Hydrological modelling of Bhagirathi Basin up to Tehri Dam using SWAT

A. R. Senthil kumar*, Sandeep Chourasia, S. D. Khobragade and Manohar Arora
National Institute of Hydrology, Roorkee, Uttarakhand, India
Corresponding author e-mail id: arsk.nihr@gov.in

Abstract: Estimation of runoff from snowmelt and rainfall are of high interest for flood warning and management of reservoirs for hydropower generation in drainage basins with significant snowmelt contribution. The rivers originate from Himalayas receive a significant flow from snow melt. Conceptual models such as Snowmelt Runoff Model (SRM) and SNOWMOD have been developed to simulate the snow melt runoff using elevation, rainfall, aspect, temperature and snow cover area as input. The Soil and Water Assessment Tool (SWAT), a semi-distributed, continuous time watershed modelling system can model the runoff from snowmelt and rainfall effectively. In this study, SWAT has been used to simulate runoff of Bahgirathi basin upto Tehri dam using the meteorological and hydrological data from 1994-2007 and input data such as DEM, Land use land cover map, soil map from different sources such as NASA, BHUVAN, NRSC, National Bureau of Soil Survey and Land Utilisation Planning (NBSSLUP) and Harmonised World Soil Database (HWSD). For stream flow calibration, the data from 1994-2005 and 2006-2007 are taken as calibration and validation data respectively. SWAT-cup is run to find out the sensitive parameters for the simulation of streamflow. The streamflow has been simulated with the sensitive parameters. The coefficient of correlation (R^2) between observed and computed streamflow during calibration and validation are 0.78 and 0.74 respectively. The Nash-Sutcliffe Model efficiency (NSE) during calibration and validation are 74 and 69 % respectively. The results clearly indicate that the SWAT simulated the streamflow fairly well. The optimized parameters of SWAT can be used to simulate the discharge for future climate scenarios such as RCP2.6, 4.5 and 8.5.

Keywords: Snowmelt runoff; SWAT; Bhagirathi basin; Tehri dam, climate scenarios.

1. Introduction

The relationship between precipitation such as snowmelt, rainfall and runoff is highly nonlinear and complex process and its determination is very important for hydrologic engineering design, flood warning and management of reservoirs for hydropower generation. It is dependent on numerous factors such as initial soil moisture, land use, watershed geomorphology, evaporation, infiltration, distribution and duration of rainfall and so on. Many of the watersheds are gauged to provide continuous record of streamflow data. But situations such as high flood season, instrument failure, etc force the engineers or hydrologists to generate the streamflow records using rainfall and snowmelt by simulation models. Many rainfall-runoff and snowmelt-runoff models such as empirical, lumped and distributed models have been developed and used for simulating the streamflow at the catchment outlet by many researchers. The rivers originate from Himalayas receive a significant flow from snowmelt.

