Application of SWAT model in estimating Surface Runoff values for Shimsha Watershed

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Abstract - **This study has presented comprehensive modelling environment for SWAT including manual calibration and validation. The goal of this study is to estimate the surface runoff of a selected watershed at ungauged stations using Soil and Water Assessment Tool (SWAT) model. To examine and demonstrate how it functions, Shimsha river basin was used in the present study. The various inputs like Digital Elevation model (DEM), Land use & Land cover (LU/LC) map, soil map, slope map, weather data, etc., were used in SWAT model to simulate runoff values on daily and monthly basis for the period 2000-2020. The calibration and validation of the software was carried out for a period 2011-2015 and 2016-2020 respectively. The simulated values were compared with the observed discharge values of Igloor dam. The model behaved well during calibration with an R2 value of 0.6613 and during validation 0.6469. The study demonstrates the application of SWAT model in generating runoff values at the required ungauged stations which helps in implementing effective management practices.**

keywords - **Modelling, SWAT, surface runoff, watershed, calibration and validation, etc.,**

I. Introduction

Natural resources are natural phenomena that occur in nature and are beneficial to us, among which water is one of the valuable natural resources that we obtain from nature. As per 2019 estimates, the country's average annual rainfall was around 1284 mm. In India we receive an average yearly rainfall of approximately 4000 km^3 total, including snowfall. As rainfall is not evenly distributed throughout the nation, it fluctuates from location to location as well as from season to season. India has only around 4% of the world's current water resources and 18% of the worldwide population. With ever increasing population growth, climate change, needless to compete with developed nation has resulted in exploitation of water resources all over the country. Unfortunately, human involvement has resulted in many rivers drying up in the middle of the journey.

Runoff plays a crucial part in the dynamic process of Hydrologic cycle as the excess water if not used or managed properly leads to joining of nearby oceans. Temperature, relative humidity, wind speed, solar radiation, evapotranspiration, vegetation, soil properties, precipitation, land use, and land cover are just a few of the variables influencing this process. Management of surface water resources are very important as rainfall is unevenly distributed in India, many of the researches even today are concerned with the conservation and effective management of surface water resources. Runoff is often projected by using rainfall-runoff models and watershed hydrologic data, whereas modeling runoff can also help to understand, control, and monitor the quality and quantity of water resources. In developing nations like India, where higher operations and maintenance costs prohibit gauging on small and medium rivers, calculating runoff from ungauged or inadequately gauged catchments is a major difficulty. Hydrological models are excellent method for evaluating the balance between human and environmental demands because they also can represent the past and future scenarios of a water management system even in ungauged basins.

Several physically based distributed parameter models like AGNPS (Young et al., 1989), SHE (Abbott et al., 1986), HEC-HMS (Feldman 1981), HEC 2000, SWRRB (Arnold et al., 1990; Williams et al., 1985) and SWAT (Arnold et al., 1996) have been developed to predict runoff, erosion, sediment and nutrient transport from rural and agricultural watersheds under various management regimes. Among these models, Soil and Water Assessment Tool (SWAT) is the widely accepted software to predict the above said processes. (Dhruvesh P. Patel et al., 2016). The rainfall-runoff relationship is an important issue in hydrology and a common challenge for hydrologists. Due to the tremendous spatial and temporal variability the impact of rainfall on runoff becomes more intensive and their proper estimate is essential for flood and drought management. (Mrugaxi Sheth et al., 2018).

The aim and objective of this present study is to estimate surface runoff at ungauged stations and to provide discharge values at any specific reach in the river basin by using the SWAT (Soil and Water Assessment Tool) model. When data is not available or measurements are not practicable at that location, this SWAT model can be used to approximate discharge data. It can also examine the effects of land use, climate change, and management methods in the basin because it uses spatially distributed information of landforms, soil, topography, and climatic data. The SWAT model estimates the runoff from the watershed by combining GIS data with an attribute database, and it is a physically based distributed parameter model used to predict runoff, erosion, sediment etc. This SWAT Model is used in combination with Arc GIS.

II. STUDY AREA AND DATA USED

Of the major rivers of south India, Shimsha River is one of the tributaries of mighty river Cauvery which takes birth in Devarayanadurga Hills in Tiptur taluk of Tumakuru district Karnataka. The river has a course length of 221 km and has a catchment area of 8469 km^2 before joining the river Kaveri at shimshapura near the border of Chamarajanagara district. During the course of its travel from the origin many sub-tributaries join the Shimsha river such as Veeravaishnavi, Kanihalla, Chikkahole, Hebbahalla, Mullahalla and Kanva. At the mouth of the Shimsha river, a waterfall is situated at shimshapura in Malavalli taluk located 30 kms from Mandya, which was used to generate Hydroelectric power with an installed capacity of 17,200 kw and is considered to be the first ever hydroelectric project in Asia. The power generated during that time was used to light the Kolar gold fields.

