RESEARCH ARTICLE

# RAINFALL-RUNOFF MODELLING OF NAULA HIMALAYAN WATERSHED USING SOIL AND WATER ASSESSMENT TOOL (SWAT)

**Bhagwat Saran* and Anil Kumar**

*Department of Soil and Water Conservation Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India-263145.*

*Email: saran.bhagwat007@gmail.com*

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**Abstract:** This study is based on Soil and Water Assessment Tool (SWAT) Model integrates with the GIS information database to modelling the rainfall-runoff of Naula watershed of Uttarakhand. SWAT is a physically based model which has been developed to estimate the runoff from Naula watershed. The watershed area has been delineated using the DEM and then divided into seven sub-watersheds. For preparation of LULC map of Landsat-8 image has been used and the soil map was collected from NBSS&LUP Nagpur.Rainfall, runoff, temperature of min and max and relative humidity data of 33 years (1980-2012) of monthlywere used for SWAT simulation to find out the runoff. The coefficient of determination ($R^2$), p-factor, r-factor and efficiency (NS) was 0.90, 1.14, 0.68 and 0.68 for calibration period and 0.17, 0.12, 0.64 and 0.42 for validation period respectively for the estimation of runoff of Naula watershed.

**Keywords:** Naula, Rainfall, Runoff, Watershed

## INTRODUCTION

Because of non-availability of water at some places, assessment, monitoring and management of water and its resources become more important for the use. Water resources management requires a planning process that includes not only all components of water, but also the relationships, outcomes and impacts between these components. Man-made changes in the environment, including changes in land cover, irrigation and flow control, are now taking place on scales that greatly affect seasonal and annual hydrologic variations. In-depth knowledge and understanding of the various hydrological conditions and the hydrological cycle as a whole are essential in the study of the implications of these changes.

Soil erosion moves up to 40 billion tons of topsoil each year, reducing crop yields and soil storage capacity. Annual production losses due to soil erosion are estimated at 7.6 million tons lost annually due to erosion. If steps are not taken to reduce soil erosion, a complete reduction of more than 253 million tons of grain could be achieved by 2050. This loss of yield would be equivalent to removing 1.5 million square kilometres of land from crop production - or almost all of the arable land in India. Soil and Water are the tremendous gift to the humans, which are the basis for the survival and development of the world. Human foods, health and welfare, and industrial developments are dependent on quality and quantity of land and water resources. Land is a topmost layer of the earth which is composed of minerals and several organic matters which is necessary for the living organism. The topmost layer of soil is always exposed to actions of water and wind. These active forces continuously tend to erode the top soil layer and transport them from one place to another place, known as erosion. Keeping this in view, in the present study an attempt has been made to estimate rainfall-runoff modelling for the Naula watershed of Uttarakhand state using SWAT model with GIS interface under the objectives of the develop of the rainfall-runoff model using SWAT model and also assess the performance of SWAT model for simulation of rainfall-runoff from the Naula watershed.

## MATERIALS AND METHODS

This chapter covers mainly with the study area description, data collection and methods used for model processing. Soil texture, LULC and slope maps using with the ArcGIS for the further processing.

### Location of Study area

The Naula watershed is located in the middle range of Himalayas near Ranikhet of Uttarakhand state, India. It is located between 79° 10′ 30″ E to 79° 31′ 30″ E longitude and 29° 42′ 0″ N to 30° 3′ 0″ N latitude near the Ranikhet cityof Ramganga catchment in Uttarakhand state. The shape of Naula watershed is nearly rectangular and covered of 1071.26 square kilometre area with the minimum and maximum elevations ranges from 724 to 3079 m, respectively.

### Data Collection

In this study a large number of data were used such as soil map and its properties, LULC map DEM, meteorological and runoff data. The detail description of this data set has been discussed below:

### Meteorological data

The weather information required for the analysis of the models is Precipitation (mm), temperature of min

*Corresponding Author

and max (˚C), wind velocity (meter per second) and relative humidity (%). These data sets were obtained from Divisional Forest Office, Ranikhet, which is 58 km away from the Naula watershed outlet. The monthly weather data for the years 1980 to 2012 were used as input to the model. Monthly values for 33 years (1982-2012) data on rainfall, temperature, relative humidity and air velocity were adjusted in excel worksheet, based on SWAT format for the Naula watershed.

