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***Key words: Runoff, Hydrological modeling, Calibration, Validation, ArcSWAT.***

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## *Certificate of Participation and Appreciation*

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**Authored by**

**Manish Nema**

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# HYDROLOGICAL SIMULATIONS FOR TAWI RIVER BASIN UPTO JAMMU USING SWAT MODEL

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## ABSTRACT

Runoff is a key component of hydrological cycle and it is relevant for the basin planning and management programme for conservation and development or natural resources. This implies the need to develop and test hydrological models for understanding the hydrological characteristics of the region of interest for appropriate mitigation and adaptation measures to cope with future water demands. Soil and Water Assessment Tool (SWAT) is a physically based semi-distributed hydrological model, which has been developed to predict runoff, erosion, sediment etc. and it employs the hydrological response unit (HRU) as the basic unit of the basin. In the present study, SWAT was applied to the Tawi River Basin of Western Himalayan region of India. Tawi is a forested mountainous basin with geographical area of 2167 km$^2$. Model parameters were identified using sensitivity analysis and long-term calibration procedures, which enabled the historical behavior of the catchment to be reproduced. Following validation, the parameters were used to simulate the streamflows. In order to establish the effectiveness of model to simulate hydrological responses to climatic variations, the simulated values were subjected to rigorous calibration with observed runoff data on a monthly time scale. Fifteen-year monthly rainfall and runoff data were used to simulate the hydrological behavior of the basin for the study. During the simulation, the monthly observed stream flows matched well with simulated flows with Correlation coefficient and Nash-Sutcliffe coefficients values of 0.72, 46% during calibration (1983–1992) and 0.92, 84% during validation (1993–1997) respectively, suggesting a better parameterization and simulation performance. Since the database on SWAT model's potential in simulation performance on Himalayan basins is scanty, this paper is successful in showcasing the potential of SWAT in simulating the runoff of Western Himalayan basins.

***Key words: Runoff, Hydrological modelling, Calibration, Validation, ArcSWAT***

## 1. INTRODUCTION

For river basins, water discharge is an important hydrological parameter because it defines the shape, size and course of the stream. Assessment of flow for all the watersheds using the modeling framework is very essential for taking up any development work. The results of monitoring water discharge can be useful information for flood forecasting, predicting sediment loads and assessing the impact of climate change to water resource. Hydrological modelling of the basin to simulate the flow at various locations in the river where observations are being made to validate the model. Hydrological models of varying degrees of complexity and scale are now available ranging from basin scale models to macro-scale models. Some of the distributed hydrological models that are in common use are MIKE-SHE model (Abbott et al 1986), TOPMODEL (Beven and Kirkby, 1984 and 2001), WATBAL (Knudsen et al 1986), and HMS (Capehart and Carlson 1994; Yu et al 1999). Soil Water Assessment Tool (SWAT) model is a hydro-dynamic and physically-based hydrologic model. SWAT is an evaluating tool of soil and water developed by the USDA-Agricultural Research Service (Neitsch et al., 2002). The GIS based hydrological model SWAT has a modular structure and consists of hydrological, sedimentological and chemical subroutines applicable to watershed scales. A central part of

SWAT is the general water balance equation. Surface runoff is determined by the SCS curve number approach. The basic spatial unit to the calculation is the Hydrologic Response Unit (HRU) that is the result of the combination of soil type, a class of land cover and a sub-basin. Literature indicates that SWAT model can be an effective tool for accurately simulating the hydrological processes of the watersheds on different time steps. The present study describes the application of SWAT (ArcGIS Soil and Water Assessment Tool) model for simulation of flows in Tawi River basin of India.