The Markonahalli dam, a multi-purpose reservoir has been erected across the river after it originates in Tiptur, Tumakuru district. It is reported to have been erected primarily as a flood-prevention measure for communities lying downstream, as well as to safeguard the safety of the nearby revered Yediyur Siddhalingeshwara Temple. Also, a barrage named after former Prime Minister H.D Devegowda has also been encountered during the course of its travel at Channapatna taluk, Ramanagara district – Igloor Dam Devegowda Barrage. The river then continues a southerly route and reaches the Mandya district. The river travels in a south-eastern direction through Mandya district, with a waterfall at Shimshapura in Malavalli Taluk. Shimsha river is often referred as Madduru hole as the river passes through Maddur town and many villages of Maddur taluk. Shimsha is the principal irrigation supply for thousands of farmers in Nagamangala, Maddur, and Malavalli taluk, as well as hundreds of riparian villages in Tumakuru, Mandya, and Chamarajanagar taluks. Figure 1, below presents the selected study area along with the delineated watershed.

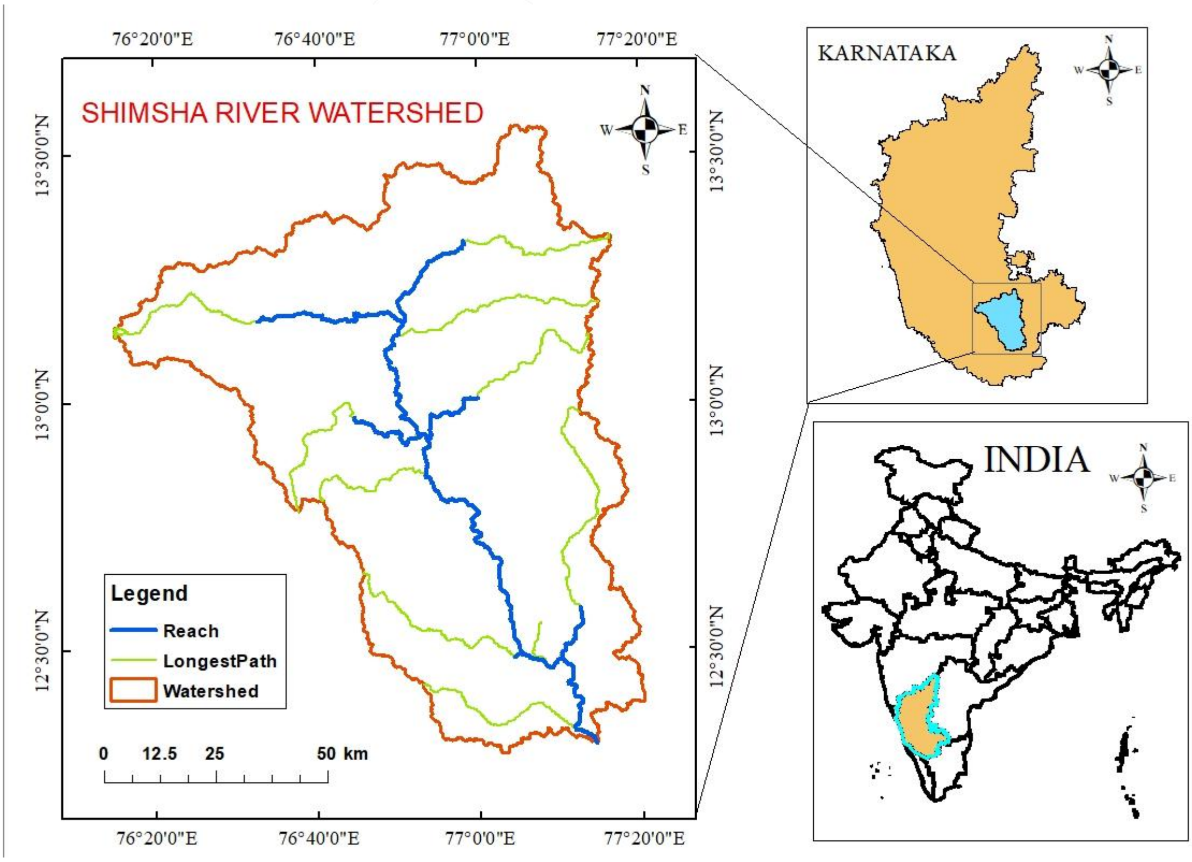

Fig. 1- Location map of the study area

DATA USED

The SWAT model requires both spatial and non-spatial datasets. Spatial datasets such as DEM, land use map, soil map, and slope map were created using the Arc-GIS 10.3 interface.

