APPLICATION OF SWAT MODEL IN GENERATING SURFACE RUNOFF FOR BENNIHALLA RIVER BASIN

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Abstract - *Surface runoff is a major component of the hydrological cycle and it is a prime source to satisfy the needs of human being. Hence managing this becomes is very important and it is possible through the conservation of soil and water on a certain scale such as watershed. In India, data availability on surface runoff is very limited. Hence there is a need to estimate the surface runoff at the desired location on watershed. In order to do this, the Distributed Hydrological Model SWAT (Soil & Water Assessment Tool) is often used to estimate the surface runoff. The authors have made an attempt to demonstrate the estimation of the annual discharge values for the point selected on a river stretch using SWAT model. The performance evaluation of model is done by Regression co-efficient (R^2) and Nash and Sutcliffe Efficiency (NSE).*

Key Words: Hydrologic model, SWAT, Regression co-efficient, Nash and Sutcliffe Efficiency.

1. INTRODUCTION

Water is one of the natural resource that India receive through nature. The average annual rainfall of the country is estimated to be around 1083 mm (as per 2014 estimates). On an average, India receives annual precipitation of about 4000 km^3 including snowfall. However, the distribution of rainfall throughout the country is not same, it varies from place to place and also from time to time. It is estimated that out of the 4000 km^3 water, 1869 km^3 is the average annual potential which flow in rivers available as water resource. Out of the total water resource available, only 1123 km^3 is usable. Of this 1123 km^3 of available water resources, the surface water resources is 690 km^3 and the ground water resources is of about 433 km^3[1].

Most of this water resources flows through rivers and streams. At times, this useful resources turns to be disastrous when flood occurs. Bennihalla watershed in Karnataka State experiences severe floods during monsoon seasons due to the flat terrain, encroachment, sedimentation, insufficient carrying capacity of the channel, etc... The southwest monsoon sets in by June and ends by the middle of October. During this period the basin receives more than 50% of the annual rainfall and the climate is generally be humid. Bennihalla River basin is comprised of black cotton soil (high clay content soil) which are rich in Montmorillonite which is having the property imparting high degree of expansiveness [3]. All these problems put together was posing a serious threat in the form of flooding. Hence there is a need to such floods to reduce damage caused to men and animals and also the useful property.

In order to estimate the daily discharge values in a particular reach of Bennihalla, SWAT model was used. The model is calibrated and validated using the short length of available data. The model performance is evaluated using R^2 and NSE values. Once the model is found to give satisfactory results for the selected river segment, the same can be used to generate the daily or monthly or yearly discharge data. This SWAT model helps to estimate discharge data when data are either not available or the measurements cannot be possible at the location.

2. STUDY AREA AND DATA USED

The Bennihalla basin (Fig.1) is one of the tributary of Malaprabha River which ultimately joins Krishna River. The basin lies between latitudes north 15°04'27" and 15°50'23" and longitudes between east 74°58'43" to 75°38'44". The study area covers Rona, Gadag and Shirhatti taluks in the east, Dharwad and Hubli taluks in the west. Shiggaon taluka in the south west and Nargund and Parasgad taluk in the north. Navalgund taluk in the Center. The watershed Bennihalla falls in the semi-arid region. The physiography of the study area is portrayed by tenderly undulating landscape with altering ridges [3].

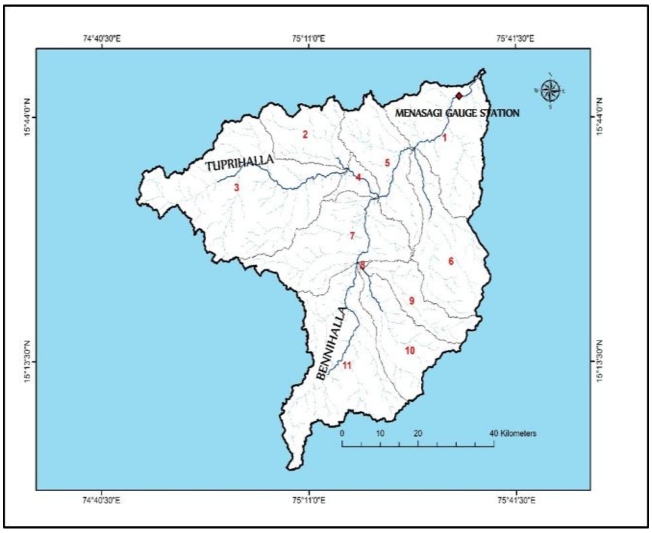

Fig -1: Bennihalla Watershed

The point considered in the present study, Menasagi village, is close to the outlet point of the watershed and it is used to generate the Monthly discharge data using SWAT model and it lies in the sub-watershed 1 out of 12 sub-watersheds (Ref. Fig.1) as delineated by SWAT. From the record of the available data with the concerned department, it has been found that only this station, Menasagi, has certain observed data and being the point nearer to outlet point, represents the entire watershed. Hence chosen for the study. The record of Menasagi station, available with Irrigation Investigation Department Dharwad, which are available for the period from 1988 to 2014 were made used for calibration and validation of the model. The observed stream data were collected from.

