International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Application of SWAT Model for Estimating Runoff of Nethravathi River Basin using Sequential Uncertainty Fitting Technique

Geethu Krishnan[1], Kuduluru Srinivas Kumar[2], Rejani R[3]

[1, 2]Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, India

[3]ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad, India

Abstract: ***Nethravathi river basin, located in Dakshina Kannada district of Karnataka experiences from water scarcity during summer, severe runoff and soil loss during rainy season. In the present study, an attempt was made to predict runoff from Nethravathi river basin using SWAT model for 36 Years (1970-2005). SWAT-CUP (SWAT-Calibration and Uncertainty Programs) was used to ascertain the model sensitivity, calibration and validation by Sequential Uncertainty Fitting (SUFI-2) technique. Both monthly and daily discharge data calibration was performed for the period from 1995 to 1999, and then validated for the period 2000–2005 using Central Water Commission (CWC) discharge data recorded at Bantwal station. Modeling results indicated that monthly time step yield better results than that for the daily time step during both calibration and validation. For monthly calibration, the R^2 and NS values were 0.96 and 0.94 and for validation it was 0.91 each. On the other hand, for daily calibration, the R^2 and NS values were 0.88 and 0.84 and for validation, it was 0.8 and 0.79 respectively. A simulation that exactly corresponds to observed data would be described by a P-factor of 1. The value of simulated results indicated that p-factor and r-factors during monthly and daily calibrations were satisfactory. The estimated average annual runoff is equivalent to 30% of average annual rainfall of the entire river basin. The runoff varied spatially from 774 mm to 1527 mm. The average annual runoff resulted from different land use, land cover patterns inferred that minimum runoff (1068 mm) was observed in the evergreen forest land and the maximum was in orchard and agricultural crop area (1394.1 mm). From the results of estimated runoff during the above normal, normal and drought years, it can be suggested that appropriate soil and water conservation structures are needed for the sustainable management of the study area.***

Keywords: Nethravathi river basin, runoff, SUFI2SWAT, SWAT-CUP

1. Introduction

Water is one of the most valuable natural resource which supports human health, economic development and ecological diversity (Jha et al. 2007). The rise in water demands combined with decline in water supplies is one of the major problems that we face nowadays. The demand for available water resources is increasing due to abnormal increase in population, rapid industrial development and recent trends in climate change. It is found that the demand for water will increase from 30 billion m^3 in 2000 to 161 billion m^3 in 2050 in India (Amarasinghe et al. 2007). So, proper managing and planning of water resource is very important. The reliable estimates of hydrologic parameters for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable to utilize suitable methods and techniques for quantifying the hydrological parameters or runoff. Use hydrologic models is the best method to achieve this (Sathian et al.2009) and extraction of watershed parameters using remote sensing and geographical information system (GIS) in high speed computers are the aiding tools and techniques for it (Jain et al. 2010; Rejani et al. 2015). Estimation of runoff is essential for designing conservation structures and to implement watershed management programs with limited financial resources.

There are various rainfall-runoff models developed for estimating runoff and sediment loss like Agricultural Non-Point Source (AGNPS) (Young et al. 1989), MIKE SHE (Refsgaard and Storm., 1995), Water Erosion Prediction Project (WEPP) (Lane et al. 1992), Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998) etc. Among all the models, SWAT has gained popularity among the scientific community for predicting more accurate values of water flow, sediment loss and nutrient balances in complex and large catchments. It is a semi-distributed, continuous time step long-term simulation model and is originated from agricultural models .In recent times, SWAT has been extensively used worldwide to carry out hydrological modeling at a watershed/basin scale under varying agro-climatic conditions (Verma and Jha., 2015). SWAT has been extensively used in many countries for discharge prediction for soil and water conservation (Spruill et al. 2000; Zhang et al. 2010; Patel and Srivastava 2013). In India, many researchers used SWAT model to estimate runoff and surface yield in different river basins (Singh et al. 2013; Jain et al.2014; Narsimlu et al. 2015; Malunjkar et al. 2015; Swami et al. 2015).

A careful calibration and uncertainty analysis is needed to simulate the hydrological process accurately. Calibration of hydrological models is a rigorous process, which depends on the number of input parameters and model complexity. Sensitivity analysis and uncertainty analysis helps to reduce the uncertainties within the model parameters. Studies on model calibration confirmed that SWAT model is an effective tool in managing water resources (Tang et al. 2012). There are various techniques of calibration and uncertainty analysis that have been linked through SWAT model through SWAT_CUP algorithm. Abbaspour et al. 2004 and Yang et al. 2008 applied the SUFI-2 technique for evaluation of SWAT model. The SUFI-2 technique needs a minimum number of model simulations to attain a high-quality calibration and uncertainty results (Yang et al. 2008). With this background, the current study was undertaken on the application of the SWAT model having an interface with ARCGIS software (ARCGIS 10.3 with ARCSWAT 2012 extension) for estimation of runoff from Nethravathi river basin, located in Dakshina Kannada district, Karnataka. The SWAT-CUP tool (SWAT Calibration and Uncertainty Procedures) was used to perform calibration, validation and sensitivity analysis of the SWAT model. The study was performed to compute the runoff of the Nethravathi river basin using SWAT model for planning proper soil and water harvesting structures.

2. Materials and methods

2.1 Study Area

The Nethravathi river basin (Fig.1) of Karnataka which lies in west coast of India is selected for study. The geographic location of river lies between 12° 29′ 27.9″ to 13° 10′ 58.7 N″ latitudes and 74° 51′ 35.36″ to 75° 47′ 13″ E longitudes. It originates at an altitude of 1,000 m above the mean sea level in the evergreen tropical rain forest called the Western Ghats (mountain range) along the west coast of India and flows westward to join the Arabian Sea. Total length of the river is about 103 km which drains in to an area of 3,657 km² CWC (2006). The elevation of Nethravathi river basin ranges from 0 to 1700 m and is characterized by undulating topography with a slope ranging from 0 to 71%. The main soil types of the basin are sandy clay loam, sandy loam and loamy. The major portion of the basin is covered by forest followed by orchard and agricultural crops. It joins Arabian Sea at Manglore. Average rainfall over the Nethravathi basin is 3721 mm. This region experiences a minimum temperature of 17°C in December–January to a maximum temperature of 37°C during April–May. The relative humidity is generally very high, which exceeds 85% during southwest monsoon (June to September). Nethravathi river provides water supply for Mangalore city, industries, hydropower production and agricultural activities in the basin.