A. DEM

The digital elevation model (DEM), which provides the elevation at every location in a particular area at a certain spatial resolution, is the primary input for SWAT modelling. DEM having spatial resolution of 32 m from CARTOSAT-3R1 satellite was downloaded from ISRO's Bhuvan Geoportal website and mosaicking of DEM to get the required study area was done by utilizing tools within the ArcGIS 10.3 interface. The watershed delineation provided drainage pattern of land surface terrain including the stream network, and outlets of the river basin. Watersheds were defined by the model using a DEM-based automated method. Figure 2 shows the elevation map of the study area whose value ranges from 314 to 1194 meter.

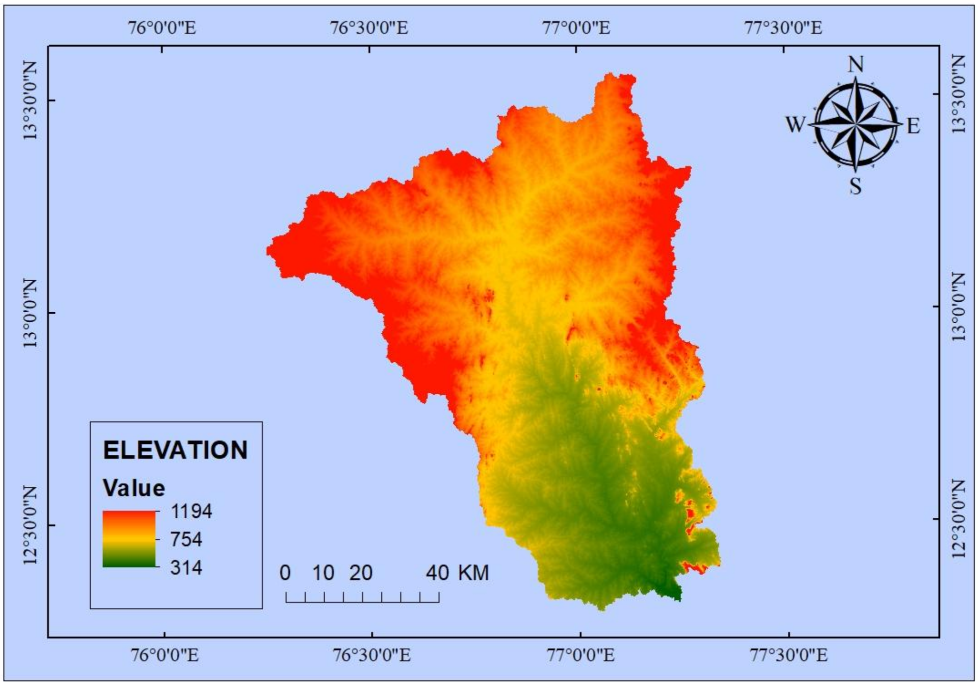

Fig. 2 – Digital Elevation Model of the Shimsha watershed

B. LU/LC

It is the map illustrating different utilization or land cover type of the selected area which affects runoff, and evapotranspiration processes in the watershed during simulation. Land use and Land Cover data were taken from the LANDSAT-7 satellite available at the Bhuvan website. The map included 19 land use groups namely urban, rangeland, bare soil, and farmland and so on. It was then divided into 11 different land covers, each of which is represented by a distinct colour in the Figure 3.