## 2. STUDY AREA

The River Tawi, which passes through the heart of the Jammu city, is one of the major left bank tributaries of the river Chenab. It rises from the lapse of Himalayan glaciers at a place named Kalikundi and adjoining areas. The basin shape in the upper part is elongated while broad in the lower part. The catchment of Tawi river upto Jammu is about 2167 sq. km. falls mostly within the districts of Jammu and Udhampur of J&K state.  The upper part of the catchment is characterized by rugged mountainous topography; whereas lower catchment consists of low hills and aggradatioal plain. The average height of the catchment is about 2200 m above mean sea level (MSL). The region experiences hot summers and severe winters. Temperature is lowest between November & February when the minimum night temperature dips below zero degree in the hill area and 3°-4° C in the outer plain area. Temperature rises from March onward. It becomes unbearable during May-June. Maximum day temperature in June touches sometime 47° C in the outer plain and about 30°- 35°C in the hills. Most of the rainfall is received through the southwest monsoon, which lasts from the last week of June to end of September. Location of the Tawi River basin in India has shown in Fig. 1.

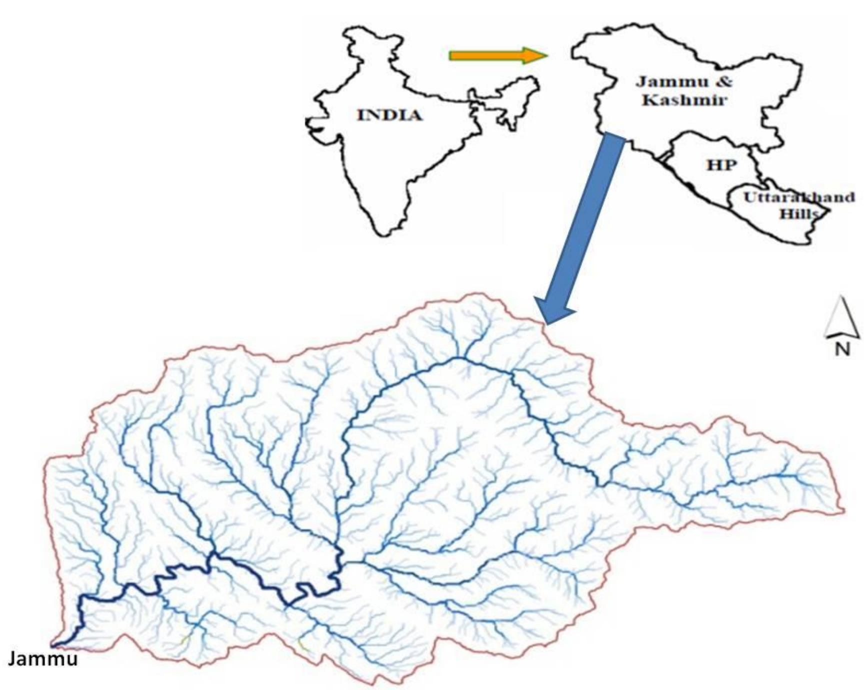



**Fig. 2.1: Location Map of Tawi River Basin in India**

## 3. DATA USED

The SWAT model used in the study for hydrological simulation needs a variety of data, mainly the climatic parameters, hydrologic data, soil data and the landuse land cover information. The source, period and resolution of the various data used in the study area depicted in the Table 1.

**Table 1. Details of various data used in the study**

| Data | Source | Scale | Period | Description |
|---|---|---|---|---|
| Topographic Data | SRTM | 30m | 2014 | Elevation, aspect, slope, flow direction and accumulation |
| Soil Data | NBSSLUP | 1/500,000 | 1999 | Soil component parameter |
| Satellite Images | USGS | - | 1995 | To build the land use maps for different time periods |
| Hydrological Data at Jammu Bridge | CWC | Daily | 1983-1997 | Water level, streamflow |
| Meteorological Data (Observed) at Jammu | IMD WHRC | Daily | 1983-1997 | PCP, HMD, TEMP, SLR, WND |

SRTM: Shuttle Radar Topography Mission
NBSSLUP: National Bureau of Soil Survey and Land Use Planning
USGS: United States Geological Survey
CWC: Central Water Commission, Jammu
IMD: Indian Meteorological Department, Pune
WHRC: Western Himalayan Regional Centre, NIH, Jammu

Although the catchment area of Tawi River is more than 2000 sq. km but it has only one discharge measuring point at Jammu which has been considered as the out of the basin and the entire study is focused on the catchment up to Jammu bridge.