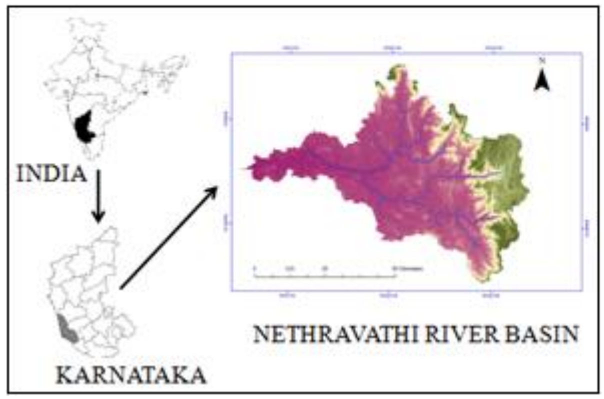

Figure 1: Location map of Nethravathi river basin

Dataset

SWAT model was used in this study to estimate runoff from Nethravathi river basin. Topography, land use, soil, weather and hydrology databases were collected from different sources/agencies and are listed in Table 1.The daily discharge data from Bantwal gauge station, provided by central water commission is used in this study. The detailed land use/land cover map (Fig. 2a), soil map (Fig. 2b) details used in this study are summarized in the following sections.

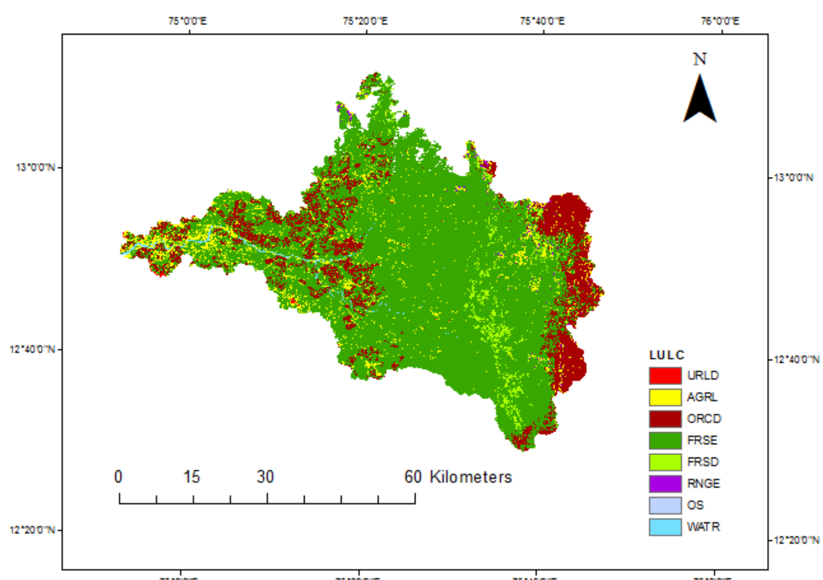

Figure 2 (a): Land use land cover map of selected basin

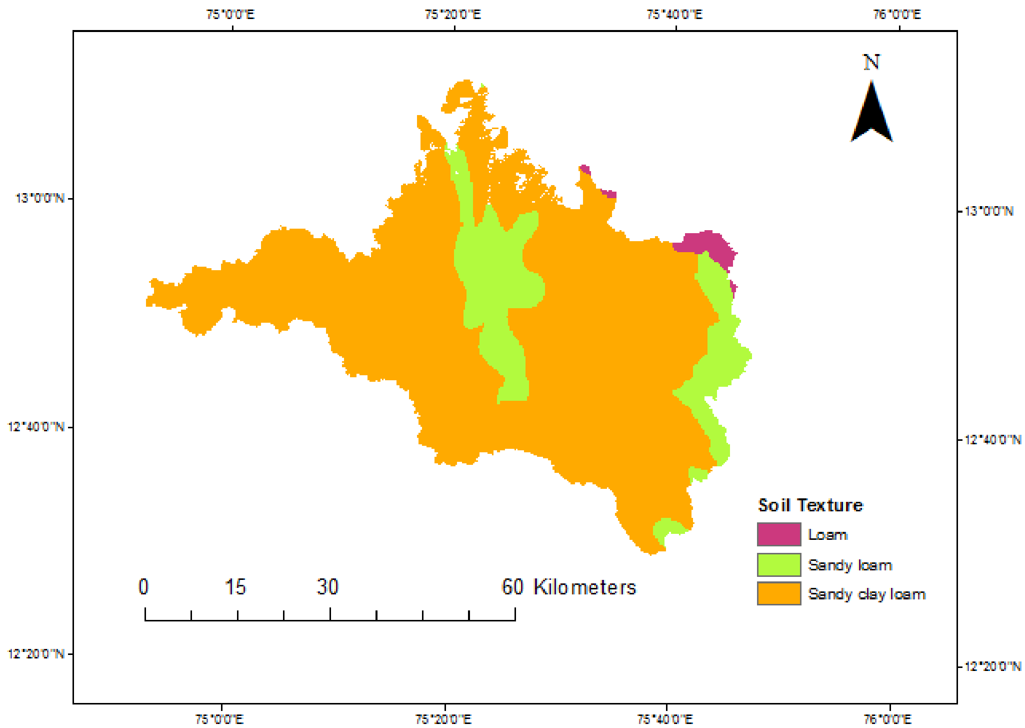

Figure 2 (b): Soil texture map of selected basin

Table 1: Description of spatial data used for Nethravathi River Basin

S.N	*Spatial data*	*Description*	*Source*
1	Digital Elevation Model	30x30m grid DEM has been used to delineate the boundary of the river basin and analyze the drainage pattern of the terrain.	ASTER
2	Land use and land cover	The NRSC land use data contains crop specific digital layers suitable for use in Geographical Information System(GIS)	National Remote Sensing Centre, Government of India (GOI)
3	Soils data	The soil data has been obtained from NBSSLUP -ICAR	National Bureau of Soil Survey and Land Use Planning-Indian Council of Agricultural Research, GOI
4	Weather data	Precipitation: 0.5 km×0.5 km re gridded data Temperature: 1.0 km×1.0 km regridded data	Indian Meteorological Department, Pune, India
5	Hydrological data	Gauge data at Bantwal gauge station	Central Water Commission, Ministry of Water Resources, GOI

Land use land cover and soil properties

The major portion of the basin is covered by evergreen forest (76.2%), followed by orchard (15.1%), agriculture (4.9 %). The remaining portion of the basin is deciduous forest (2.8%), range grass (0.42%) and urban land (0.047%) (Fig. 2a). The main soil types found in the basin are sandy clay loam (82%), sandy loam (16%) and loam (2%) (Fig. 2b).