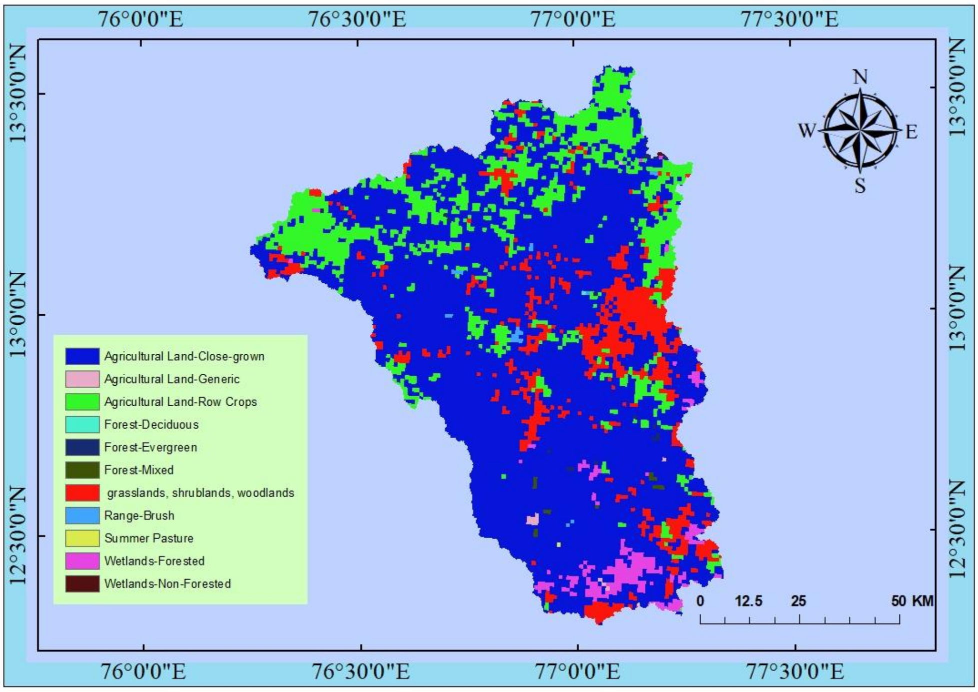

Fig. 3 - Land use land cover map of the Shimsha watershed

C. Soil map

Soil map is a geographical representation showing diversity of soil types and soil properties in the area of interest. The soil map was obtained from FAO (Food and Agricultural organization), digital soil maps at 1:50000 scale. The soil classes in the selected watershed were found to be: clay, loam clay, sandy clay loam. Figure 4 depicts the soil categories found in the Shimsha watershed.

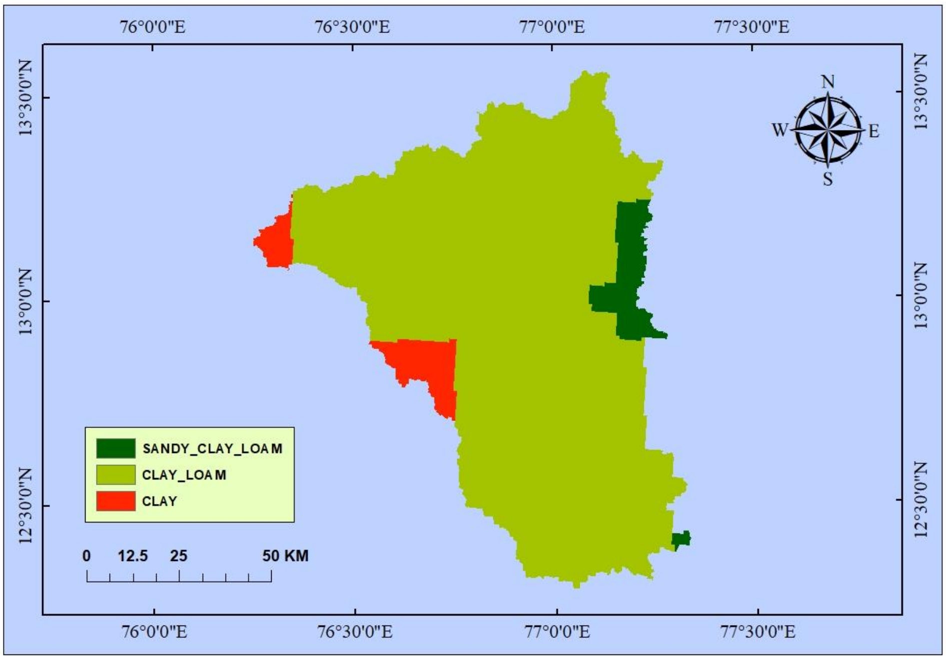

Fig. 4 - Soil map of the Shimsha watershed

The slope map was created with the use of the Arc-GIS interface tools and DEM raster data. After then, it was sorted into four different orders, ranging from 0 to 56.

The non-spatial datasets such as meteorological data required for SWAT model are precipitation, temperature, relative humidity, solar radiation and wind speed. For the year 2000 to 2020, daily rainfall data from 20 rain gauges within the watershed were gathered from the statistical department of Mandya and Tumakuru district. For the same time period, the Maximum and Minimum temperature data were collected from University of Agricultural Sciences, V C Farm, Mandya. The other non-spatial data such as relative humidity, wind speed and solar radiation were taken from the SWAT database.

D. Observed Discharge Data

Discharge data from Igloor Dam, which is located within the study area, were collected on a monthly basis from 2000 to 2020. These data were used for calibration and validation purposes. Figure 5 portrays the monthly discharge data or monthly inflow pattern observed at the Igloor Dam.