## 4. METHODOLOGY

### 4.1 Database Development for the Study Area

The basic input datasets used by the model include the digital elevation model (DEM), land use/cover data, soil data and climatic data. The digital elevation model (DEM) of the basin was generated using 1 Arc-Second SRTM Global elevation data. The land use map of the study area was prepared using satellite data of LandSat of May 15, 1995. In the present study, the unsupervised classification method was used for preparation of the land use map. The land use categories and their coverage in the study catchment are presented in Table 2.

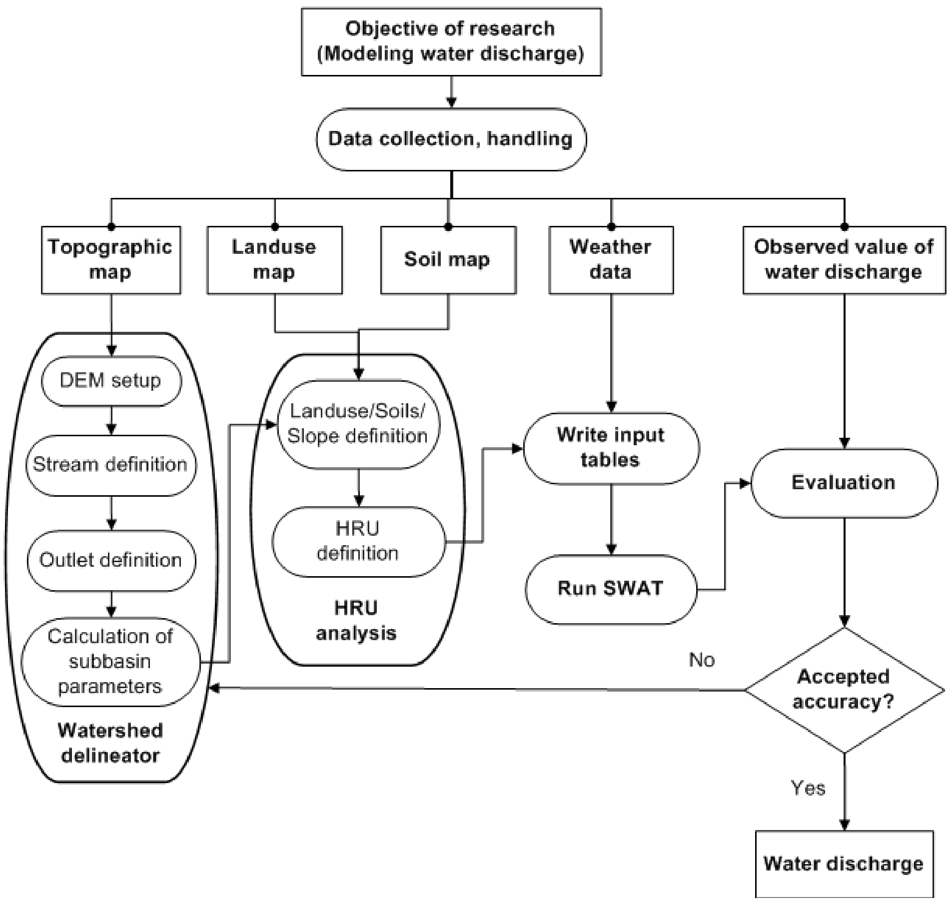
**Table 3.2: Major land use classes in study areas of Tawi basin**

| Land use Class | Area ($km^2$) | % Total |
|---|---|---|
| Built-up (Urban & Rural | 62.23 | 2.87 |
| Crop Land | 317.04 | 14.63 |
| Evergreen Broad Leaf Forest | 1147.16 | 52.94 |
| Grassland | 25.02 | 1.15 |
| Shrubs Land | 552.45 | 25.49 |
| Water Bodies | 63.10 | 2.91 |
| Total | 2167.00 | 100 |