Conceptual models such as Snowmelt Runoff Model (SRM) and SNOWMOD have been developed to simulate the snow melt runoff using elevation, rainfall, aspect, temperature and snow cover area as input. The Soil and Water Assessment Tool (SWAT), a semi-distributed, continuous time watershed modelling system can model the runoff from snowmelt and rainfall effectively. Arnold et al. (1998) explained about SWAT model development, operation, limitations and assumptions. SWAT was developed to estimate the impact of land management on runoff, sediments and pollutants. Many researchers applied SWAT model to simulate the runoff from watersheds varying from micro to large watersheds. Shrivastava et al. (2004) tested SWAT model for estimating runoff on monthly basis from small watershed in eastern India and demonstrated the importance of weather generator in SWAT in absence of observed data. Tripathi et al. (2006) studied the effect of watershed subdivision on the water balance mechanism for Nagwan watershed in eastern India. Their study showed that the number and size of sub-watersheds did not significantly affect surface runoff but had noticeable effect on other components like evapotranspiration, percolation of water and soil water content. Moriasi et al. (2007) reviewed several research papers about SWAT model performance analysis and discussed about various statistical and graphical techniques to evaluate model performance. Setegn et al. (2008) made his study for Lake Tana Basin to assess the hydrological water balance using SWAT model. The objective of his study was to test the applicability of SWAT model for prediction of stream flow in the basin. Mengistu and Mccray (2008) had done his study to see the effects of variation of spatial resolution of soil data on stream flow using SWAT model. Xu et al. (2009) applied SWAT model to simulate the runoff in Miyun river catchment, China. The model accurately predicted the daily and monthly runoff. Lin et al. (2010) did his work to observe the effect of Digital Elevation Model (DEMs) resolution on runoff and concluded that the runoff was not sensitive to different spatial resolution. Raneesh et al. (2010) carried out work for prediction of stream flow in chaliyar river basin, Kerala, India using SWAT and the model performance was reasonably high during calibration and validation. Nagraj et al. (2014) carried out work for simulation of runoff using SWAT model in Bhima River, Krishna basin and concluded that SWAT model was applicable for simulating runoff for small watershed. Tyagi et al. (2014) had done his work to examine the applicability of SWAT model in two mountainous forest watersheds in Himalaya, India. The two forest watersheds are Bansigad, Arnigad. They assessed impact of degraded oak forest cover, dense oak forest on stream flow and sediment yield. Omani et al. (2015) simulated the effect of management practices on surface runoff in Gharasu watershed using SWAT model and showed that SWAT was capable tool for simulating the effect of management practices. Tomas D. Reyes, JR. (2017) applied the Soil and Water Assessment Tool (SWAT) model to predict streamflow in Wahig-Inabanga Watershed, Bohol, Philippines. The result of the SWAT model performance evaluation on stream flows was satisfactory. Various applications of SWAT model and its capability to simulate the runoff encouraged to use SWAT to simulate the runoff of Bahgirathi basin upto Tehri dam using the data obtained and generated from different sources.

2. Study area and Methods

Stydy area

Tehri is a multipurpose project, located at 145 Km downstream of Gangotri glacier on river Bhagirathi. Tehri project is important for power generation, irrigation and flood control. Tehri dam catchment is bounded between longitude 78°9'15''E to79°24'55''E and latitude 30°20'20''N to 31°27'30''N and is represented in Fig. 1. The catchment area of the Tehri Dam is 7288 Km^2 out of which 2042 Km^2 is permanently snow-covered. The elevation of the catchment varies between 600 m at dam site and 7000 m at the peak of Gangotri glacier. The catchment receives most of the rainfall during southwest monsoon. Annual rainfall ranges from 1016 to 2630 mm. River Bhagirathi Bhilangana and Balganga are the three major rivers which contribute to Tehri reservoir. Bhagirathi River originates from Gangotri near Gomukh at an elevation of 4255 m and traverses a distance of about 168 Km to its confluence with river Bhilangana at 1.5 Km upstream of Tehri dam. River Bhilangana traverses a distance of 72 Km before meeting with river Bhagirathi. Some minor tributaries like Mangad, Nilapani, Jadganga, Garunganga, Ganeshganga, Asiganga, Dharshugad, Jalkurgad also meet with river Bhagirathi. River Balganga is a major tributary of river Bhilangana, and it meets at Ghansali, 3 Km downstream of Sarasgaon at EL 818m, falling directly into the reservoir. The study basin receives moisture-bearing winds mainly from the Arabian Sea and heavy rainfall during June to September. The annual rainfall of the catchment varies from 1000 mm to 2615 mm. During the period June to September, high flows and floods are experienced in the river. The climatic condition variations are high in the study basin and these are related to changes in elevations and aspect. The rock at dam site consists of the Chandpur Phyllite. Based on lithological characteristics and engineering properties, this has been classified into broadly three grades viz. Grade I (Phyllite Quartize), Grade II (Quartzitic Phillite) and Grade III (Schistose Phyllite). Riverbed consists of large boulders. Average upstream slope of the river is 1:22 (Agarwal et al. 2019).