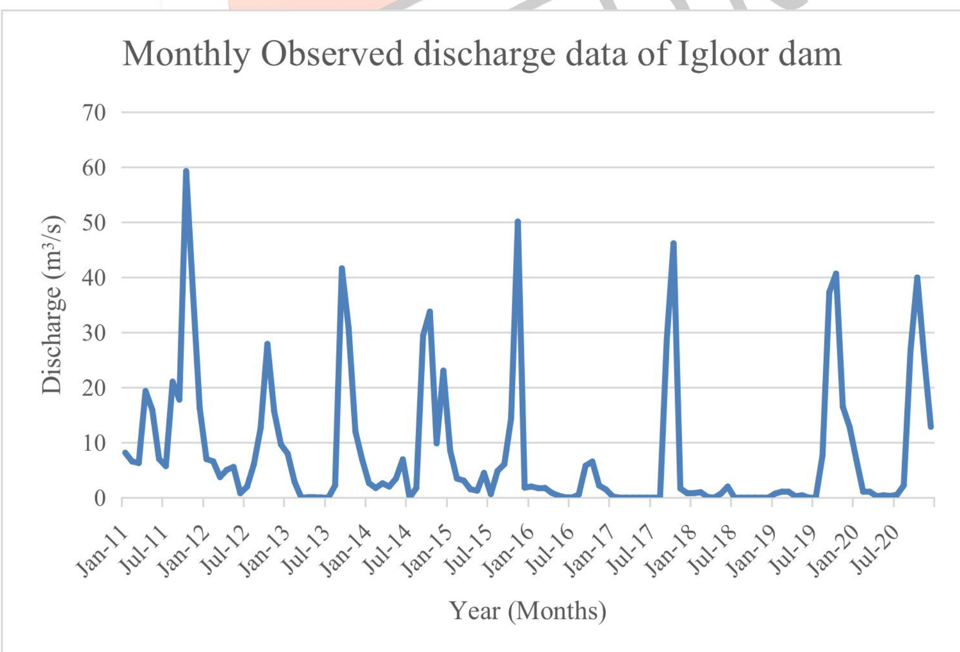

Fig. 5 – Observed Monthly discharge data of Igloor dam

III. Model Setup & Methodology

In the present study, Arc-SWAT 2012 version has been used in the GIS interface which is a continuous simulation macro scale hydrologic model developed by USDA's Agricultural Research Service (ARS) for predicting runoff, sediment, and various land management practices. SWAT necessitates a large number of geographical and temporal input data sets. SWAT, as a semi-distributed model, uses GIS to process, aggregate, and evaluate this data spatially. As a result, the model was integrated with GIS software as an extension Arc-SWAT for ArcGIS to make it easier to use. The SCS curve number method was used to estimate surface runoff, which uses an empirical relationship between rainfall and runoff to provide a consistent basis for estimating the amount of runoff under varying land use, soil type, and soil moisture conditions. Depending on the user-defined condition during the SWAT run, surface runoff can be generated on a daily, monthly, or yearly basis.

The SCS-CN equation is given by (SCS, 1972);

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (1)$$

Where,

Q_{surf} = daily runoff depth (mm),
R_{day} = daily rainfall depth (mm),
I_a = initial abstraction (mm) which includes surface storage, interception and infiltration prior to runoff, which is approximated as 0.2*S
S = retention parameter (mm), the retention parameter varies spatially due to changes in soil water content which is defined by Eq.

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (2)$$

CN = Curve Number for the day.

Methodology:

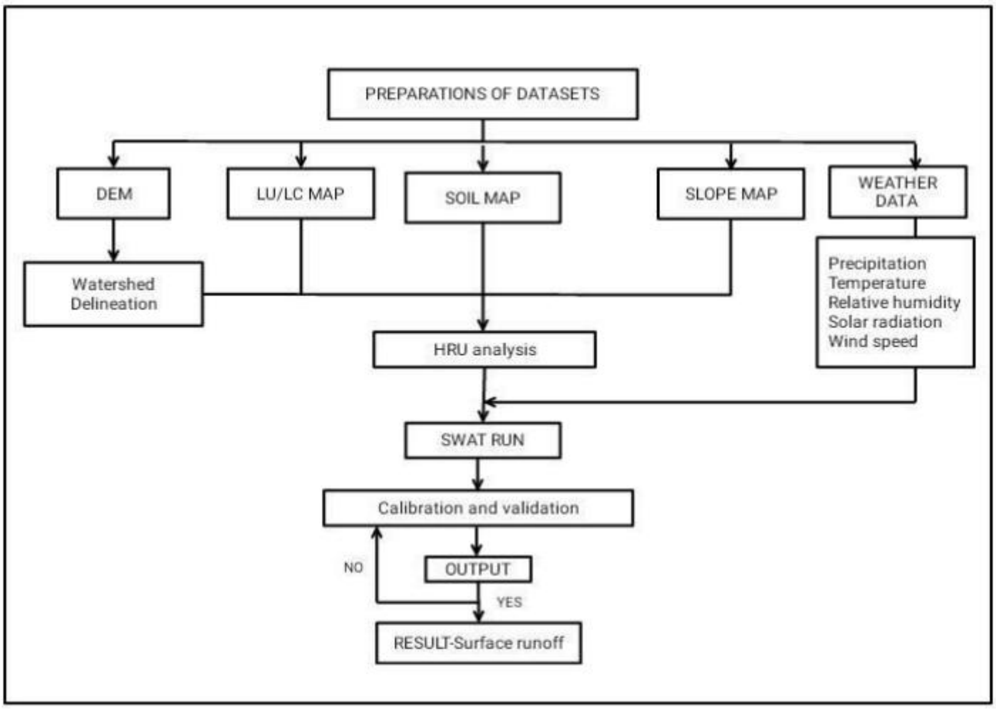

Fig. 6 – Work flow process adopted in generating Surface Runoff values using SWAT model

The first step in model setup is to use a DEM raster file to delineate the watershed, sub-basins, and reaches. The definition of the watershed gave a drainage pattern of land surface terrain, including the stream network and river basin outlets. The model used a DEM-based automated technique to delineate watershed. In which the watershed was divided into 11 sub-watersheds, after providing a LU/LC map, soil map, and slope variation, they were further subdivided into 29 HRUs by the model (Hydrologic Response Units). HRUs, on the other hand, are combined units made up of homogeneous land-use and soil characteristics. A 10% threshold percentage has been implemented for all land use, soil, and slope classes in order to exclude minor land use, soil, and slope. The HRU report was then generated which included area of watershed (8694.15 km^2), detailed descriptions of the land use, soil, and slope classes in each sub-watershed. The model was then fed with the weather data collected from various departments. The sun radiation, wind speed, and relative humidity data were extracted from the SWAT database as those data were not available for the selected study area. The model was simulated once the SWAT input tables were written with a warm up period of 2 years.

IV. Calibration & Validation

Calibration is the iterative process of comparing the model with real results, revising the parameters within the realistic range and comparing again until the model and observed discharge are equitable. Calibration is required because there may be considerable uncertainty in the model input as a result of spatial variability. Model validation is the process of rerunning the simulation using alternative input data and not modifying any parameter values that have been altered during calibration. The discharge from SWAT output was compared with the observed discharge from Igloor dam. Calibration was performed manually from 2011 to 2015, and validation was performed from 2016 to 2020. The following parameters were used to calibrate the model: CN2, ESCO, ALPHA_BF, SURLAG, RECH.DP, and SOL_AWC. Model performance indicator R^2 was used to evaluate the SWAT model's output multiple times until acceptable surface runoff values were reached.

V. Results & Discussions

The Runoff values for 18 years from 2002-2020 at the Igloor dam was simulated by the SWAT model and the comparison of output values with the observed data have been presented in the below figure 7 from which it can be seen that for most of the year, SWAT simulation seemed to overestimates the discharge when compared to observed values. This is because of uncertainties in input data, model structure and model parameters. The calibration was carried out as a process of adjustment for these uncertainties.

