploring hydrological characteristics of Musi basin. The automatic watershed delineation at HRU level clearly shows the basic features like land use, soil and slope have an effect on the hydrology of the catchment. SWAT-CUP advance calibration and uncertainty analysis tool has been used for automatic calibration of stream flow measurement on daily basis for the period from 2004 to 2012 using the SUFI-2 procedure. The sensitivity analysis adopted for calibration shows variations between parameter values which had been initialized for model calibration on daily basis. After considering all the uncertainties like inconsistency in the observed flow data and with only one outlet available, the SWAT model is a good result for daily simulated flow. The developed SWAT model was calibrated and the results obtained are in acceptable ranges of R^2 and NSE values of 0.5 and 0.43 during calibration. In the case of validation too, the results obtained are in acceptable ranges of R^2 and NSE values of 0.48 and 0.44. The R^2 and NSE for daily calibration more than 0.4 indicate that model gives good results which mean the results obtained are satisfactory.

REFERENCES

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area hydrologic modeling and assessment part I: Model development1.

Gamvroudis, C., Nikolaidis, N. P., Tzoraki, O., Papadoulakis, V., & Karalemas, N. (2015). Water and sediment transport modeling of a large temporary river basin in Greece. Science of the Total Environment, 508, 354-365.

Hernandez, M., Miller, S. N., Goodrich, D. C., Goff, B. F., Kepner, W. G., Edmonds, C. M., & Jones, K. B. (2000). Modeling runoff response to land cover and rainfall spatial variability in semi-arid watersheds. In Monitoring Ecological Condition in the Western United States (pp. 285-298). Springer Netherlands.

Kim, S., Noh, H., Jung, J., Jun, H., & Kim, H. S. (2016). Assessment of the Impacts of Global Climate Change and Regional Water Projects on Streamflow Characteristics in the Geum River Basin in Korea. Water, 8(3), 91.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. (2002). Soil Water Assessment Tool theoretical documentation. Version 2000. Texas Water Resource Institute, college station, Texas. TWRI Report. TR-191.

Saha, P. P., Zeleke, K., & Hafeez, M. (2014). Streamflow modeling in a fluctuant climate using SWAT: Yass River catchment in south eastern Australia. Environmental earth sciences, 71(12), 5241-5254.

Szcześniak, M., & Piniewski, M. (2015). Improvement of hydrological simulations by applying daily precipitation interpolation schemes in meso-scale catchments. Water, 7(2), 747-779.

Uniyal, B., Jha, M. K., & Verma, A. K. (2015). Assessing climate change impact on water balance components of a river basin using SWAT model. Water Resources Management, 29(13), 4767-4785.

Vu, M. T., Raghavan, S. V., & Liong, S. Y. (2012). SWAT use of gridded observations for simulating runoff-a Vietnam river basin study. Hydrology and Earth System Sciences, 16(8), 2801.

Xu, X., Li, J., & Tolson, B. A. (2014). Progress in integrating remote sensing data and hydrologic modeling. Progress in Physical Geography, 38(4), 464-498.

Yang, X., Liu, Q., He, Y., Luo, X., & Zhang, X. (2016). Comparison of daily and sub-daily SWAT models for daily streamflow simulation in the Upper Huai River Basin of China. Stochastic Environmental Research and Risk Assessment, 30(3), 959-972.

Yen, H., White, M. J., Jeong, J., Arabi, M., & Arnold, J. G. (2015). Evaluation of alternative surface runoff accounting procedures using SWAT model. International Journal of Agricultural and Biological Engineering, 8(3), 64-68.