Original Article

PARAMETERIZATION OF SYNTHETIC UNIT HYDROGRAPH USING SWAT MODEL FOR KUMBHI RIVER BASIN, INDIA

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DOI: 10.47750/pnr.2022.13.S08.346

Abstract

Hydrological modeling is an important aspect in watershed management. To process the hydrological models various types of hydrological, meteorological and tempo-spatial data is required. Those basin does not have the facility to record the data can use synthetic unit hydrograph method to simulate the parameters. In present work, SWAT (Soil & Water Assessment Tool) model was processed to parameterize the unit hydrograph for Kumbhi river basin in Kolhapur, India. The meteorological data was used from 2000-2014 to process the SWAT model. The outputs are validated with the help of SWAT-CUP tool using SUFI-II algorithm. It was observed that by K-fold method the peak discharge was 69.3 m3/sec, peak time was 4.9 hrs and base time is 14.32 hrs. The results obtained from SWAT model and those obtained from K-fold method shows good degree of fitness indicating the acceptance of model. The outcomes of this work will be helpful to researcher and policy makers to draw the hydrograph for Kumbhi basin and to plan the sustainable water resource management.

Keywords: Hydrologic modeling, rainfall-runoff, SWAT, calibration, validation.

Introduction

Two valuable natural resources are found on the earth namely soil and water. Both are essential for the continued existence of life on Earth. The earth ecosystem is maintained by the soil and water working together. Additionally, they play a crucial role in the development of physical, biological, and hydro-geological systems (Tapase et al. 2022). Therefore, it is crucial to comprehend the water balance and soil health of the watershed. Moreover, understanding water balance is a crucial component of water resource development and management strategies.

Water balance equation is given by,

$$\mathbf{P = Q + E + \frac{ds}{dt}} \qquad \text{………………… eq. (1)}$$

Where, P = Precipitation (mm)

Q = Discharge (m^3/s)

E = Evaporation (mm)

$\frac{ds}{dt}$= Rate of change of storage per unit time

The hydrological parameters and hydrological process are quantified as per the water balance scenario of that area. The parameters of water balance equation are governed by physical, meteorological and geo-biological characteristic of drainage basin. These parameters include land use, type and condition of soil, evaporation, size & shape of drainage basin. For any hydrological program it's important to have the information about relationship between physical parameters and hydrological components in the basin. Also this information is useful to design the sustainable water management system and to prevent soil loss. The water resource development and development of hydrological projects are more complex task in developing country like India, as due to lack of knowledge, funds and infrastructure available, so it's a challenge in front of society.

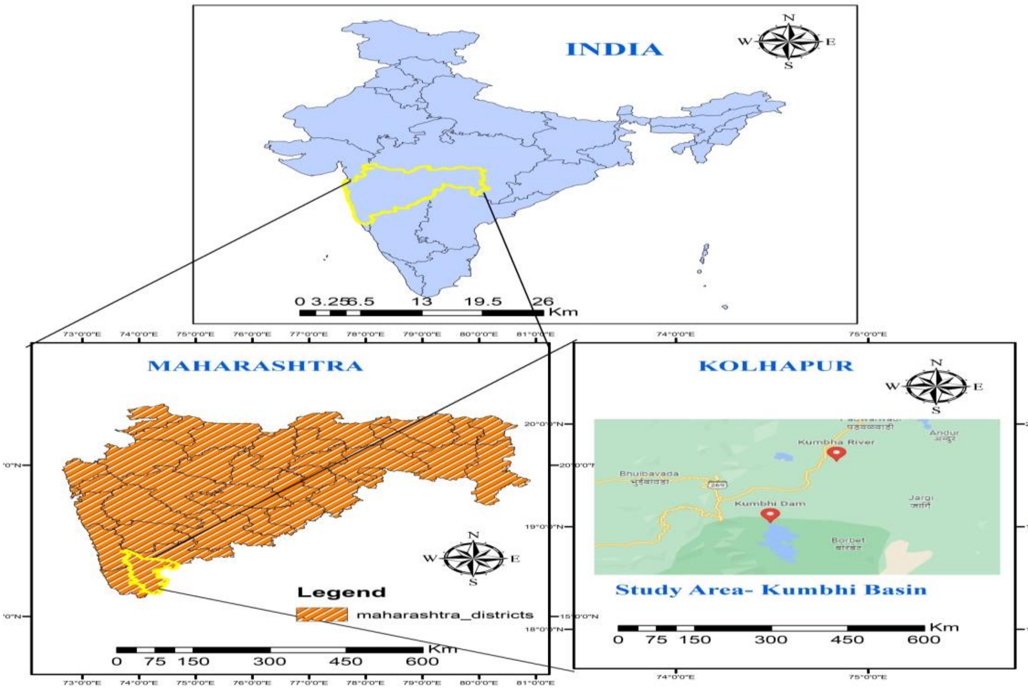
The hydrological analysis is very complex and it is not possible manually, so there is need of technological approach. Now, the more developments are going on in computing technologies and GIS (Geographic Information System) fields. The SWAT model is developed to overcome difficulties in hydrological modeling; basically it is advance version of SWRRB (Williams et al 1985, Sabale and Jose 2021). The model was designed to quantify theimpacts of land used and management on sediment yield, surface runoff, nutrients yields and evapotranspiration in watershed (J.G.Arnold et al. Version 2012). The SWAT model was used for hydrologic modeling of Manimala river basin in Kerala (B. Venkatesh et al. 2018). According to the literature survey, there are about 1500 peer-reviewed research papers on soil water models. The SWAT model is used to calculate the impacts of hydrologic and water-related issues on agricultural and land management (D.K. Borah, and M. Bera 2004). (Haddad et al. 2013) Utilized the model to forecast the influence of changing climate and human activities on runoff in the Huifa river basin in northeast China.