**Hydrological data**

Daily runoff data was obtained from the Divisional Forest Office, Ranikhet, Uttarakhand, and 58 km away from the Naula water source. The data of runoff in cubic metre per second (1980-2012) were used in this research. The runoff values were used to compare with the simulated values generated from the SWAT model. The discharge data of two years from 1980-81were used for warm-up, from 1982-period for the SWAT model. The hydrological and meteorological data from 1982-2002 were used for calibration and data from 2003-2012 were used for validation for Naula watershed using SWAT-CUP.

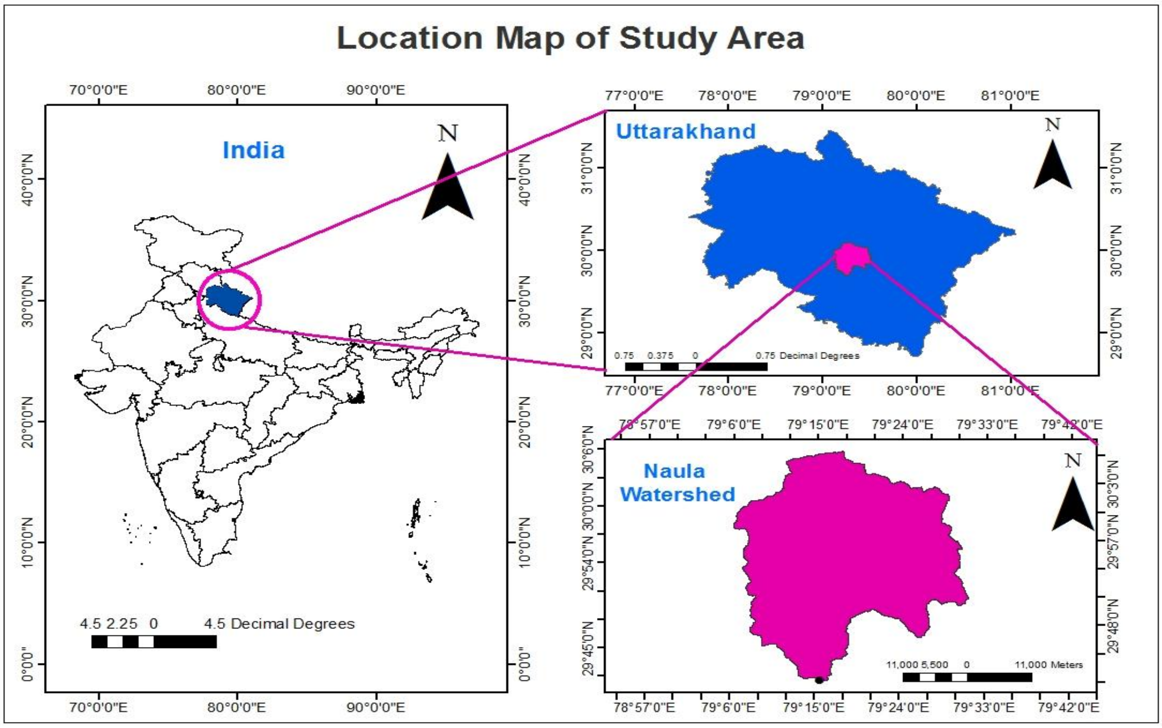


**Fig. 1.** Location of Naula Watershed

**LULC map**

LULC data has been significant effect on the hydrological modelling. The detail analysis and mapping of these are crucial for proper hydrological modelling; these affect the runoff within the watershed. In order to prepare the land use land cover maps of the study area, the satellite data of LANDAT-8 were used. The combination of unsupervised and supervised image classification was performed with the image processing software Arc-GIS. The land use land cover map of Naula watershed was downloaded from the Bhuvan portal. Major part of the LULC in the Naula watershed was covered by the dense forest (47.849%), Water bodies (0.211%), Scrub/deciduous forest (36.342%), fellow land (0.869%), built-up land (0.015%), crop land (11.073) and barren land (3.641%). LULC map of the Naula watershed is shown in figure 3.2.