Digital Elevation Model (DEM)

In this study, ASTER DEM (30 m) resolution was used as SWAT input for watershed delineations and topographic parameterization (Fig. 1). The Nethravathi river basin has been divided into 31 sub-basins and 682 Hydrological Response Units (HRUs) based on uniform soil, land use and slope with a threshold area of 290000 ha.

SWAT MODEL

The SWAT is one of the most recent models developed jointly by the United States Department of Agriculture–Agricultural Research Services (USDA–ARS) and Agricultural Experiment Station in Temple. SWAT model having an interface with ARCGIS software is known as ARCSWAT. It is a physically based model which has proven to be an effective tool for assessing water resources for predicting surface runoff Neitsch et al. (2011). The model was designed for the prediction of long-term yields rather than single flood events (Arnold et al. 1998). The computational components of SWAT can be placed into eight major divisions: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides and agricultural management. The main processes in the model comprises of general water movement, sediment transport, crop growth or nutrient cycling. SWAT estimates surface runoff using SCS-CN method. SWAT calculates the hydrologic cycle based on the water balance equation given below.

$$SW_t = SW_o + \left(R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw}\right) \quad \text{(1)}$$

Where SW_t = Final soil water content (mm H_2O), SW_o = Initial soil water content on day (mm H_2O), R_{day} = Amount of precipitation (mm H_2O), Q_{surf} = Amount of surface runoff (mm H_2O), E_a = Amount of evaporation (mm H_2O), W_{seep} = Amount of water entering the vadose zone (mm H_2O), Q_{gw} = Amount of return flow (mm H_2O) and t = time (days).

The methodology involved in estimation of runoff and sediment yield using SWAT is described involves delineation of watershed, HRU definition, providing weather data inputs and output generation. The sub watersheds were divided into HRUs by assigning the threshold values of land use and land cover, soil and slope percentage. In this study, multiple HRU definition with a threshold value of 1% land use, 1% soil and 5% slope overlap were given. Hence, the Nethravathi river basin was divided in to several HRU's, each has a unique land use soil and slope combinations. Subsequently, sensitive analysis, calibration and validation is done in SWATCUP.

SWAT-CUP

(SWAT Calibration & Uncertainty Program) was used in this study for sensitivity analysis, calibration and validation of surface runoff. SWAT-CUP is an automated model calibration tool for the SWAT model (Abbaspour, 2015). In this study, SUFI-2 algorithm in SWAT_CUP was used for sensitivity analysis, calibration and validation of stream discharge using monthly and daily data. Sensitivity analysis was done for finding out the crucial parameters influencing model simulation. 17 SWAT parameters were used for sensitivity analysis using SWAT-CUP. The parameters include curve number (CN2), base flow alfa factor (ALPHA_BF), groundwater delay time (GW_DELAY), threshold depth of water in shallow aquifer required for return flow (GWQMN), base flow alpha factor for bank storage (ALPHA_BNK), maximum canopy storage (CANMX), soil evaporation compensation factor (ESCO), Manning roughness for main channel (CH_N2), plant uptake compensation factor (EPCO), Manning's "n" value for overland flow (OV_N), threshold depth of water in the shallow aquifer for revap to occur (REVAPMN), soil hydraulic conductivity (SOL_K), deep aquifer percolation fraction (RCHRG_DP), surface runoff lag time (SURLAG) and available water capacity of the first soil layer (SOL_AWC).

In the SUFI-2 algorithm there are two indicators to quantify the strength of the calibration and uncertainty of the model, namely the P-factor and R-factor. P-factor is the percentage of observed data bracketed by the 95% prediction uncertainty (95PPU) whereas R-factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data. The calibration was done for the period 1993-1999 with a warm up period of 2 years and validation for the period 2000-2005. To assess the goodness-of-fit of the model, coefficient of determination (R^2) and the Nash-Sutcliffe efficiency coefficient (NSE) were used.

Coefficient of determination (R^2)

The coefficient of determination R^2 is defined as the squared value of the coefficient of correlation and is given by equation

$$R^2 = \frac{\sum_i[(Q_{m,i} - \acute{Q}_m)(Q_{s,i} - \acute{Q}_s)]^2}{\sum_i(Q_{m,i} - \acute{Q}_m)^2 \sum(Q_{s,i} - \acute{Q}_s)^2}$$

Where, Q_m is the observed stream flow on day i (m³/s), Q_s is the simulated stream flow on day i (m³/s), and bars indicate averages. The value of R^2 ranges from 0 to1. A value near to 1.0 indicates good performance of the model and the value near to 0.0 indicates poor performance of the model.

Nash-Sutcliffe efficiency coefficient (NS)

The Nash-Sutcliffe efficiency coefficient is used to assess the predictive power of the hydrological models.

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \acute{Q}_m)^2}$$

where NS is the Nash-Sutcliffe efficiency coefficient.

The value of NS varies from 1.0 (perfect fit) to minus infinity. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al. 2005). The NS value of 0 indicates that the model predictions are as accurate as the mean of the observed data.

Analysis of spatial and temporal variation

The SWAT model was run for 36 years from 1970-2005.The average annual runoff for the selected period (1970-2005) were analyzed for its temporal variation and were examined spatially. The mean annual rainfall during 1970–2005 was estimated for categorizing the years into normal, above normal and drought years. The years with mean annual rainfall > +19 % was classified as above normal year, −19 to +19 % as normal year rainfall, −19 to −25 % as mild drought year, −25 to −50 % as moderate drought year and <−50 % as severe drought year (Rejani et al. 2015). The runoffs occurring in the basin during normal, above normal and drought years are very essential for planning the water harvesting structures needed for supplementary irrigation. The spatial and temporal variation of annual rainfall and runoff was also analyzed.