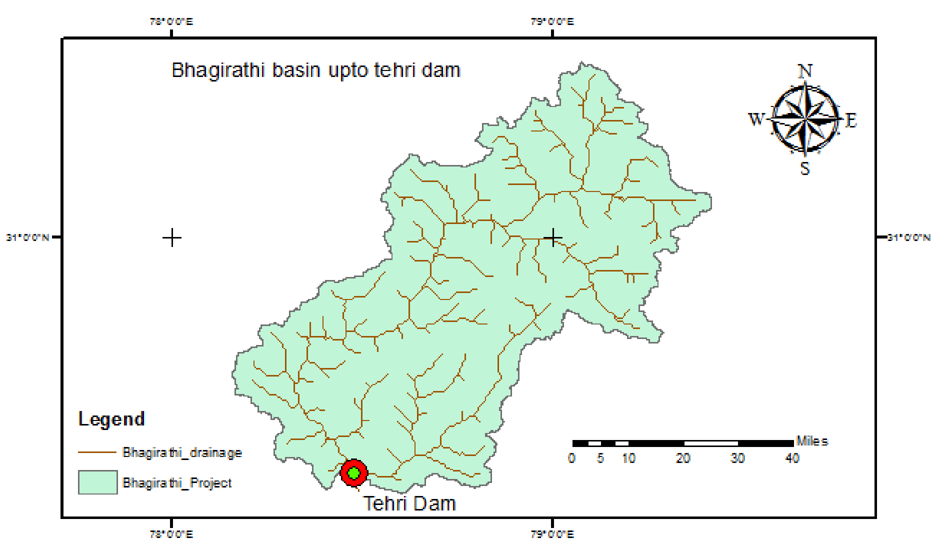

Fig. 1 Bhagirathi basin up to Tehri Dam

SWAT Modeling

The Soil and Water Assessment Tool (SWAT), a semi-distributed, continuous time watershed modelling system to model the runoff from snowmelt and rainfall. It is a physically based model operating on a daily time step. SWAT is integrated into GIS environment to be capable of simulating a high level of spatial detail by allowing the division of a watershed into a large number of sub-basins (Gassman et al., 2003). It can predict the impact of land characteristics and management practices on water, sediment and agricultural yields in watersheds of different sizes with varying soils, land use and management conditions. SWAT is a deterministic model, which means that each successive model run using the same inputs will result in the same outputs. Therefore, this type of model is suitable to separate and evaluate the effects of a single variable, and it is easy to compare the relative effects from one to another. In applying the SWAT model, the study area is first divided into sub-basins based on the DEM, and then these are further divided into one or more hydrologic response units (HRUs). Each HRU, consisting of unique land use, management, topographical, and soil characteristics, is an independent unit of the SWAT model and does not interact with the other HRUs. SWAT simulates surface runoff in a watershed by considering a number of different physical processes, which include evaporation, runoff, infiltration process, potential and actual evapotranspiration, lateral flow and ground water contribution. In SWAT model, simulation of the hydrology can be divided into land phase and routing phase of the hydrologic cycle. The land phase of hydrologic cycle is simulated by following the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{N} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw} \right) \tag{1}$$

where, SW_t = final soil water content, SW_o = initial soil water content, t = time in days, R_{day} = amount of precipitation of ith day, Q_{surf} = amount of surface runoff of ith day, E_a= amount of evaporation of ith day, W_{seep} = amount of water entering the unsaturated zone from the top soil profile of ith day, Q_{gw} = amount of return flow of ith day.

SWAT model provides two methods for simulating surface runoff; one is SCS curve number (SCS, 1972) and another one is Green and Ampt infiltration method (Green and Ampt equation, 1911). The SCS curve number method includes the permeability of soils, antecedent moisture conditions, soil hydrological group, varying land use and soil type whereas the Green and Ampt infiltration method calculates surface runoff as a function of effective hydraulic conductivity assuming that above wetting front, the soil is completely saturated. SWAT allows the user to calculate the surface runoff in daily and hourly time steps of rainfall data. In case of daily time basis, SWAT model uses the SCS curve number (CN) method and for hourly time steps SWAT model uses the Green and Ampt equation. In this study, the SCS curve number has been adopted for the simulation of surface runoff in SWAT since daily precipitation data is readily available. According to the Soil Conservation Service equation