**Soil data**

For the modelling of the runoff, the soil characteristic is needed to be known. Soil data mainly depends on the percentage of sand, silt, clay particle presents in that soil. For the study, Soil data were obtained from the National Bureau of Soil Survey and Land Use planning (NBSSLUP), Nagpur. The soils in the Naula watershed is broadly classified sandy loam, loam and silt loam soils with boulders and rocks. Soil and Water Assessment Tool (SWAT) model evaluate soil data as an input.

**Digital elevation map (DEM)**

The SRTM-DEM was extracted from the global USGS Earth Explorer with a spatial resolution of approximately 30*30 m. DEM was projected to WGS1984 UTM Zone 45N using the raster projection in Arc-Map toolbox after exporting to Arc-SWAT to delineate the watershed. The processed digital elevation model (DEM) of the Naula watershed is shows in figure 3.3.

**Slope map**

Slope of terrain is an important factor, which controls the hydrological process. As the earth's slope increases, water flow also increases, which directly affects the runoff. Slope map was prepared in Arc-SWAT using digital elevation map and slope was reclassified into 5 different groups namely; 0-15%, 15-30%, 30-45%, 45-60% and 60-9999%.

**Table 1.** Details of LULC map of Naula watershed

| S. No | Data type | Class | Area (% ) | Area (ha) | Area ($km^2$) |
|---|---|---|---|---|---|
| 1. | LULC | Dense forest (FRST) | 47.849 | 51258.720 | 512.587 |
| | | Water bodies (WATR) | 0.211 | 226.035 | 2.260 |
| | | Scrub forest/ Deciduous forest (FRSD) | 36.342 | 38931.740 | 389.317 |
| | | Fallow land (PAST) | 0.869 | 930.924 | 9.309 |
| | | Built-up land (URLD) | 0.015 | 11862.062 | 0.160 |
| | | Crop land (AGRL) | 11.073 | 16.069 | 118.620 |
| | | Barren land (BARR) | 3.641 | 3900.450 | 39.005 |
| Total Area | | | 100% | 107126 | 1071.26 |