According to the literature review and the author's best understanding, SWAT is the most integrated and complete model for river modeling. In this study, the hydro-geologic parameters of the Kumbhi River in Maharashtra, India, are calculated using the SWAT model and those are validated by using K-fold method. The aim of work was to apply the SWAT to examine stream flows, rainfall-runoff, and sediment output and to parameterize the unit hydrograph.

Study Area

The Kumbhi river begins at Bavda and travels roughly 24 kilometres north-east to Kirwai. After there, it heads east, until it meets the Dhamni River, an important tributary at Chaugalewadi. Then it runs into a large basin that is covered in alluvium. It flows into the Tulsi and Bhogavati rivers in Bahireshwar, about 12.8 kilometres south of Kolhapur. The catchment of Kumbhi river is situated on the leeward side of Sahyadri hill range. The length of river between Origin and Confluence is 56 km. The basin area is almost hilly and thickly covered by forest.

Fig.1. Location Map



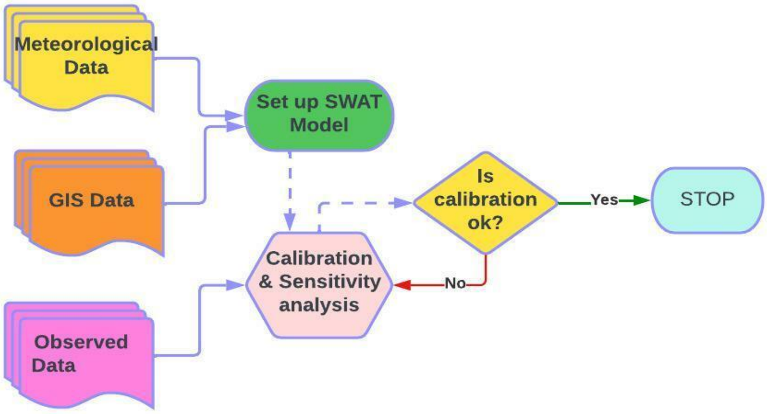
The Southwest monsoon (June-September) brings the most rain to the Kumbhi river catchment basin, with the Northeast monsoon bringing the rest (Oct-Nov). The annual average yearly rainfall for watershed is 4500 mm. The lateritic soil and light soil are seen in the basin. The main crops in the basin are Paddy, Nagali, Cashewnut and Groundnuts. The temperature variation in basin is in between 9^0C to 40^0C. The study's location is depicted in Fig. 1 with the drainage region highlighted in blue.