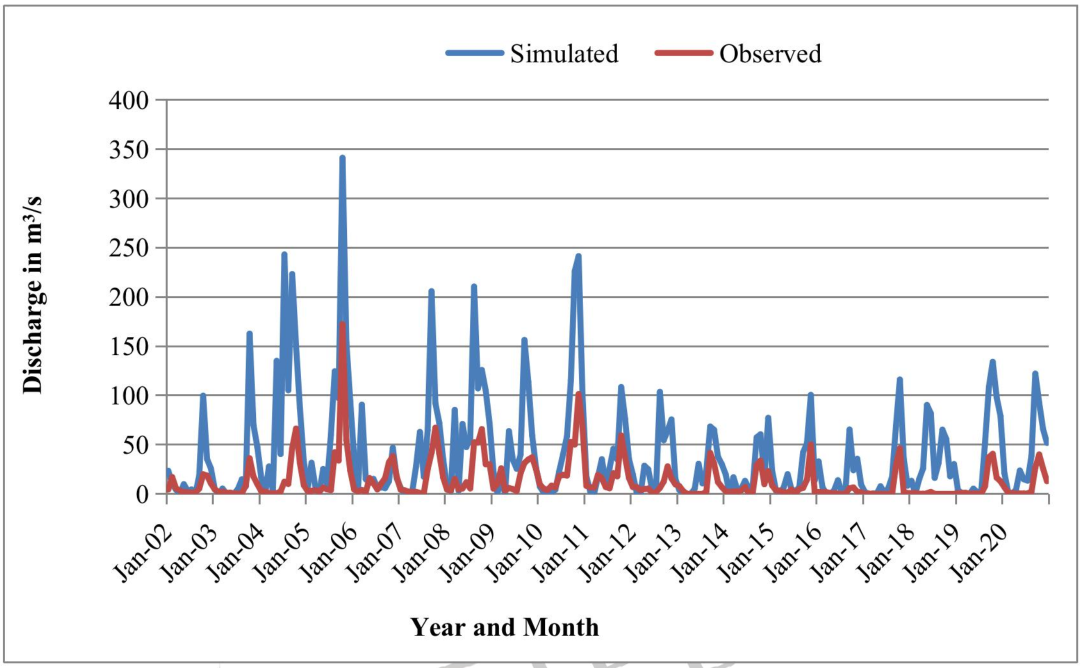

Fig. 7 - Comparison between observed and simulated discharge values before calibration

The sensitive parameters for the present study were selected based on the study conducted by Douglas –Mankin et al., (2010) and Tuppad et al., (2011) on 64 selected watersheds. SWAT simulates the interaction of processes; many parameters affect more than one process. It's a kind of ripple effect. (For example, CN has direct impact on runoff; however, change in runoff changes other components of hydrology. There is direct impact of runoff change on soil erosion and nutrient transport affecting plant growth and nutrient cycling). So, Santhi et al., (2001) highlight this as the primary reason for manual calibration to start with hydrology balance and surface runoff, then sediment, and finally calibrating nutrients. From the above studies it was concluded to use the sensitive parameters such as CN2, ESCO, ALPHA_BF, SOL_AWC, SURLAG and RECH.DP and their initial and final values have been illustrated in the table 1.

Table 1: Parameters used for calibration of the model

PARAMETERS	BEFORE CALIBRATION	AFTER CALIBRATION
CN2	84	77
ESCO	0.95	1
ALPHA_BF	0.048	0.052
SOL_AWC	0.09	0.005
SURLAG	4	24
RECH.DP	0.04	0.01

The model was simulated for various scenarios by changing the above parameters which are sensitive to runoff values. In this study, the coefficient of regression (R^2) was used to assess the model's performance. In general, model simulation can be judged as satisfactory if R^2 value is greater than 0.5 for stream flows (Santhi et al., 2001; Van Liew et al., 2007).

After numerous iterations of altering the parameters within the range, the regression coefficient (R^2) for calibration and validation was found to be 0.6613 and 0.6469 respectively which is found to be satisfactory. Calibration and validation results have been presented in the below figures.

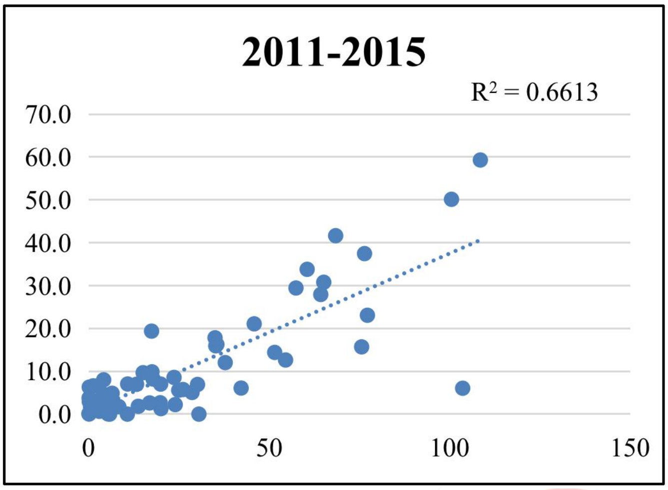

Fig. 8 - Scattered chart of observed and simulated discharge values after calibration