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

Where Q_{surf} is the accumulated runoff or excess rainfall, R_{day} = depth of precipitation of *i*th day in mm of water, S = retention parameter

$$S = 25.4\left[\frac{100}{CN} - 10\right] \quad (3)$$

Where, CN is the curve number I_a = initial abstraction which includes surface storage and interception, I_a is commonly approximated as 0.2S

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (4)$$

The systematic and dynamic behavior of the SWAT model can be visualized by drawing graph between time and simulated flow, observed flow on the same coordinate system. To assess the goodness of the model; three methods have been used normally during the calibration and validation periods. These are coefficient of determination (R^2), the Nash-Sutcliffe efficiency (NSE) and Percent bias (PBIAS). These three statistical parameters are used to measure the model performance. In this study only coefficient of determination (R^2) and the Nash-Sutcliffe efficiency have been used for the evaluation of SWAT model performance.

3. Results

Input data to SWAT model

The SWAT model, being physical-based, claims for more complex types of input data in order to become operationally functional. The discharge up to Tehri reservoir have been simulated using ARCSWAT Version 2012.10_2.19. The general data requirement for running the ARCSWAT model are landuse, soil map, DEM, rainfall, wind velocity, relative humidity, temperature, solar radiation, potential evaporation, runoff at outlet, sediment yield at outlet, runoff and sediment yield to the storage structures in the catchment and elevation-area-capacity curve of the storage structures. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRUs). In this study, there are several types of data obtained from different reliable sources. The inputs for running the ARCSWAT have been generated using different sources available in the web sites of different organizations such as NASA, National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Indian Council of Agricultural Research, Harmonized World Soil Database (HWSD) International Institute for Applied Systems Analysis (IIASA) and National Remote Sensing Centre (NRSC). For this study, the DEM of Bhagirathi up to Tehri dam has been created using **t**he 30 m resolution topography data from the **ASTER Global Digital Elevation Model** and is presented in Fig. 2. The slope map has been created from DEM using ARC GIS software and is presented in Fig. 3. The elevation range of Bhagirathi is 688 to 7084 m and the slope range is between 0 to 601 percent. The landuse land cover map has been prepared from LISS-III (2007-2008) LULC mapping on 1:50,000 scale from the BHUVAN, NRSC website and is given in Fig. 4. Soil map is prepared from National Bureau of Soil Survey and Land Utilisation Planning (NBSSLUP) map and Harmonised World Soil Database (HWSD) (for that portion which is not a part of Indian region as per NBSSLUP soil map) and are given in Fig. 5 and Fig. 6.

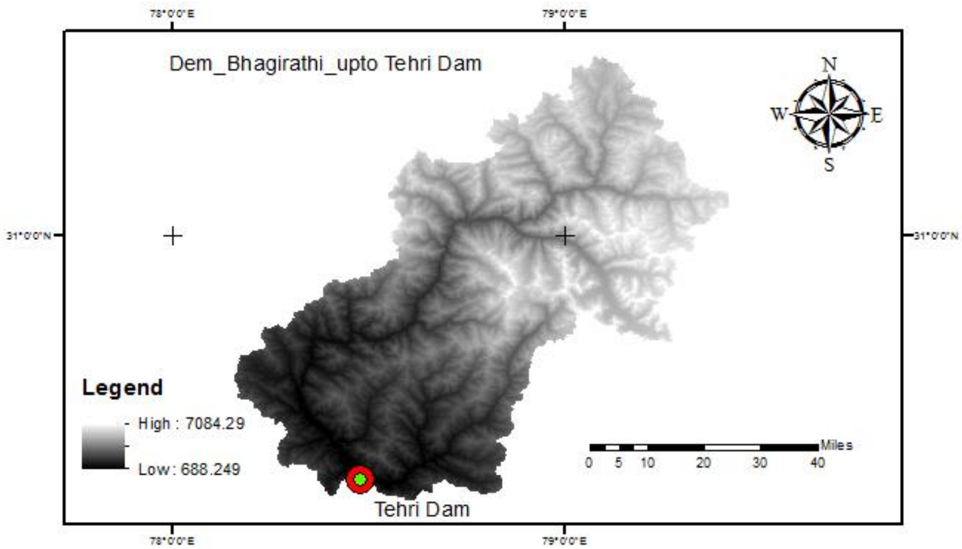

Fig. 2 DEM map of Bhagirathi upto Tehri Dam

The daily rainfall values at Mukhim, Tehri, Bhatwari, Dunda, Maximum and Minimum temperature at Mukhim, relative humidity and wind speed at Mukhim have been obtained from IMD. The location of the station and availability of the data are given as follows:

Table 1. Location of the rainfall station

Station	Long	Lat	Elevation(m)	From	To	Frequency
Mukhim	78.4833	30.5833	1920	1957	2008	Daily
Tehri	78.4833	30.4000	850	1956	2014	Daily
Bhatwari	78.8333	30.8333	3050	1967	2016	Daily
Dunda	78.5833	30.7167	5550	1967	2016	Daily

Other climatic data like temperature, relative humidity & wind speed are available as per following details:

Table 2. Availability of other meteorological data

Station	Data	Start year	End Year	Frequency
MUKHIM	Temperature	1969	2008	Daily
MUKHIM	RH, Wind speed	1969	2008	Daily

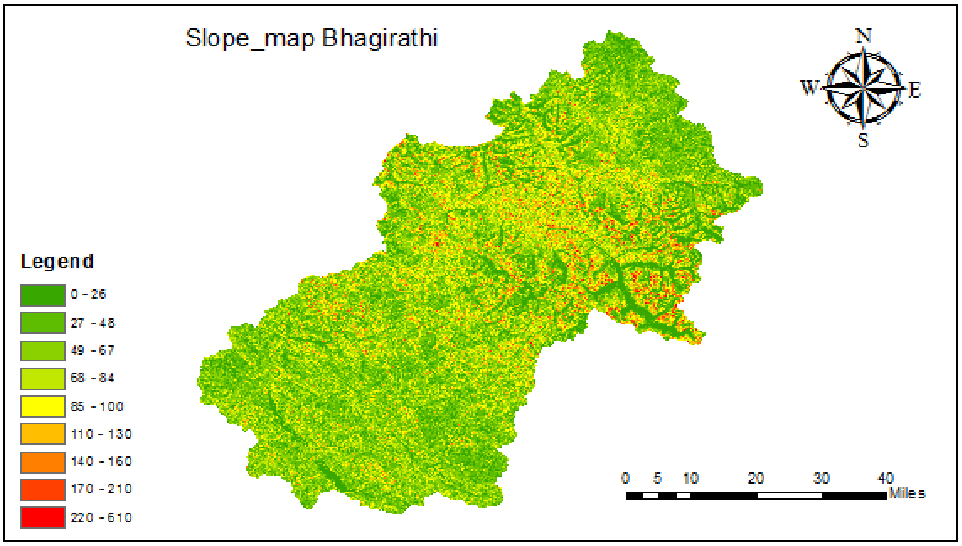

Fig. 3 Slope map of Bhagirathi upto Tehri Dam

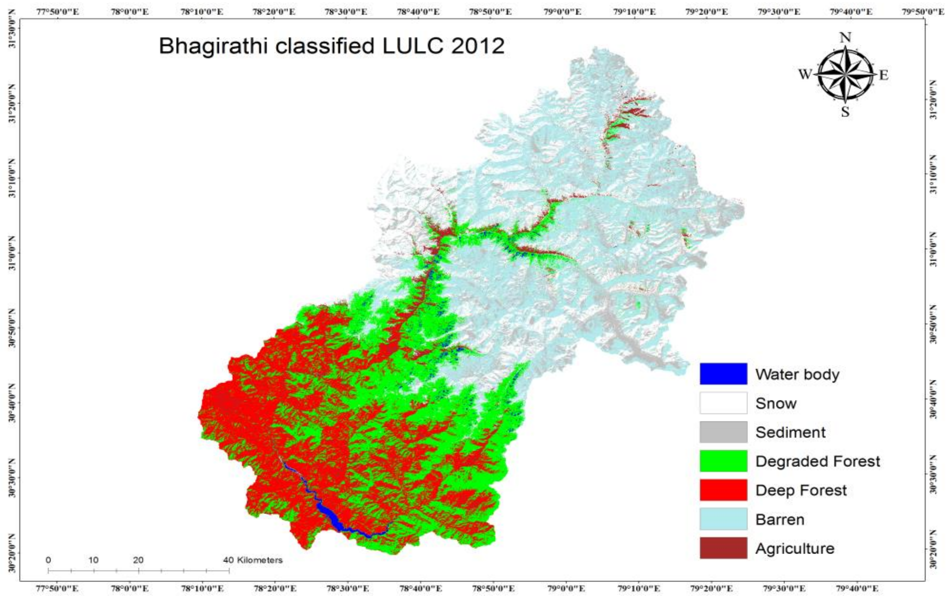

Fig. 4 LULC map of Bhagirathi up to Tehri Dam

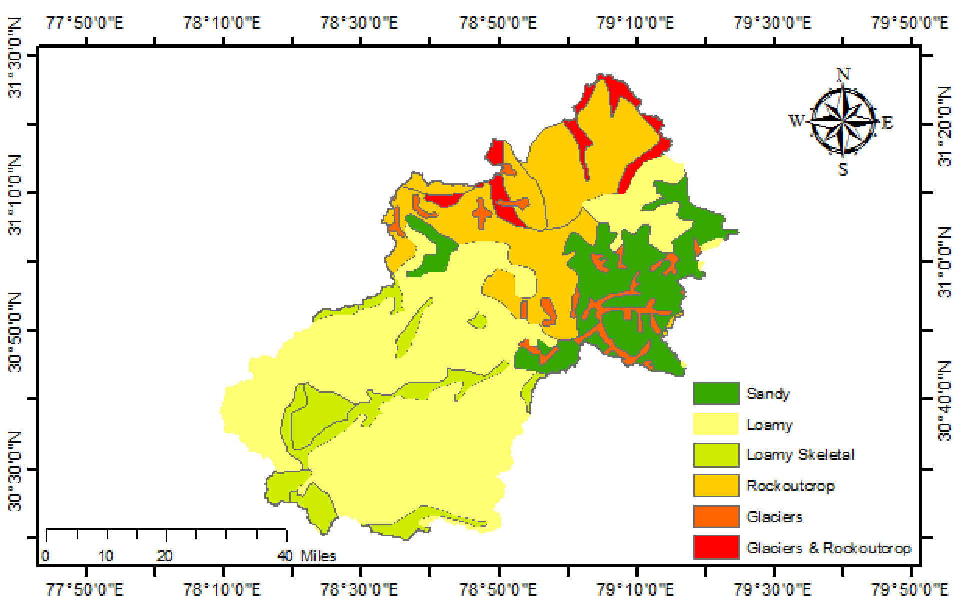

Fig. 5 NBSSLUP Soil map of Bhagirathi up to Tehri Dam

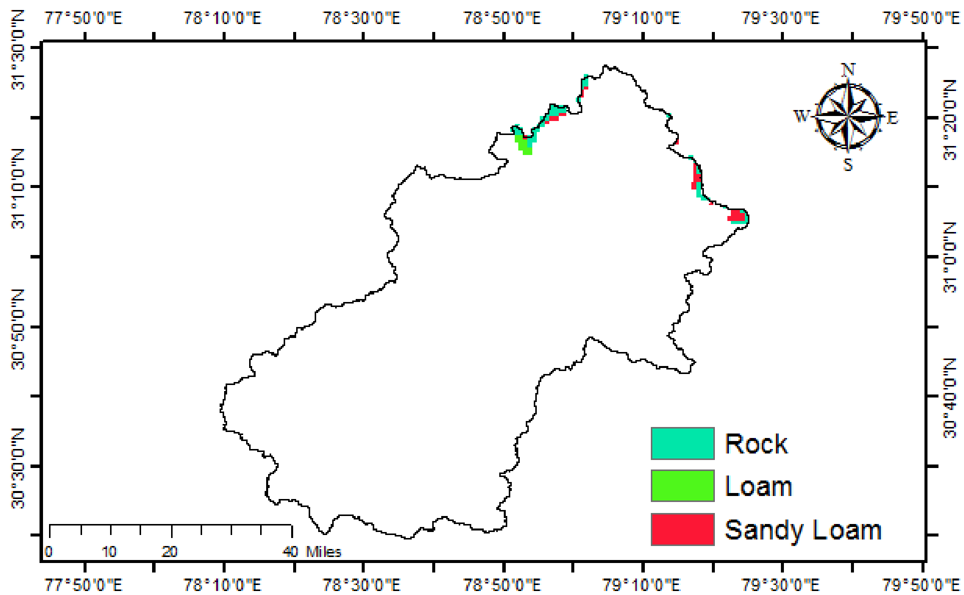