SWAT Model

It is a model which works on daily time steps, continuous simulation and long term hydrologic model. The model is used to determine impacts of land management on runoff, sediment yields, chemical yields and it operates on daily time steps. The SWAT model is utilized to simulate high level spatial data and gives output in required format. The first step in model, entire catchment is divided into sub-basin and again sub-basin to Hydrologic response units (HRU). HRU is a small portion of sub-basins that have unique land use land cover management and soil attributes (Sabale and Jose 2023). As a common practice a sub-basin should contain optimum HRUs in between 1 to 10 in numbers. HRU is used in SWAT model because itsimplifies a run by adding all similar attributes of soil and land use area into a single response unit. For the HRU in basin the hydrologic attributesare represented by 4 storage volumes namely: Deep aquifer (more than 20 m), Shallow aquifer (2-20 m), Soil profile (0-2 m) and rainfall (mm). The ground profile is divided into number of layers. The soil and water process includes evaporation, infiltration, lateral flow, plants uptake and deep percolation. The details from each HRU like flow, nutrients, and sediments are summed together and resulting information are used for further process.

The SWAT models have 8 major and important modules namely; Climate, hydrology, sediment, Agriculture, water quality& quantity, land cover, main channel and water bodies. Modified CN technique was used to simulate runoff daily basis (USDA-NRCS 2004). Thepotential evapotranspiration (PET)is calculated by Hargreaves, Penman-Monteith (PM) and Priestley- Taylor (PT) methods. Watershed time of concentration for surface runoff has been calculated using Manning's formula. A detail description and guidelines for SWAT is available on SWAT website (J.G.Arnold et al. Version 2012).

Fig.2. SWAT Model



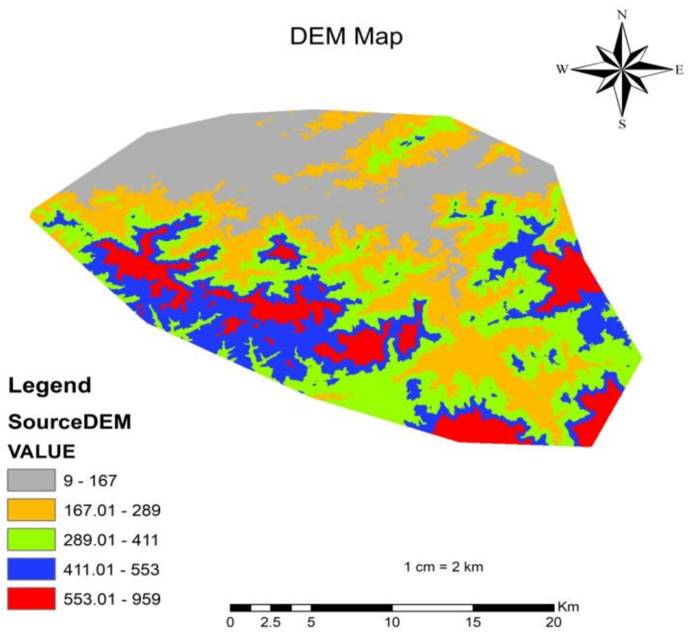
SWAT model Input data

DEM

The DEM(Digital Elevation Model) is raster data, is a three dimensional computer graphics representation of altitude data to represent terrain e.g. Earth. A global digital elevation modelrefers to a discrete global grid. It is often used in geographic information system (GIS). The DEM is nothing but matrix of numbers. To understand and interpret it is being converted to a visual image. The best qualitydigital elevation data is available with Advanced Spaceborne Thermal Emissions and Reflection Radiometer.This data covers almost 99% of global area and gives elevation at 30m resolution. Previously the high resolution data was available with Shuttle Radar Topograph Mission (SRTM). The shuttle data does not cover the polar region.

DEM is used for watershed delineation and computation of several hydrological parameters for basin. For present study, the DEM was downloaded from USGS earth data websiteand projected in WGS-1984-UTM-ZONE-43N coordinate system.