The soil properties like soil texture, hydraulic conductivity, organic carbon content, bulk density, available water content are required by SWAT as input to the model for simulating various hydrological processes. Soil map procured from NBSS&LUP was used as a base map to extract these information. Soils of the study areas mainly falls in the hydrologic soil group C & D. The daily data of meteorological parameters (viz. rainfall, temperature, wind speed, relative humidity etc.) and river discharge at Jammu station in the Tawi river basins has procured from IMD and CWC respectively for the period for 1983 to 1997.

### 4.2 Model Setup

The SWAT model approach applied to the study area of Tawi river basin is shown in Figure 2. The main steps involved in GIS interface of SWAT i.e. ArcSWAT are watershed delineator, HRU analysis, write input tables, Parameter sensitivity analysis, SWAT run, Calibration and uncertainty analysis and model evaluation.




### 4.3 Performance Evaluation of the Model

Evaluations always involve a comparison of the model's output to corresponding measured variable. Results of the calibration and validation were evaluated based on the visual comparison and statistical criteria such as, Nash Sutcliffe Efficiency (NSE) and coefficient of determination (R2).

**The coefficient of correlation :** The quantity CC, called the linear correlation coefficient, measures the strength and the direction of a linear relationship between two variables. The linear correlation coefficient is sometimes referred to as the Pearson product moment correlation coefficient in honor of its developer Karl Pearson. The mathematical formula for computing r is:

$$r = \frac{n\sum O_i S_i - \left(\sum O_i\right)\left(\sum S_i\right)}{\sqrt{n\left(\sum O^2\right) - \left(\sum O^2\right)}\sqrt{n\left(\sum S^2\right) - \left(\sum S^2\right)}} \quad (1)$$

**Nash-Sutcliffe Efficiency (NSE):** The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed from the following equation:

$$\text{NSE} = \left\{1 - \frac{\sum_{i=1}^{n}(O_i - S_i)^2}{\sum_{i=1}^{n}\left(O_i - \bar{O}_i\right)^2}\right\} * 100 \quad (2)$$

## 5. RESULTS AND DISCUSSIONS

### 5.1 Model Calibration

The SWAT model was calibrated using the monthly data of runoff recorded at the outlet of the study arae for the years 1983 to 1992. Several simulation runs were applied to achieve the model calibration. The time series of the observed and simulated monthly discharge for the calibration period were plotted for visual comparison (Figure 3).