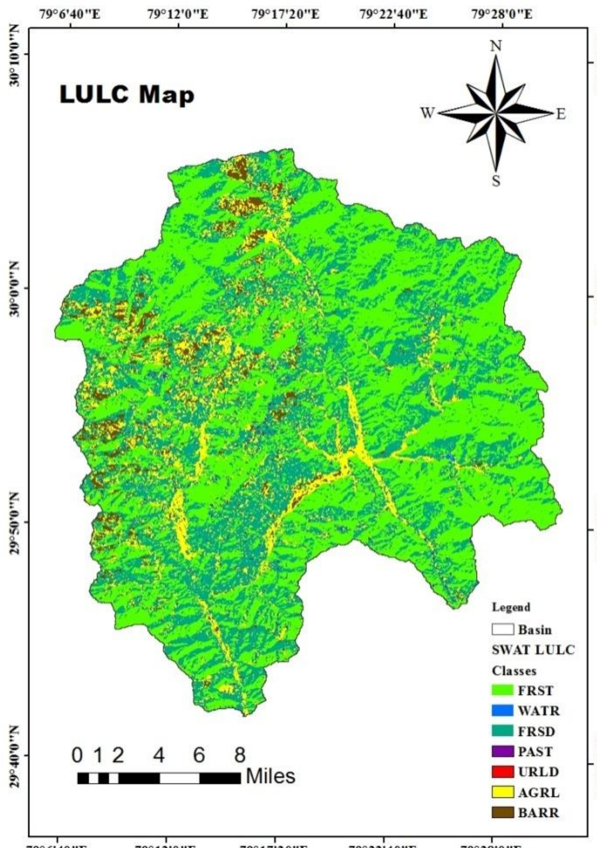


**Fig. 2.** LULC map of Naula watershed

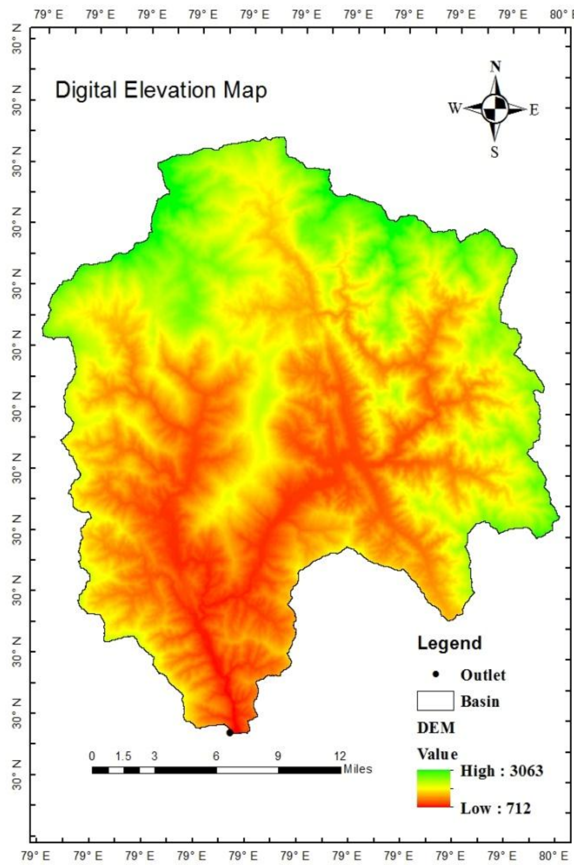


**Fig. 3.** DEM of Naula watershed

**Specifications and development of SWAT Model**

The SWAT (Soil and Water Assessment Tool) model is a ceaseless time, semi-conveyed, measure based stream basin model. The Soil and Water Assessment Tool (SWAT) is a public domain model developed by the collaboration of USDA, ARS and Texas A and M University (Arnold *et al.*, 1998). SWAT is advancement of SWRRB model (Simulator for Water Resources in Rural Basins, Williams *et al.*, 1985), removed the limitation of only being able to simulate 10 sub-watersheds as in the case of SWRRB. Models that that can be used to the development of SWAT were CREAMS, GLEAMS (Leonard *et al.*, 1987), and EPIC (Williams *et al.*, 1984). SWAT is a continuous daily time-step model which is use to evaluate land-management practices in large and small gauged watersheds. Calibration and uncertainty analysis for SWAT the software package SWAT calibration and uncertainty-programme (SWAT-CUP) (Abbaspour *et al.*, 2007) has been developed. According to (Shivhare*etal*., 2014), it is a physical, continuous time model with long term simulation for complex and large watersheds.General equation for the SWAT model to evaluate the amount of runoff to the main channel of the Naula watershed follows the basic water balance equation-

$SW_t = \{SW_0 + \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})\}$ ... (1)

Where; $SW_t$ = Final soil water content (mm), $SW_0$ = Initial soil water content (mm), $R_{day}$=Amount of precipitation on day *i* (mm), $Q_{surf}$ = Amount of surface runoff on day *i* (mm),$W_{seep}$=Amount of percolation and bypass exiting the soil profile bottom on day *i* (mm), $Q_{gw}$= Amount of return flow on day *i* (mm), $E_s$= Amount of evapotranspiration on day *i* (mm), t = Time in days.

SWAT model simulation in Naula watershed is divided into a number of sub-watersheds. The use of sub watersheds in simulation is particularly beneficial when the various areas of the water/dams are dominated by the use of land or soil that is not sufficiently different in areas that may affect the hydrology. Complete flow mainly depends on the actual hydrologic state of each type of soil in the soil cover and the slope present in the water flow area. Therefore, the effect of each type of land use is considered in this model to calculate the flow of the watershed. After the application of land use, soil maps and slopes, the distribution of Hydrological Response Units (HRUs) was decided. Runoff was predicted separately for each HRU and delivered to get full drainage operation. This increases the accuracy and provides the best physical explanation for water balance.