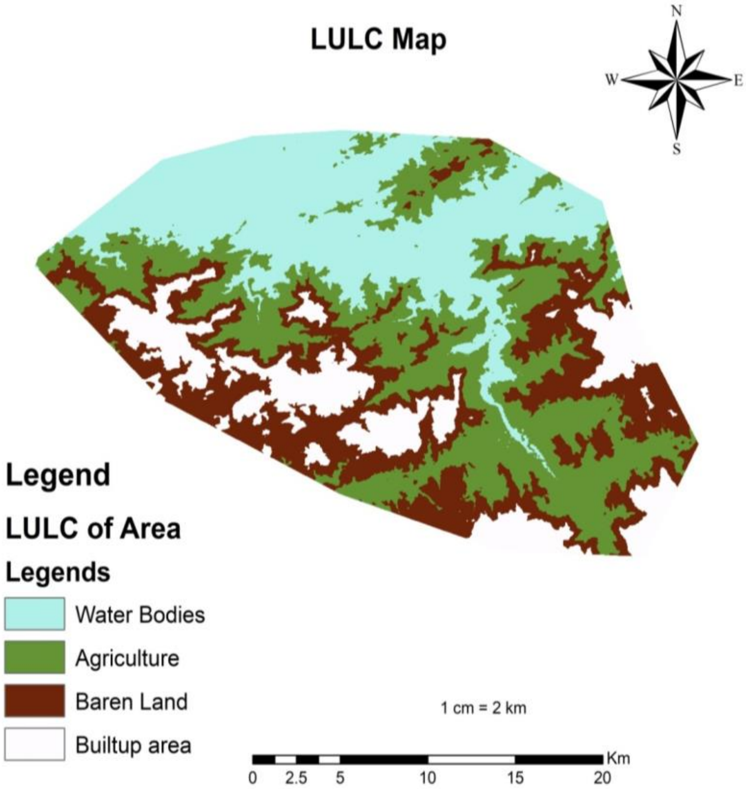
Fig.3. DEM of study area.



Land Management of Study Area

Hydrological parameters are greatly affected by vegetation present in the basin. The LULC data is used by SWAT model to process HRUs and simultaneously to compute curve numbers (CN). The SCS curve numbers are being used to find runoff in SWAT. The factors like surface runoff, surface absorption, infiltration, erosion and evapotranspiration are governed by land management of study area (Sabale and Jose 2021a). For the present work, the Land use data was obtained from USGS earth data center and is provided by Landsat-8. The same data can be made available from BHUVAN website under National Remote Sensing Center (NRSC), India.

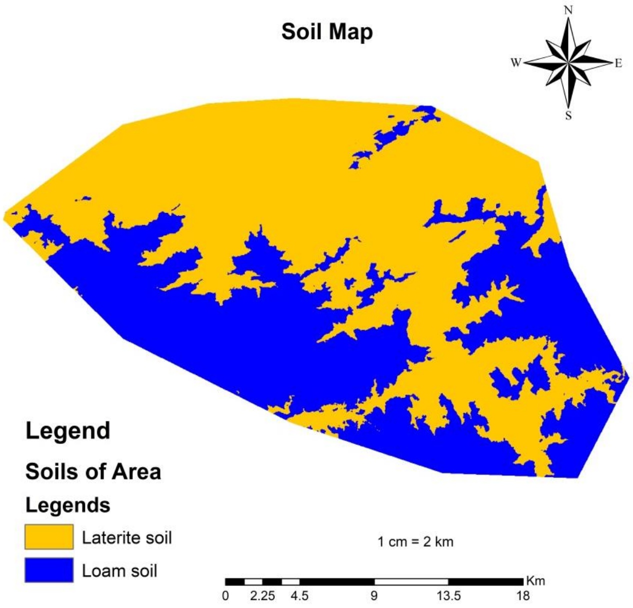
Fig.4. LULC of study area



Soil Map

The soil data and soil map for present study was downloaded from Food and the Agriculture Organization of US (FAO). The data is available in digital form for soil and in ESRI shapefile format. This data covers soil data for India as well as for all worlds. The data provides the information of about 4932 records of soil characters. According to USDA taxonomy the soil is categorized as: Typic Haplustalfs, Ultic Haplustalfs, Typic Rhodustalfs, Typic Ustipsammeuts, Rhodic Paleustalfs, Typic Haplusttepts, and Vertic Endoaquepts.