The DEM (Digital Elevation Model) of the study area was downloaded from Bhuvan site using CARTOSAT-1 satellite having 32m spatial resolution. Soil data was extracted from Harmonized World Soil Database for the present work for the year 2000 from FAO (Food and Agricultural Organization). Land use and land cover data were extracted using LANDSAT-7 imagery satellite for the year 2003. Precipitation data for the study area was collected from Irrigation Investigation Department, Dharwad for the period 1988 to 2014. Temperature data having resolution of 10X10 was collected from IMD (Indian Meteorological Department) for the period 1988 to 2014.

3. SURFACE RUNOFF ESTIMATION

In order to estimate the surface runoff in SWAT model SCS curve number procedure (SCS, 1972) is used. The surface runoff may be generated on daily, monthly and yearly basis depending on the user defined condition during SWAT run. The work flow process to generate surface runoff at different locations in a watershed is illustrated in the Fig. 2.

The SCS-CN is used to estimate runoff and is given as:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Where,

Q_{surf} = accumulated runoff or rainfall excess (mm of H_20),

R_{day} = rainfall depth for the day (mm of H_20),

I_a = initial abstractions which includes surface storage, interception and infiltration prior to runoff,

S = retention parameter (mm of H_20).

The retention parameter is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

Where,

CN = Curve number for the day,

I_a = commonly approximated as 0.2*S.

Source: SWAT Theoretical Documentation, 2011[2].

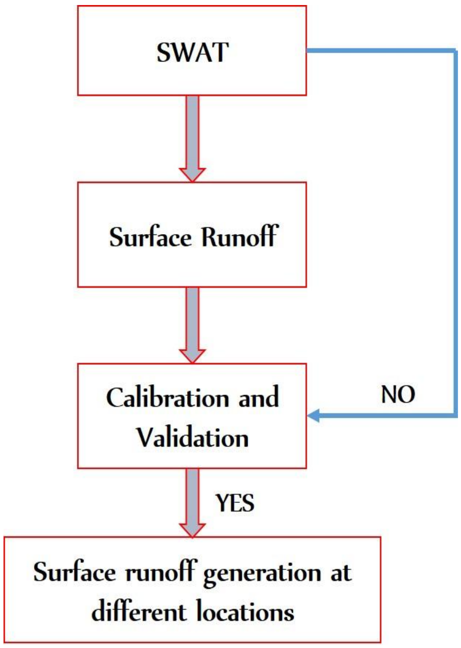

Fig -2: Work Flow

4. SWAT MODEL SETUP

First step in setting up of SWAT model is the watershed delineation using DEM. An interface Arc-SWAT was used in this case to prepare necessary input files to run the SWAT model. Arc-SWAT processes the Digital Elevation Model (Fig. 3) and automatically delineates the watershed and sub-watersheds, generates the stream network, outlet for a given threshold value.

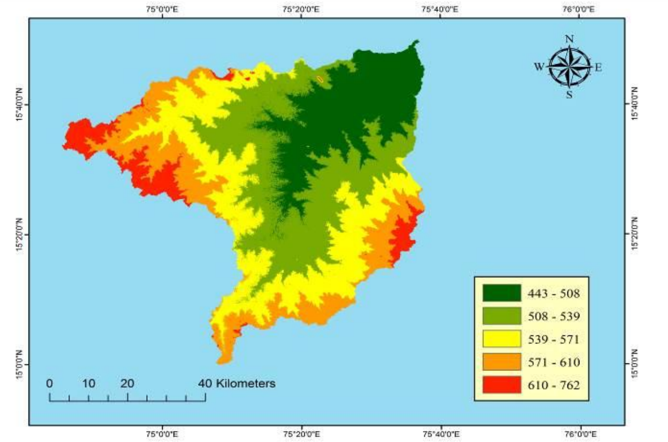

Fig -3: Digital Elevation Map of Bennihalla

The meteorological data required for the SWAT model are precipitation, temperature, relative humidity, solar radiation and wind speed. Precipitation data were collected from Irrigation Investigation Department, Dharwad for the period 1988 to 2014. Temperature data was collected from IMD (Indian Meteorological Department) for the period 1988 to 2014.

The land use and land cover data are collected from LANDSAT – 7 Satellite for the year 2003. Then this data was subjected to supervised classification process. Fig. 4 illustrate the map of different land use and land cover for the study area.