Fig. 6 HWSD Soil map of Bhagirathi upto Tehri Dam(outside_India)

The daily discharge (1994 to 2007) has been obtained from THDC, Rishikesh and is given Fig. 7.

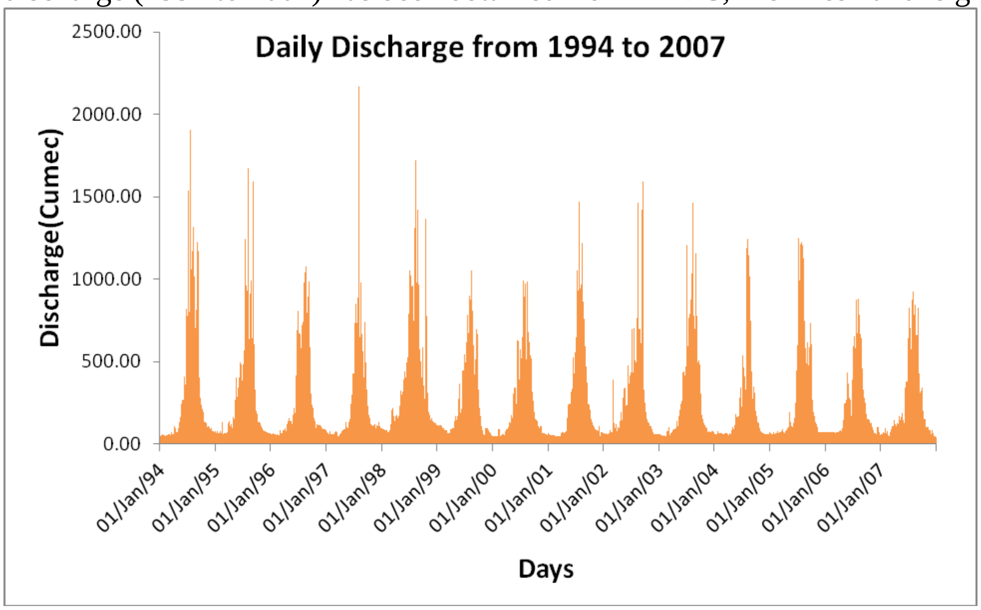

Fig. 7 Daily discharge at Tehri dam from 1994 to 2007

Simulation of streamflow

For simulation of streamflow in SWAT, the Soil Conservation Service (SCS) curve method has been used to calculate the surface runoff generated by each independent HRU resulting from the daily input precipitation and the confluence is eventually obtained in the exit section. The Penman–Monteith method has been used to calculate the potential evapotranspiration in the study area and the variable storage routing method developed by Williams(1969) has been selected to calculate the water evolution in the main channel. The DEM, slope, LULC and soil map generated from different sources such as NASA, National Bureau of Soil Survey and Land Use Planning (NBSSLUP), Indian Council of Agricultural Research, Harmonized World Soil Database (HWSD) International Institute for Applied Systems Analysis (IIASA) and National Remote Sensing Centre (NRSC); rainfall, maximum and minimum temperature, relative humidity and wind speed from IMD and discharge from THDC India Ltd have been used in the setup of the SWAT model.

Model Setup

In the setup of SWAT model for the study area, the first step is identification and delineation of hydrological response units (HRUs). To obtain a reasonable numbers of HRUs within each subbasin, a unique combination of landuse and soil (thresholds of 5% in land use and 10% in soil or slope) have been used. The Bhagirathi River Basin has been divided into 29 sub-basins and 209 HRUs.