Fig.5. Soil map of study area



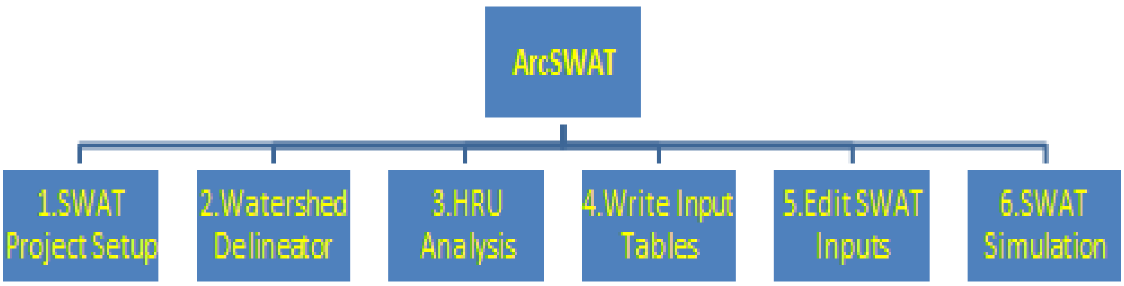
Meteorological Data

The SWAT model uses the data like Precipitation (Pcp), solar radiation (Slr), Relative humidity (Rh), Temperature (temp), Wind velocity (wind).The above said meteorological data is available with website i.e. global weather data for SWAT for whole world. For India, the data is available with India Meteorological Department and CWC. Mostly data is with missing readings and therefore error of (-99.000) is present in it. So by averaging or by interpolation method those errors are removed. The Notepad++ is a best tool to remove such types of errors from numerous files.

Model Setup

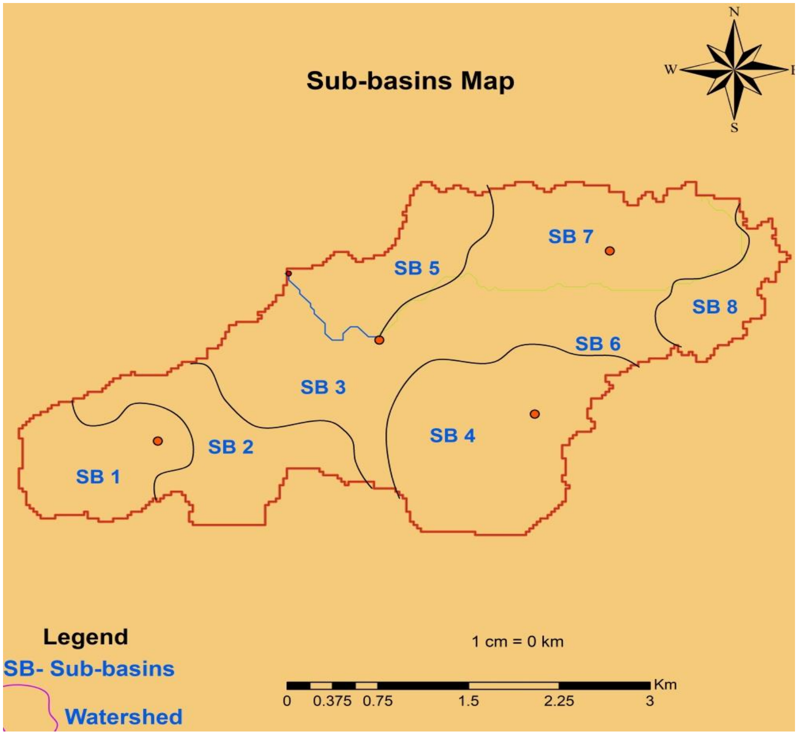
The SWAT model works in the following steps,

Fig.6. SWAT Model setup



After the project setup step is completes the next important step is basin delineation. The digital elevation data is used to delineate given watershed in to number of sub-watersheds. Again the subbasins are divided into HRUs. Land use management and soil characteristics are unique to HRUs. The hydrological budget of each HRU in a given catchment is represented by the depth of the soil profile (0-2m), the shallow depth of the aquifer (2-20m), the deep depth of the aquifer (greater than 20m), and rain (Sabale et al. 2023).

Fig.7. Delineation of Study area



The hydrological parameters like discharge, runoff, sediment yield, pesticides, contamination loading and nutrients from each HRU are summed together and applied to the channel, reservoir or ponds in watershed outlet (Duan 1992). In current work there are total 8 sub-basin and 193 HRUs. In SWAT the data is operated on daily time step to analyze the HRUs. While delineating the data model shows the threshold limit of respective values. In this study the threshold value of 1% for landuse, 10% for slope and 10% for soil is considered. For calibration purpose the data used was from 2000-2009 and for validation the data used of 2010-2014.