3. Results and Discussions

Analysis of Model Parameterization

From the Table 2, it can be ascertained that all the 17 sensitive parameters are applicable to surface runoff, groundwater, channel routing, and soil properties. However, the parameter which is having high t-stat value (1.6) and low p-value (0.14) i.e., v_REVAPMN.gw is found more sensitive to the discharge as compared to others. In addition to this, REVAPMN, ALPHA_BNK, CH_N1, SOIL_K, RCHRG_DP, ALPHA_BF can be correlated to aquifer recharge and base flow and hence could be the reason for their higher ranking in the sensitivity analysis. CN2 is a function of soil permeability, land use/ land cover and the antecedent soil moisture. It therefore affects the rate of surface runoff generation. An increase in CN2 increases the stream flow, but the effect is more pronounced on surface runoff. ESCO is a co-efficient that plays a major role in the routing of the flow in the channel to the outlet and is used to modify the soil depth distribution to meet evaporation demands.

Table 2: Summary of Global Sensitivity Analysis

Parameters	Range of values	t-Stat	P-Value	Rank
v__ REVAPMN.gw	0-1000	1.6	0.14	1
v__ ALPHA_BNK.rte	0 – 1	1.46	0.17	2
v__ CH_N1.sub	0-1	-1.45	0.17	3
r__ SOL_K.sol	0-2000	1.22	0.25	4
v__ RCHRG_DP.gw	0 – 1	1.09	0.3	5
v__ ALPHA_BF.gw	0 – 1	0.86	0.41	6
v__ GWQMN.gw	0 – 5000	-0.71	0.49	7
v__ CH_K2.rte	-0.01-500	0.65	0.53	8
r__CN2.mgt	-0.2 – 0.2	-0.42	0.68	9
v__ ESCO.hru	0-1	0.38	0.71	10
v__ SURLAG.bsn	1-24	-0.32	0.75	11
v__ EPCO.hru	0-1	-0.27	0.79	12
v__ CH_N2.rte	0-0.5	0.25	0.81	13
r__ SOL_AWC.sol	-0.25 – 0.25	0.22	0.83	14
v__ OV_N.hru	0.01-30	0.2	0.84	15
v__ GW_DELAY.gw	0 – 500	-0.19	0.86	16
v__ CANMX.hru	0-100	-0.09	0.93	17

Calibration and Validation

The monthly model calibration and validation results are presented in Fig. 3a & 3b). From the results, it can be observed that during calibration, the maximum model simulated peak runoff noticed is 1800 m^3/s against observed value of 1650 m^3/s during August 1997 and during validation, the maximum simulated peak rate of runoff is 1600 m^3/s as against the observed value (1390 m^3/s) during the month of August 2005. The p-factor and the r-factor during calibration and validation are 0.83, 0.98 and 0.70 and 1.0 respectively, which indicates a good performance of the model. The reduction in 95PPU (p-factor) from 0.83 to 0.70 during calibration and validation, indicates the uncertainties in input driving variables mostly rainfall. Careful examination of calibration and validation results showed that the observed data is not falling under 95PPU band at the base flow part. This may be due to the limitation of SWAT model for simulating groundwater flow and the same is substantiated in the results indicated by Rostamian et al. 2008 for a catchment in Iran.

Many researchers have used SWATCUP for monthly and daily calibration and validation (Singh *et al*. 2013 ;Chandra *et al.* 2014; Narsimlu *et al.* 2015; Briak *et al*. 2016) and reported the range of R^2 and NSE.The coefficient of determination (R^2) and Nash and Sutcliffe (NS) for calibration period is 0.96 and 0.94, respectively (Fig.3a). On the other hand, for validation period it was 0.91 and 0.91, which infers that the model performance is reasonably good both in terms of both calibration and validation stages (Fig.3b).

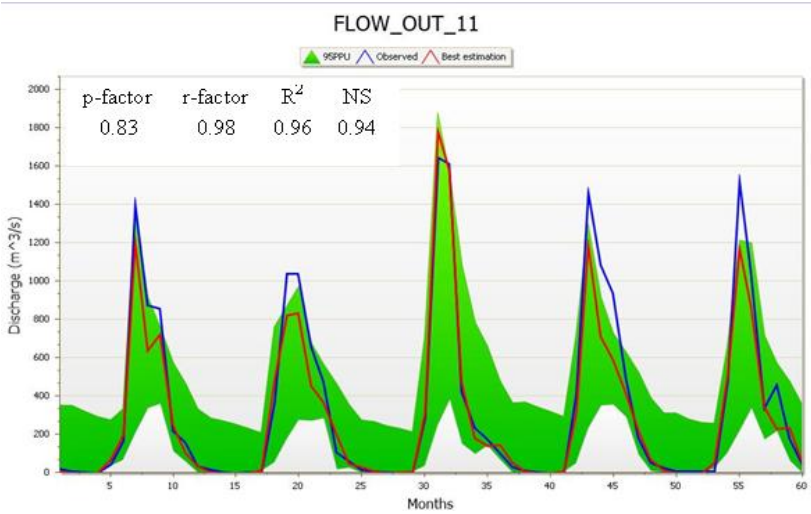

Figure 3 (a): Monthly discharge calibration (1995-1999)

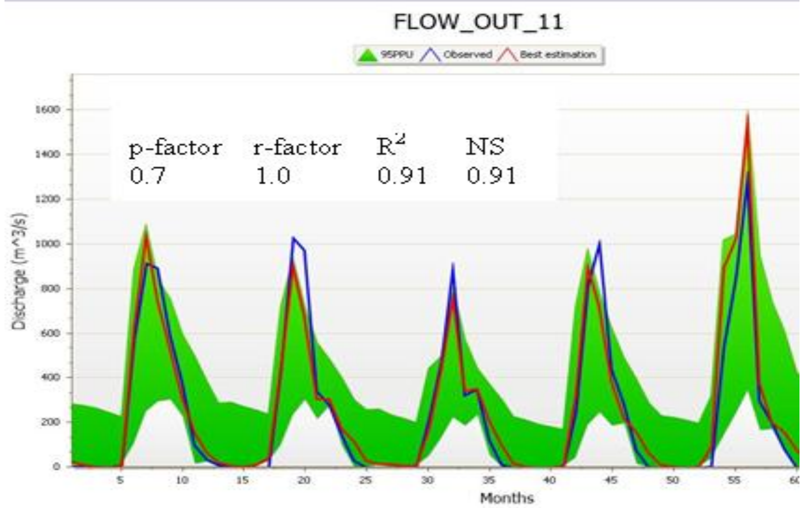

Figure 3 (b): Monthly discharge validation (2001-2005)

The daily calibrated and validated model results of discharges in the study area are presented in (Fig.3c & 3d). From the figure, it is evident that the p and r-factors are found to be 0.84, 0.78 for calibration and 0.71 and 0.87 for validation, respectively. On the other hand, the coefficient of determination (R^2) and Nash and Sutcliffe (NS) for calibration period are 0.88 0.84 and 0.80, 0.79 for validation, which indicates that the model showed a good performance both at calibration and validation.