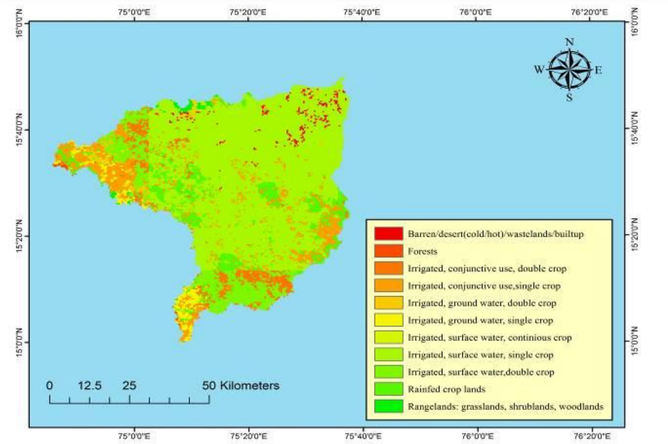

Fig -4: Land Use and Land Cover Map

Soil map was obtained from the FAO (Food and Agricultural Organization) digital soil maps at 1:50000 scale. Fig. 5 illustrates the soil classes within the study area.

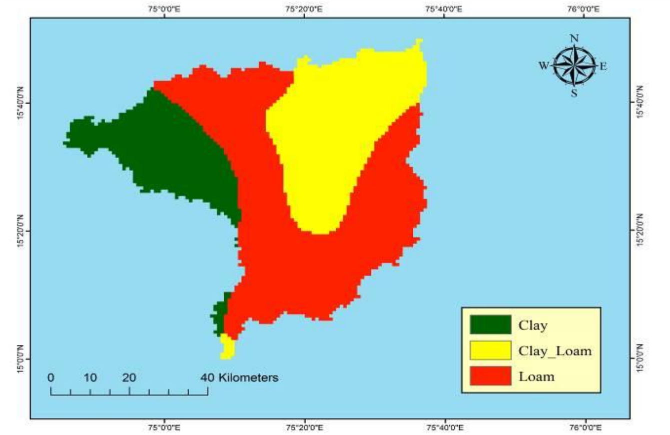

Fig -5: Soil Map of Bennihalla

Monthly observed discharge data (1988-2014) for the Menasagi Station, located within the study area, was obtained from Irrigation Investigation department, Dharwad. These observed discharge data was used for the calibration and validation of the model. Fig. 6 represents the observed monthly discharge data of the Menasagi gauging station.

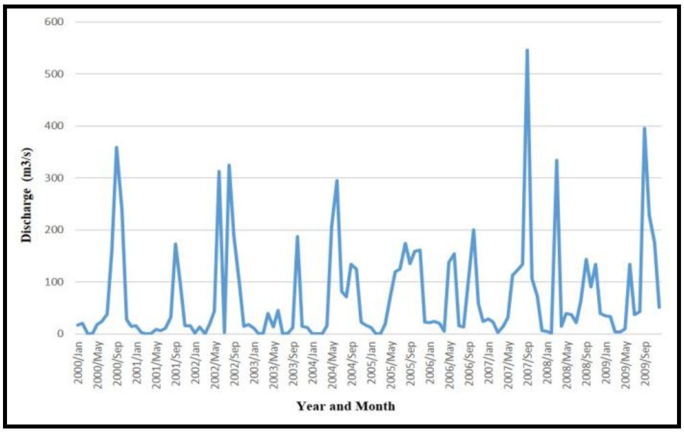

Fig -6: Observed Monthly Discharge (2000-2009)

Land use/ land cover map and soil map were overlaid after the watershed delineation process is done. Based on the overlaying, basic units of modelling (Hydrologic Response Unit, HRUs) were extracted. In the present study, HRUs were defined by taking all land uses, soil type and slope occupying 10% or more of sub-basin area. HRU report was then generated. Precipitation and temperature data obtained from Irrigation dept. and IMD, Pune was fed into model as a user defined data for the weather parameters. Weather generator was used to generate and write meteorological parameters files. Then the SWAT was run for the period of 26 years from the year 1988 to 2014 with the warm up period of 02 years.

5. RESULTS AND DISCUSSIONS

The model is used to generate discharge values at the selected point, Calibration is done for the year 2000 to 2004 period and Validation of the model for the period 2005 to 2009 period. Before calibrating the model the discharge values were under predictive as simulated peaks were lower than the observed peaks. The objective functions chosen for calibration purpose were R^2 and NSE. For the first run, R^2 and NSE were obtained as 0.561 and 0.303 respectively.

The model was simulated for different scenarios by changing the various sensitive parameters (Table 1). On doing sufficient number of iteration by assigning different values for sensitive parameters the objective functions were improved as R^2=0.608 and NSE=0.665. Fig.7 shows the relative variations of observed versus simulated flow on model calibration for the period 2000 to 2004.