Model evaluation

Marshall et al. (1999) used graphical presentation of simulated and observed values of flow and sediment yield for sensitivity analysis. Root mean square error (RMSE) is a statistical metric that can be used to assess model performance. percent bias (Pbias) and Nash Sutcliff efficiency (NSE) are used to evaluate hydrologic model performance (Nash& Sutcliffe 1970). The NSE gives the relative magnitude of measured data variance and residual variance as follows,

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(\text{xi obs} - \text{xi sim})^2}{\sum_{i=1}^{n}(\text{xi obs} - \text{x mean})^2} \qquad ---------- \text{eq. (2)}$$

Where x obs and x sim represent observed and simulated values for time step I respectively, x mean represents the mean of observed data, and "n" represents the number of observations. Table 1 shows the value of Nash Sutcliff efficiency as well as other statistical parameters; according to this table, the best value of NSE is 1 and the acceptable value is between 0.6 and 1. The negative and zero value show unacceptable readings. Similarly Pbias is given by,

$$\text{Pbias} = \frac{\sum_{i=1}^{n}(\textbf{xi obs} - \textbf{xi sim})\ \textbf{X 100}}{\sum_{i=1}^{n}\textbf{xiobs}} \qquad ----------\text{eq. (3)}$$

The low value or zero of Pbias shows better results i.e. optimum value, while positive value shows under estimation and negative value of Pbias means model is over estimated. The RSR is calculated as,

$$\text{RSR} = \frac{\sqrt{\sum_{i=1}^{n}(\text{xi obs} - \text{xi sim})^2}}{\sqrt{\sum_{i=1}^{n}(\text{xi obs} - \text{x mean})^2}} \qquad ----------\text{eq. (4)}$$

Optimal value of RSR is zero.

Table.1. Statistical performance indicators.(Moriasi et al.2006)

Performance rating	**RSR**	**NSE**	**Percentage bias (Pbias) %**	
			Sediment	**Stream flows**
Very good	0.00 to 0.50	0.75-1.00	< ± 15	< ± 10
good	0.50 to 0.60	0.65-0.75	± 15 to ± 30	± 10 to ± 15
satisfactory	0.60 to 0.70	0.50-0.65	± 30 to ± 55	± 15 to ± 25
unsatisfactory	> 0.70	< 0.50	> ± 55	> ± 25

Observed output is used for calibration to check and compare the model results. In this work,the model is calibrated and validated on daily and monthly basis. The SWAT-CUP is model which includes Sequential uncertainty fittings Algorithm were used for calibration purpose (Zhang 2008, Sabale and Jose 2022). After the number of iterations model was considered for further evaluations.

Results and Discussions

After the calibration and validation the outcomes are analyzed by two ways, by statistical and by graphical ways. Prominently NSE is used as objective function to evaluate model performance and its feasibility. NSE givesthe output as the fraction of measured sediment yield and stream discharge which are measured in SWAT model. The values of NSE are shown in table 2.

Table.2: Daily and Monthly Model performance Model performance daily

Calibration Period			Validation Period		
Parameters	Runoff	Sediment	Parameters	Runoff	Sediment
NSE	0.72	0.54	NSE	0.71	0.63
Pbias	5.5	23.8	Pbias	8.9	23.6
RSR	0.51	0.68	RSR	0.52	0.61
P-Factor	0.43	0.34	P-Factor	0.51	0.50
R-Factor	0.91	0.79	R-Factor	0.00	0.00