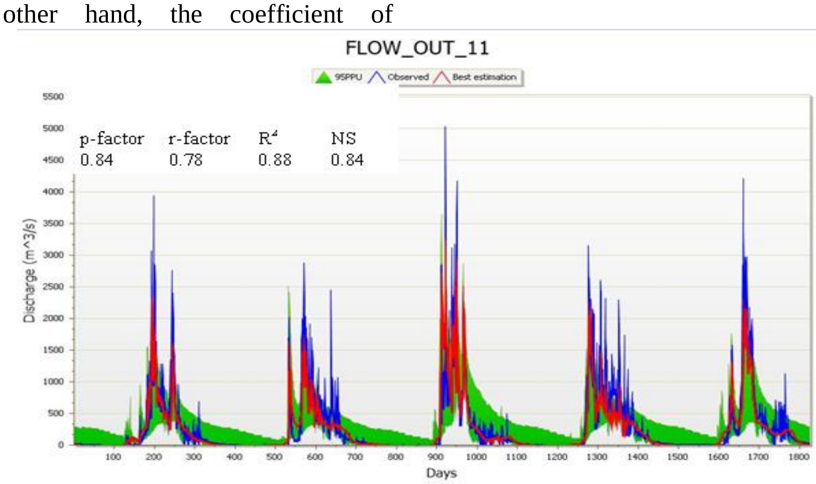

Figure 3 (c): Daily discharge calibration (1995-1999)

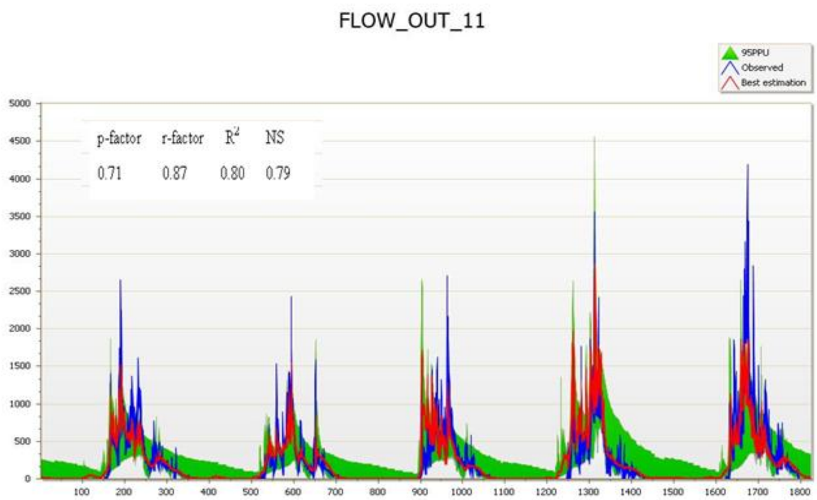

Figure 3 (d): Daily discharge validation (2001-2005)

Table 3: Summary of monthly and daily calibration and validation

Discharge	p-factor	r-factor	R^2	NS
Monthly calibration	0.83	0.98	0.96	0.94
Monthly validation	0.74	0.99	0.91	0.91
Daily calibration	0.84	0.78	0.88	0.84
Daily validation	0.71	0.87	0.80	0.79

Temporal variation of rainfall and runoff

Rainfall is the major input factor to be given in the model that decides the simulated runoff from the model. The total annual rainfall of the region varied from a minimum of 2113.5 mm in 1987 to a maximum of 4200 mm in the year 1978 (Fig.4). On the other hand, the calculated average annual rainfall is found to be 3721 mm with coefficient of variation of 19 %. A maximum surface runoff is of 2030 mm was observed during 1997 and the minimum of 400 mm during 1987.The average annual runoff was estimated to be 1130 mm which is 30% of average annual rainfall of the study area. The coefficient of variation of runoff was 35.4.

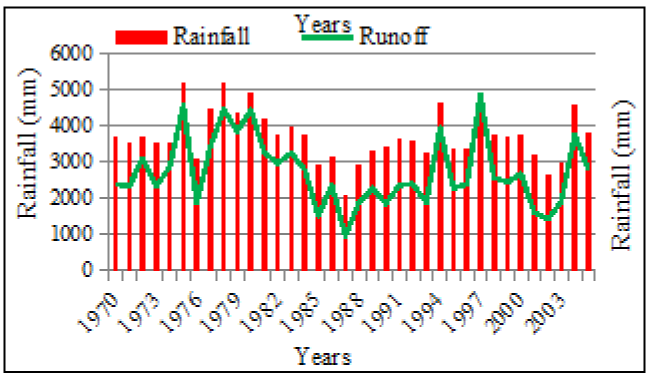

Figure 4: Temporal variation of rainfall and runoff in Nethravathi river basin

Spatial variation of rainfall and runoff

The minimum and maximum rainfall in the sub-basins ranged from 3228 to 4097 mm in the study area (Fig. 5a). Moreover it is evident that most of the region possess a rainfall which is less than 3865 mm. Apart from this, in the sub-basins viz., 2, 3,4,5,7, 8,9,10,12 and 19 have received the rainfall greater than 3865 mm. The runoff prediction in the sub-basins through SWAT is shown in the Fig. 5b. From the figure, it is evident that the runoff in the study area varies from 797 mm to 1527 mm. Moreover, it is found that the minimum average runoff is resulted from the evergreen forest (1068 mm), which is 28.7% of average annual rainfall. On the contrary, the maximum runoff is observed from the orchard and agriculture crops (1394.1 mm) which is accounted as 37.4% of average annual rainfall. In the sub-basins viz., 5, 9, 10, 11, and 12, which are under agriculture and orchard cultivation, the runoff is observed from 1263 to 1527mm. On the other hand, minimum values (797 to 848 mm) were observed in the sub-basins 24, 27, 28, 29, 30 and 31 respectively which were mostly covered by evergreen forest.