**Sensitivity Analysis (SA)**

SA was used to quantify the rate of change in model outcomes with respect to model input changes. There are many limitations to the SWAT model because it takes into account local heterogeneity processing. The SA process of this study was performed using the Latine Hypercube Sampling and LHS-OAT method. Monthly runoff data of Naula watershed from 1980-2012 were used for SA process. SA process was based on the simulation parameter effects on the runoff and identified and ranked on the basis of sensitivity.

**Performance Evaluation of SWAT Model**

**Nash-Sutcliffe efficiency (NSE):** The Nash-Sutcliffe efficiency (NS) can be calculated as:

$$NS = 1 - \frac{\sum_{i=1}^{n}(Oi - Pi)^2}{\sum_{i=1}^{n}(Oi - O\prime)^2} \qquad \ldots(2)$$

where, n is the number of measured data, $O_i$ and $P_i$ are the measured and predicted data at time I and O' and P' are the mean of measured and predicted data.

**Coefficient of determination ($R^2$)**: Coefficient of determination can be calculated as-

$$R^2 = \frac{\sum_{i=1}^{n}(\mathrm{Oi}+\mathrm{O}'(\mathrm{Pi}-\mathrm{P}\prime)2}{\sum_{i=1}^{n}(\mathrm{Oi}-\mathrm{O}\prime)2\sum_{i=1}^{n}(\mathrm{Pi}-\mathrm{P}\prime)2} \qquad \ldots(3)$$

Where; n is the number of measured data, $O_i$ and $P_i$ are the measured and predicted data at time I and O' and P' are the mean of measured and predicted data.

## RESULTS AND DISCUSSION

The SWAT model was very close to observed and estimated values of runoff for the Naula watershed. During calibration period all the parameters values yielding the best agreement between observed and estimated values were selected for the study area. Observed data of 21 years (1982-2002) duration and 10 years (2003-2012) were used for calibration and validation processes respectively. The performance of the model was evaluated by p- factor, r-factor, $R^2$, NS and PBIAS. The NS and $R^2$ calculated by using equation 2 and 3 respectively. The statistical values of the SWAT model for calibration and validation period was shown in table 3.1.