Model Performance Monthly

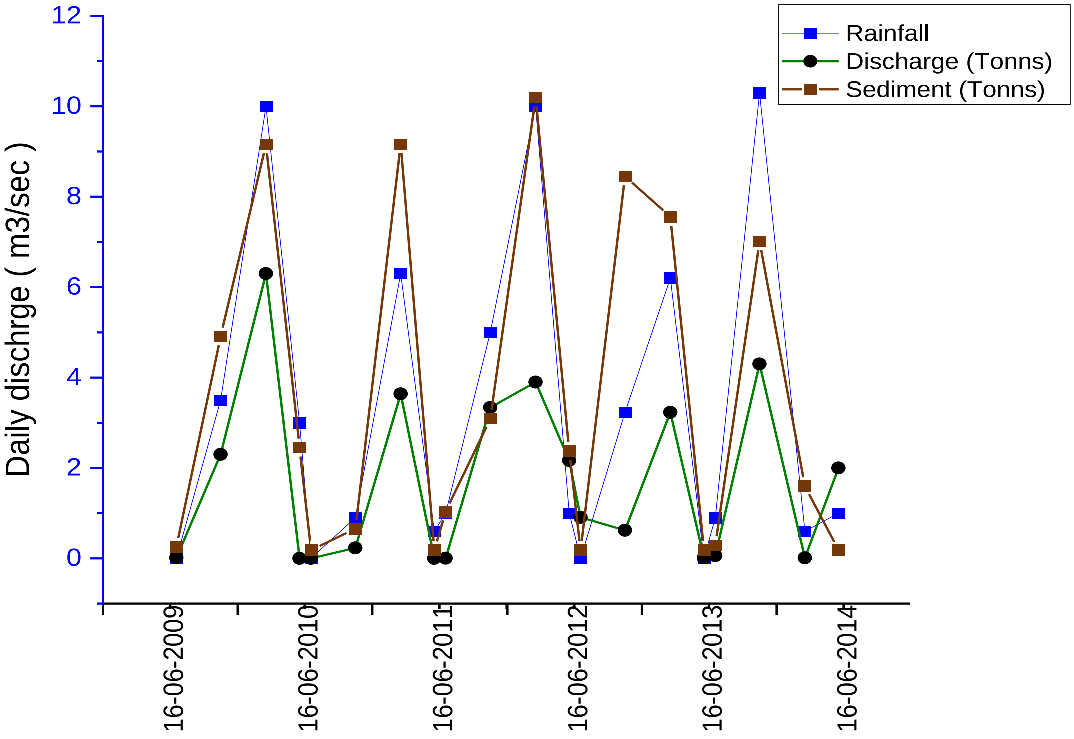
Calibration Period			Validation Period		
Parameters	Runoff	Sediment	Parameters	Runoff	Sediment
NSE	0.88	0.82	NSE	0.90	0.76
Pbias	10.2	13.2	Pbias	-3.8	3.9
RSR	0.34	0.44	RSR	0.29	0.46
P-Factor	0.48	0.98	P-Factor	0.28	0.58
R-Factor	1.16	2.93	R-Factor	0.00	0.00

As the values of NSE for surface runoff calibration shows 0.72 and for validation shows 0.71, it means model shows good performance. The sediment yield values for calibration and validation are 0.54 and 0.63, respectively. The model monthly performance has likewise been positive. The NSE value for monthly basis time step for runoff for the calibration and validation periods is 0.88 and 0.90, respectively. The calibration and validation value of NSE on monthly basis is 0.82 and 0.76.

Percentage bias (Pbias) is another criteria used to measure average nature of analyzed values to be smaller or larger than observed value. In Pbias positive value indicatesthe model is underestimated and negative value means overestimation, whereas zero stands for optimal value. The table.1 provides the range of Pbias and accordingly ratings e.g. satisfactory etc. The current study shows unsatisfactory results for sediments and runoff as the values of sediments increased by 15% and that of runoff by 10%.

The Fig.8 shows the flow calculations for basin. The daily discharge is measured in cumec. The sediments transported in basin are measured in tones and rainfall in (mm).

Fig.8. Flow Calculations



Conclusions

In the present study the Arc-SWAT model was used for estimation of hydrological parameters for Kumbhi River watershed in India. The total catchment area considered for study was 1250 sq.km. The results revels that SCS curve number is very sensitive parameter for runoff and sediment yield. The base flow value of basin was influenced by ALPHA_BF and GW_REVAP. Further the value of R^2 and NSE indicates overall acceptance of model. The simulated data by SWAT is validated with data obtained from K-fold values; the agreement between simulated and observed data shows good degree of fitness. The results show that as per K-fold validation peak discharge is 69.3 m^3/sec, peak time is 4.9 hrs. and base time is 14.32 hrs. for average unit hydrograph for the Kumbhi basin.

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