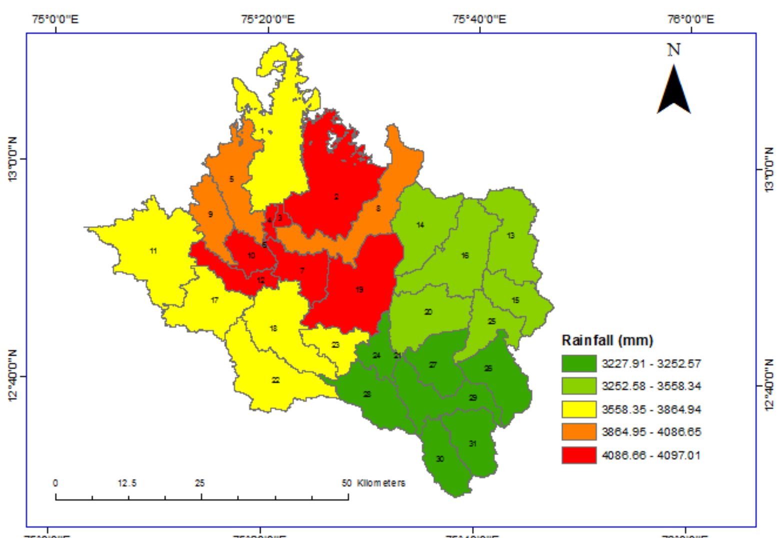

Figure 5 (a): Spatial variation of rainfall in Nethravathi basin (1970-2005)

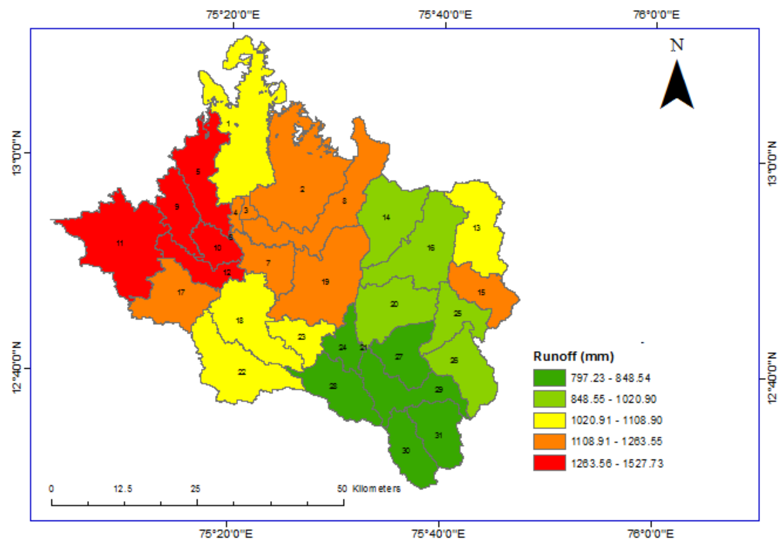

Figure 5 (b): Spatial variation of runoff in the Nethravathi basin (1970-2005)

Spatial variation of runoff during above normal, normal and drought year

During normal year runoff from the river basin varied spatially from 748 to 1438 mm. Higher runoff was observed in sub-basins 8, 9, 10, 11 and 12 and lower runoff was observed in sub-basins 24, 26, 27, 28, 29, 30 and 31, respectively Fig. 6a. During drought year, the runoff varied spatially from 266 to 987 mm. Higher runoff during the drought year was observed in sub-basins 5, 7, 9, 10, 11 and 12 and lower rainfall was observed in sub-basins 24, 26, 27, 28, 29, 30 and 31, respectively Fig.6b. During above normal year runoff varied spatially from 1534 to 2148 mm. The higher runoff was observed in sub-basins 2, 3, 10, 12, 18, 22 and 23 and lower runoff was observed in sub-basins 14, 20, 21, 24, 25, 26, 27, 29 and 31 Fig. 6c. From the results of estimated runoff during the above normal, normal and drought years, it can be suggested that appropriate soil and water conservation structures are needed for the sustainable management of the study area. The suitable locations for water harvesting structures could be identified based on soil texture, soil depth, LULC, slope of the land, rainfall, runoff etc. These locations needs to be further optimized based on the runoff available after in situ water conservation and storage in existing water-harvesting structures (Rejani et al. 2017).Constructing check dams (ex situ) substantially increased groundwater recharge (ex situ), while reducing outflows and in situ practices resulted in a higher ET, since more water was available as soil moisture in the fields, higher groundwater recharge and lower outflow (Garg et al. 2012).