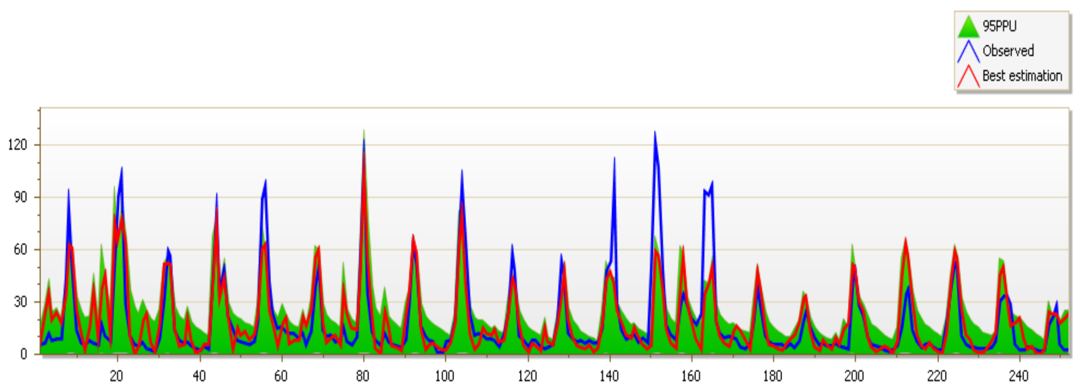


**Fig. 4.** SWAT based observed and predicted runoff during Calibration period

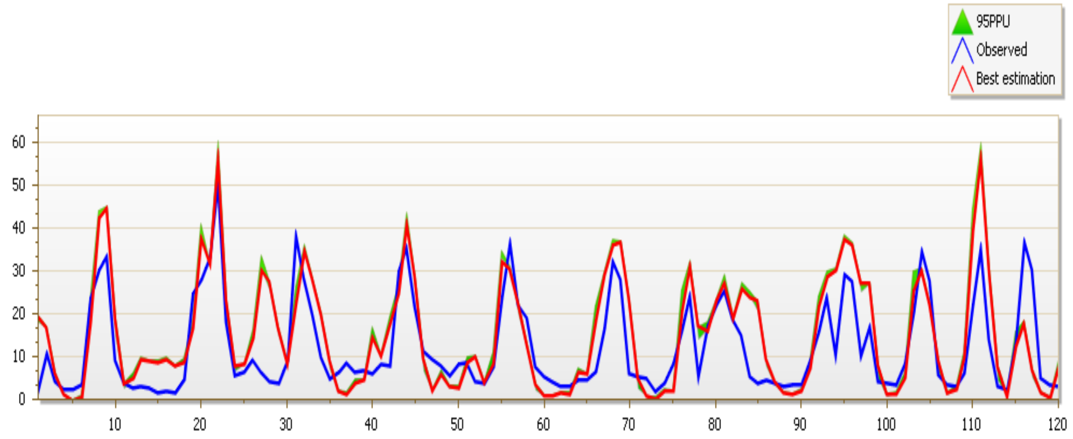


**Fig. 5.** SWAT based observed and predicted runoff during Calibration period

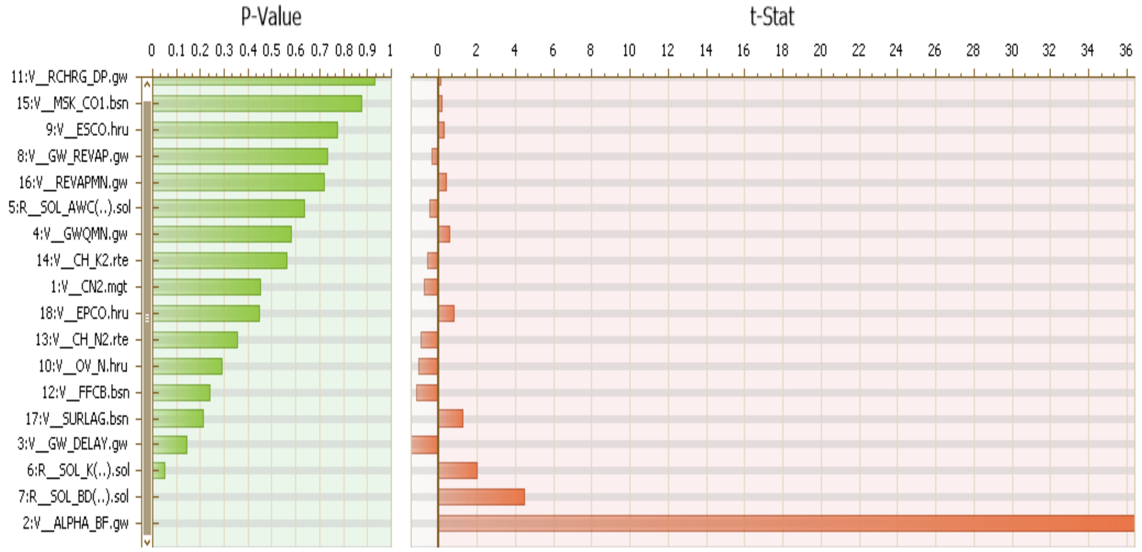


**Fig. 6.** Sensitivity analysis under SWAT-CUP for runoff based on p-value and t-value

**Table 2.** Statistical analysis

| **Calibration** | | | | |
|---|---|---|---|---|
| p-factor | r-factor | $R^2$ | NS | PBIAS |
| 0.90 | 1.14 | 0.68 | 0.68 | -3.3 |
| **Validation** | | | | |
| p-factor | r-factor | $R^2$ | NS | PBIAS |
| 0.17 | 0.12 | 0.64 | 0.42 | -22.8 |
| | | | | |

## CONCLUSION

For the Naula watershed, SWAT model produced good simulation results for monthly runoff values. The observed and predicted $R^2$ was0.68 and 0.64 respectively showing very close results for this watershed. With the help of a soil, landuse, DEM data and climatic data, the results are more accurate for the simulated runoff of Naula watershed using SWAT.

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