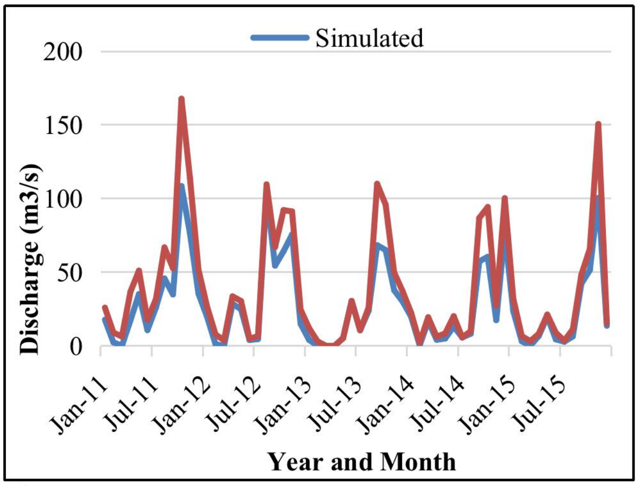

Fig. 9 - Variation in observed and simulated discharge values after calibration

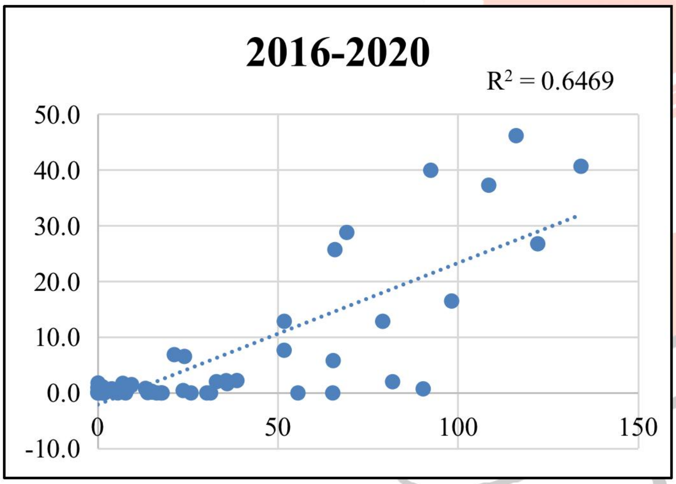

Fig. 10 - Scattered chart of observed and simulated discharge values during validation

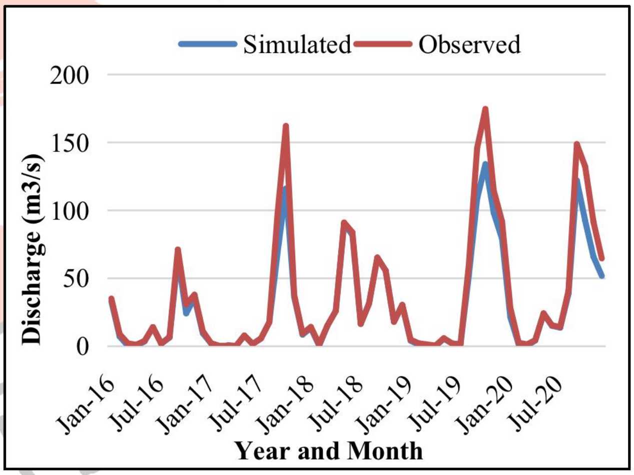

Fig. 11 - Variation in observed and simulated discharge values during validation

VI. Conclusion

As the population growing impulsively, demanding urbanization, the expansion of industries and development in agricultural practices adds up to the increasing demanding for water and it is very much essential to manage the water resource wisely. In the present study, to understand the status of water resources as well as hydrological process in the Shimsha river basin, SWAT model was applied. Since the river Shimsha waters vast areas of cultivation land our study aims at estimating the surface runoff at various ungauged stations for effective watershed management practices.

Calibration and validation were performed manually for the year 2011 to 2015 and 2016 to 2020 respectively on monthly basis. Model performance has been done using statistical parameter called Coefficient of Determination (R^2). Before calibration the R^2 value observed as 0.396 and the model has over predicted the capability for the Shimsha River. After calibration and validation R^2 value were found to be 0.6613 and 0.6469 respectively. The model indicated very good agreement between simulated and observed flow. Therefore, it can be concluded that the SWAT model helps as an effective tool for assessment of water functioning at basin scale.

Under practical conditions it may be difficult to install discharge gauges everywhere along the stretch of stream, and may be in the future it is necessary to know the surface runoff at a required stretch where the discharge gauge station facility is not available or gives faulty measurements. In such cases SWAT plays a very significant role in estimating the approximate surface runoff and it is a well-founded tool for integrated basin management in terms of water flow, and it can assist the people to improve socio-economic lives directly or indirectly. The accuracy and precision of the model can be improved drastically with better and high-resolution gridded rainfall data or if available observed meteorological data from various stations spread across the selected watershed.

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