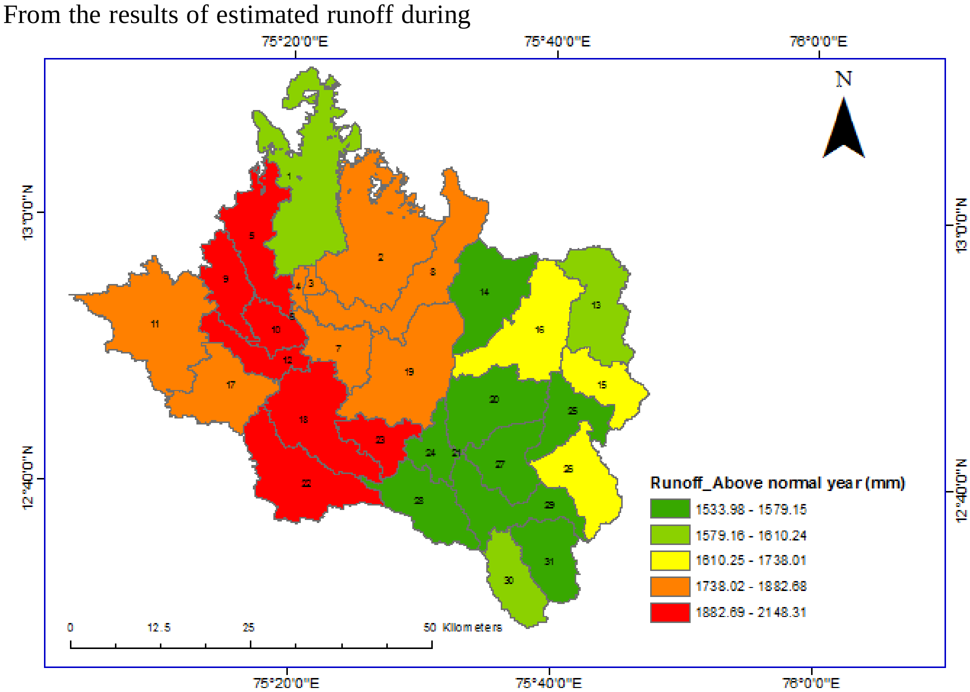

Figure 6 (a): Spatial variation of runoff during above normal year

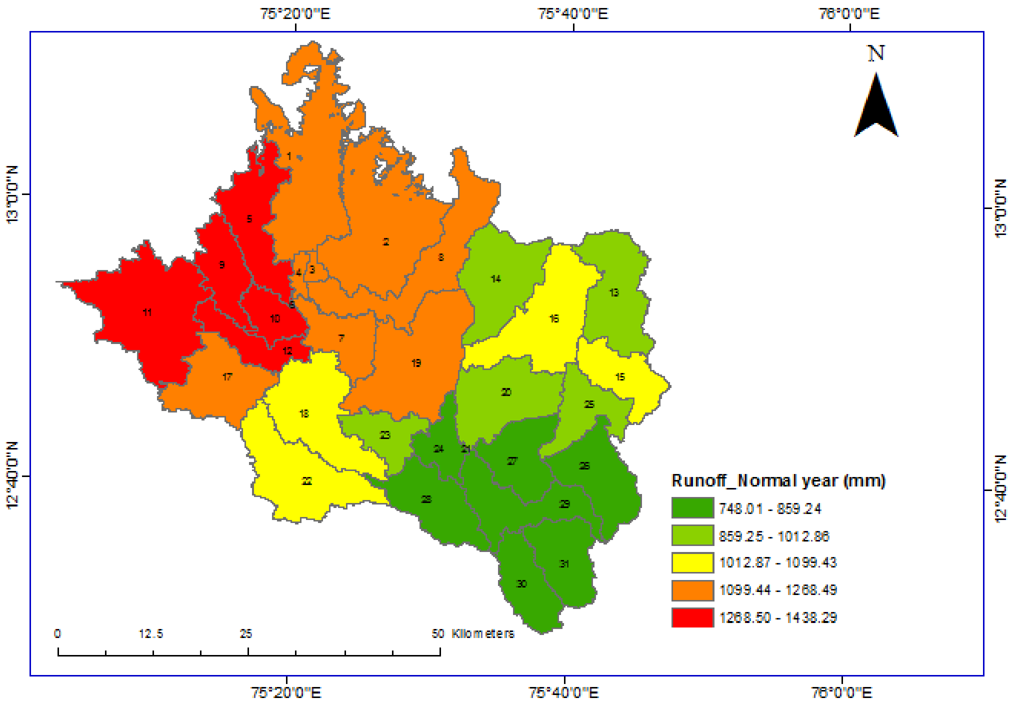

Figure 6 (b): Spatial variation of runoff during normal year

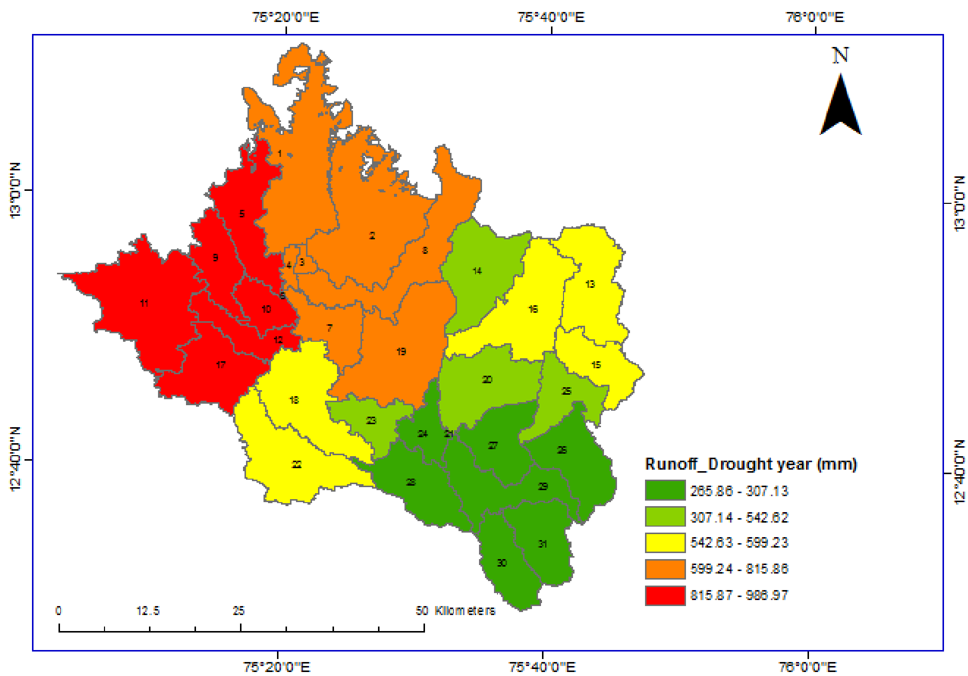

Figure 6 (c): Spatial variation of runoff during drought year

4. Conclusion

The results of SWAT simulation for Nethravathi river basin indicated that monthly time step yielded better results than that for the daily time step. The R^2 and NS values during monthly calibration were 0.96 and 0.94 respectively and for validation it was 0.91 each. On the other hand, for daily calibration, the R^2 and NS values were 0.88 and 0.84 and for validation, it was 0.8 and 0.79 respectively. The simulated results indicated that p-factor and r-factors during monthly and daily calibrations were satisfactory. The model results indicated that the average annual rainfall in the river basin was 3721 mm, while the average annual runoff was estimated as 1130 mm, which is equivalent to 30% of average annual rainfall. Runoff varied temporally from a maximum of 2030 mm during 1997 to a minimum of 400 mm during the year 1987. The coefficient of variation for runoff was 35.4%. On the other hand, the spatial runoff varied from 774 mm to 1527 mm. The results showed a minimum average runoff of 1068 mm, which is 28.7% of average annual rainfall observed from evergreen forest and a maximum runoff of 1394.1 mm which is 37.4% of average annual rainfall obtained from orchard and agriculture crops. With regard to sediment yield , the model has predicted minimum and maximum sediment yields in the study area (2 t ha^{-1}) in the year 1970 and 9 t ha^{-1} in the year 1992. The computed average annual sediment yield is 5.2 t $ha^{-1}year^{-1}$. The coefficient of variation of sediment yield was 40%. The sediment yield varied spatially from 1.4 to 9.15 t $ha^{-1}year^{-1}$. On the basis of the results obtained in this study, SWAT could be used for the simulation of runoff and sediment for Nethravathi river basin.

References

[1] Amarasinghe, U.A., Shah, T., Turral, H. and Anand, B. 2007. India's water futures to 2025-2050; Business as usual scenario and deviations. IWMI Research Report 123. Colombo, Sri Lanka: International Water Management Institute
[2] Arnold, G.J., Srinivasan, R., Muttiah, S. and Williams, J.R. 1998. Large area hydrologic modeling and assessment Part I: Model development. Journal of American Water Resources Association, 34 (1): 73–89
[3] Bicknell, B.R., Imhoff, J.C., Kittle, J., Jobes, T.H. and Donigian, A.S. 2000. Hydrological Simulation Program – Fortran (HPSF): User's Manual for Release 12. Athens, Ga: USEPA
[4] Jain, K.S., Tyagi, J. and Singh, V. 2010. Simulation of runoff and sediment yield for a Himalayan watershed using SWAT model. J Water Resour Protection, 276-281
[5] Jain, M. and Sharma, S.D. 2014. Hydrological modeling of Vamshadhara river basin, India using SWAT. International Conference on Emerging Trends in Computer and Image Processing, Pattaya (Thailand)
[6] Jha, M.K., Chowdhury, A., Chowdary, V.M. and Peiffer, S. 2007.Groundwater management and development by integrated remote sensing and geographic information systems: Prospects and Constraints. Water Resour Manag., 21:427-467