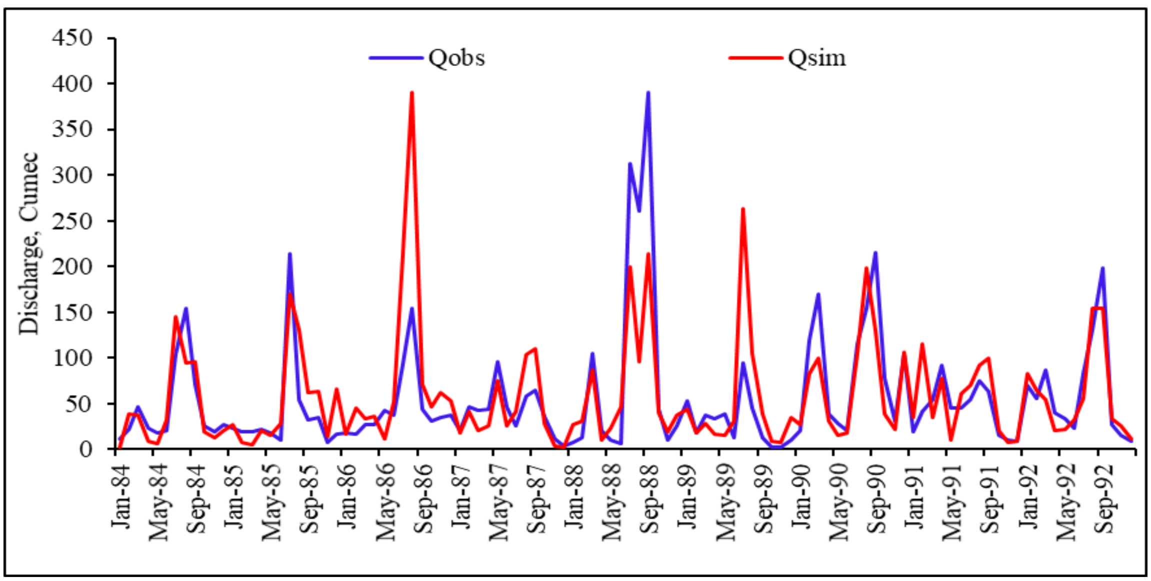



**Fig. 3. Observed and simulated discharge during Calibration period (1984-1992)**

### 5.1 Model Validation

The model validation was carried out for monthly surface runoff for the years 1993 to 1997. A graphical comparison of the observed and simulated monthly flows yield for both calibration and validation period are shown in Figure 4.

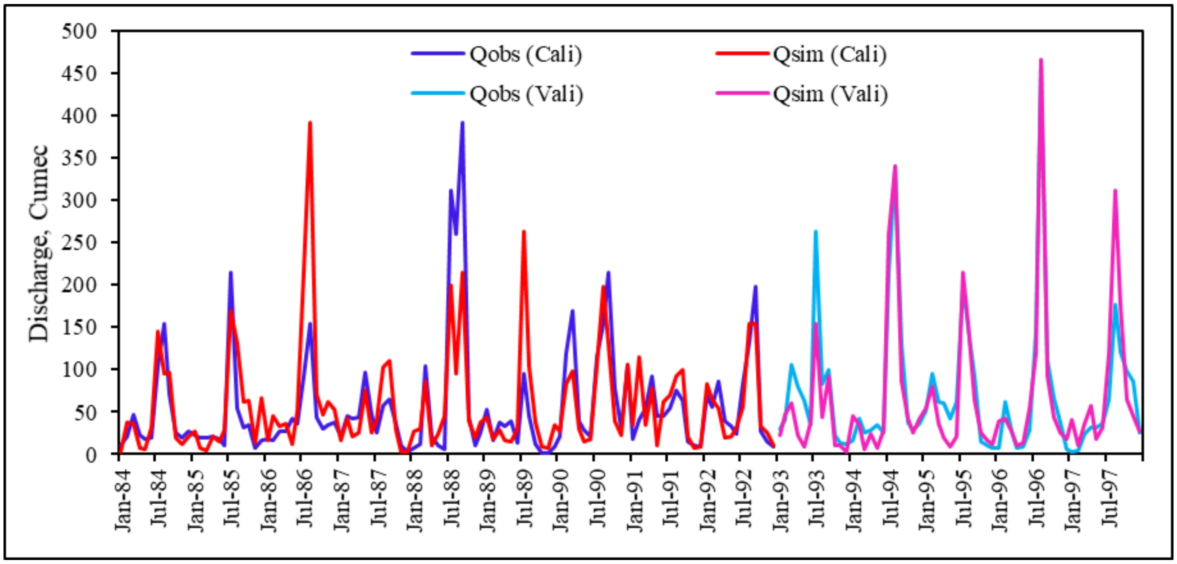



**Fig. 4. Observed and simulated discharge during Calibration period (1984-1992) and validation period (1993-1997)**

The observed and predicted values for runoff were plotted against each other in order to determine the goodness-of fit criterion of coefficient of determination (R2). The R2 for monthly values was obtained as 0.6745 for both calibration and validation period (Figure 5).