Table -1: Parameters used in Calibration of the Model

Parameters	Initial Values	Calibrated Values
CN_2	87	89
GW_DELAY	31	120
ALPHA_BF	0.048	0.85
ESCO	0.95	1
SURLAG	2	0.5
SOL_AWC	0.16	0.2

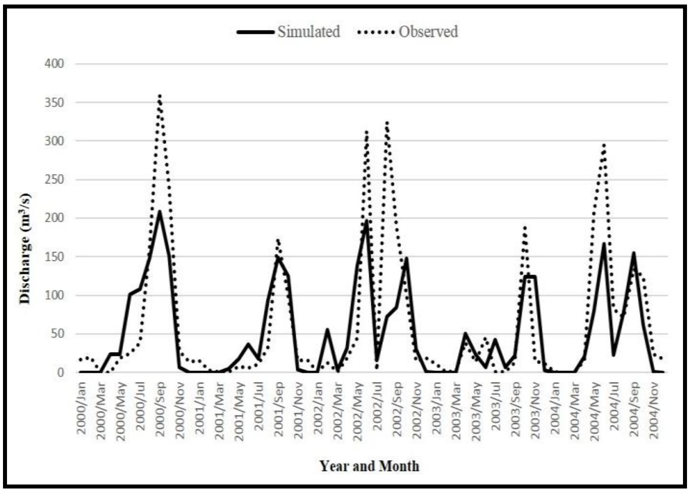

Fig -7: Comparison between observed and simulated discharge values after calibration

Next step taken was the validation of the model, once again the model was run and the simulated results was compared with observed data from 2005 to 2009. Comparison between the observed and simulated flow is shown in Fig. 8.

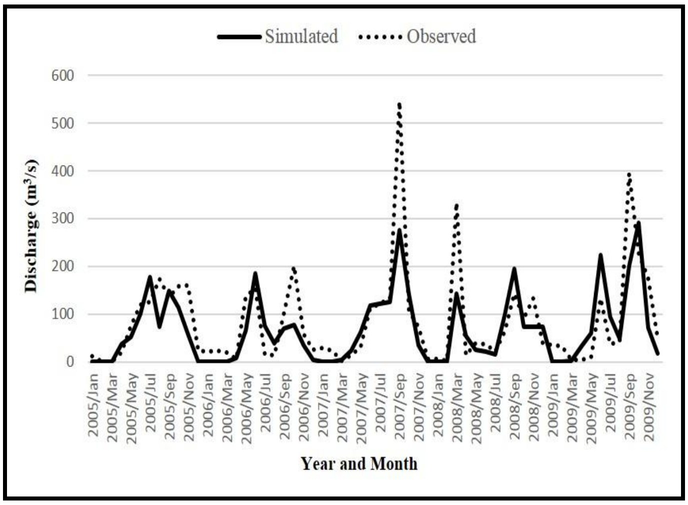

Fig -7: Variation in observed and simulated discharge values on Validation

Coefficient of determination R^2 and NSE were used to assess the model performance. In general, model simulation can be judged as satisfactory if NSE > 0.50 (Moriasi et. al, 2007) [9] and typical value of R^2 greater than 0.5 for stream flows (Santhi et al., 2001; Van Liew et al., 2003)[4][5]. The low values of R^2 and NSE may be due to the uncertainties associated with the observed data and also may be due to the use of coarser resolution data which directly affects the accuracy and the model performance. Based on the result obtained, model is assumed to be valid and further analysis of model output has been made.

The results of objective functions on calibration and validation of the SWAT model for the monthly discharge data at Menasagi gauging station is shown in the Table II.

Table -2: Parameters used in Calibration of the Model

Objective Function	Calibration	Validation
R^2	0.608	0.617
NSE	0.665	0.658

Attempt have been made to refine the values of objective function. From the studies it has been found that the most influencing sensitive parameter for surface runoff is the CN (Cure number) varying from 30 to 100 which depends on the area's hydrologic soil group, land use and hydrologic condition [12]. For the model is calibrated, the CN value attained is 89. When the value of CN was assigned more than 89 and less than 89, it is observed that prediction discharge values were either overestimating or underestimating compared to observed ones. This may be due to the fact that the Bennihalla watershed has the flat terrain and the presence of black cotton clayey soil (Ref Fig. 5) in the catchment.

6. CONCLUSIONS

The method demonstrates the use of SWAT model to generate surface runoff values for any location on the watershed. The model was calibrated and validated with the observed data for Menasagi station. In the present case, two objective functions were tested to evaluate the simulated results from SWAT model. The R2 and NSE values was found to be 0.608 and 0.665 during calibration and 0.617 and 0.658 on validation respectively.

The study reveals that, SWAT model can be applied on any watersheds to generate the surface runoff values provided, calibration and validation of the model for the selected watershed is done with the observed data and the values are within the acceptable limits.

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BIOGRAPHIES

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