[7] Kaushal, K.G., Louise, K., Jennie, B., Suhas, P.. Wani and Johan R. 2012. Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. Hydrological Processes 26: 387-404
[8] Khoi, D.N. and Thom, V.T. 2015. Parameter uncertainty analysis for simulating stream flow in a river catchment of Vietnam. Global Ecology Conserv., 4 :538–548
[9] Malunjkar, V.S., Shinde, M.G., Ghotekar, S.S. and Atre, A.A. 2015. Estimation of surface runoff using SWAT model. Int J Inventive Engg Sci., 3(4): 2319–9598
[10] Narsimlu, B., Gosain, A.K., Chahar, B.R., Singh, S.K. and Srivastava, P.K. 2015. SWAT model calibration and uncertainty analysis for stream flow prediction in the kunwari river basin, India, using sequential uncertainty fitting. Environ Processes, 2:79–95
[11] Nearing, M. 1998. Why soil erosion model over-predict small soil losses and under-predict large soil losses. Catena, 32(1): 15–22.
[12] Patel, D. and Srivastava, P. 2013. Flood hazards mitigation analysis using remote sensing and GIS: correspondence with town planning scheme. Water Resour Manag., 27:2353–2368
[13] Refsgaard, J.C. and Storm, B. 1995. MIKE SHE. In: Singh, V.P. (Ed.), Computer Models of Watershed Hydrology. Water Resource Publications, CO, USA 806-846
[14] Rejani, R., Rao, K.V., Osman, M., Chary, G.R., Pushpanjali, Reddy, K.S. and Srinivas Rao, Ch. 2015. Spatial and temporal estimation of runoff in a semi-arid microwatershed of southern India. Environ Monitoring Assess., 187: 540-556
[15] Rejani, R., Rao, K.V., Srinivasa Rao, Ch., Osman, M., Sammi Reddy, K., George, B.A., Pratyusha Kranthi, G.S., Chary, G.R., Swamy, M.V. and Rao, P.J. 2017. Identification of potential rainwater harvesting sites for the sustainable management of a semi-arid watershed of Southern India. Irrig Drain J 66: 227-237
[16] Sathian, K.K. and Shyamala, P. (2009) Application of GIS Integrated SWAT Model for Basin Level Water Balance. Indian Journal of Soil Conservation, 37, 100-105.
[17] Singh, V., Bankar, N., Sagar, S.S., Bera, A.K. and Sharma, J.R. 2013. Hydrological stream flow modelling on Tungabhadra catchment: parameterization and uncertainty analysis using SWAT CUP. Curr Sci., 104:1187-1199.
[18] Swami, V.A. and Kulkarni, S.S. 2015. Simulation of runoff and sediment yield for Kaneri watershed using SWAT model. J Geoscience Environ Protection, 4:1-15
[19] Tang, J., Yang, W. Z-y L and Liu, C. 2012. Simulation on the inflow of agricultural non-point sources pollution in Dahuofang reservoir catchment of Liao river, J Jilin Univ., 42:1462–1468
[20] Verma, A.K., Jha, M.K. 2015. Evaluation of a GIS-based watershed model for streamflow and sediment-yield simulation in the upper Baitarani river basin of Eastern India. J Hydrol Eng., 20(6):C5015001
[21] Zhang, X., Srinivasan, R. and Liew, M.V. 2010. On the use of multi-algorithm, genetically adaptive multi-objective method for multi-site calibration of the SWAT model. Hydrol Process, 24:955–969
[22] Yang, J., Reichert, P., Abbaspour, K., Xia, J. and Yang, H. 2008. Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. J Hydrol., 358:1–23
[23] Young, R.A., Onstad, C.A., Bossch, D.D. and Anderson, W.P. 1987. AGNPS: a non-point source pollution model for evaluating agricultural watersheds. J. Soil Water Conserv., 44(2): 168–173