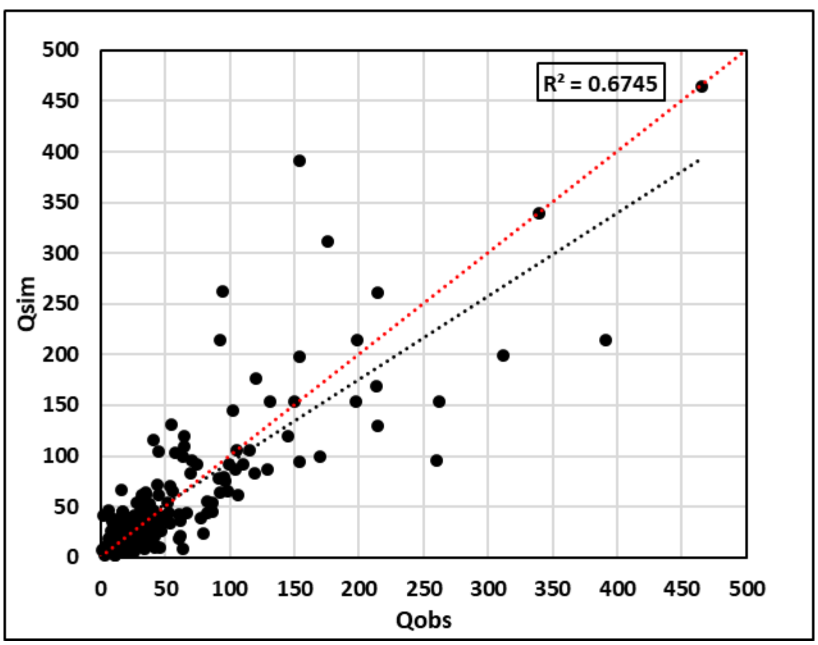



**Fig. 5. Comparison between observed and simulated discharge during calibration period (1984-1992) and validation period (1993-1997)**

The observed and simulated monthly discharge during calibration and validation (combined) along the 1:1 line illustrated in Fig. 5. It can be observed from the figure that the simulated discharge values are distributed uniformly about the 1:1 line for upper values of observed discharge. For high values of observed discharge, the simulated values are slightly above 1:1 line, indicating that the model over-predicts the high values of discharge. After calibration and validation, the value of Coefficient of correlation and Nash-Sutcliffe coefficient were found about 0.92 and 0.84 respectively. A high value of coefficient of correlation (R2 = 0.92) indicates a close relationship between the observed and simulated discharge. Further, the efficiency of the model for simulating discharge was tested by statistical analysis and the results are presented in Table 4.3 for both calibration and validation.

**Table 4.3 Statistical analysis of monthly observed and simulated discharge during calibration and validation**

| Statistical Parameters | During Calibration (1983-1992) | | During Validation (1993-1997) | |
|---|---|---|---|---|
| | Observed | Simulated | Observed | Simulated |
| Mean | 55.7 | 58.2 | 72.2 | 67.6 |
| Standard Deviation | 64.2 | 61.3 | 83.1 | 87.7 |
| Maximum | 390.9 | 390.9 | 465.1 | 465.1 |
| Coefficient of correlation | 0.72 | Good | 0.92 | Very Good |
| Nash-Sutcliffe efficiency | 0.46 | Unsatisfactory | 0.84 | Unsatisfactory |

## 6. CONCLUSION

SWAT model was calibrated and validated to examine its applicability for simulating monthly flow from catchments of Tawi river basin. The Coefficient of correlation, and Nash–Sutcliffe efficiency (NSE) were used for performance evaluation. The model simulated the monthly discharge of Tawi catchment with a high degree of accuracy with R and NSE values as 0.72, and 46% during calibration and 0.92, and 84% during validation respectively. These results indicated a very good performance of SWAT in simulating the discharge from Tawi River. Although, the model underestimated and overestimated daily discharge for some flood events, predictions were within acceptable limits despite some inconsistency in observed data and possible inaccuracies in derivation of model input parameters in view of remote and inaccessible areas. In General, the results of the study indicated that the SWAT model performed well on both the study catchments and hence can be used as a useful tool for estimation of runoff and sediment yield from Himalayan catchments.

## ACKNOWLEDGEMENT

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