Defining elevation bands

To account for orographic effect on both precipitation and temperature SWAT allows up to 10 elevation bands to be defined in each sub basin. The catchment area with elevation zone is given in Table 3 and is represented by Fig. 8.

Table 3 Catchment area with elevation zone

Zone	Elevation(M)	Area(km^2)	Percentage
1	<700	0.0603	0.001
2	700-1400	534.3911743	7.543
3	1400-2100	1240.68689	17.513
4	2100-2800	951.2783813	13.428
5	2800-3500	644.7393188	9.101
6	3500-4200	642.9959717	9.076
7	4200-4900	1113.010254	15.711
8	4900-5600	1540.567749	21.746
9	5600-6300	568.8143921	8.029

10	>6300	48.7629013	0.688

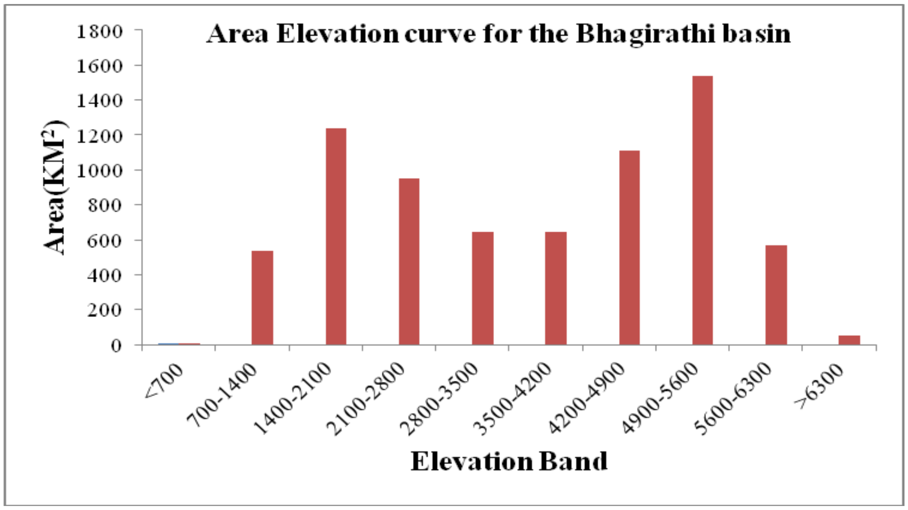

Fig. 8 Distribution of elevation band

Calibration and validation of SWAT model

The length of calibration data is an important factor in SWAT model calibration . The available data is usually divided in two sets: calibration data and validation data. For stream flow calibration, the data from 1994-2005 and 2006-2007 are taken as calibration and validation data respectively. Data for the first two years (1994-1995) were used as warm-up period for the run of SWAT**.** Since SWAT model is run on monthly interval so the daily observed runoff has been converted into monthly average flow. The runoff has been simulated with the SWAT setup and the required input data and default parameters. Then the simulated runoff has been taken into SWAT-CUP for sensitivity analysis of the parameters and optimization of the most sensitive selected parameters. The parameter optimization has been done by SUFI2 algorithm (Sequential Uncertainty Fitting version 2). SUFI-2 (Sequential Uncertainty Fitting) is a comprehensive optimization and gradient search method able to simultaneously calibrate multiple parameters and with a global search function. It also considers the uncertainty of the input data, model parameters, and model structure. Initially sensitivity analysis has been performed for runoff and the parameters have been optimized with the data from 1996-2005. In order to identify the most sensitive parameters initially SWAT-Cup is run with a 19 number of tentative parameters for simulation. The P-value & t-Stat of the parameters and their sensitivity rank are given in Table 4.

Table 4 Sensitivity analysis of parameter

Rank	Parameter	t-State	P-Value
1	SOL_K(1).sol	-18.54041	0.0000000
2	SFTMP.bsn	-15.82461	0.0000000
3	CN2.mgt	-13.615608	0.0000000
4	SNOCOVMX.bsn	-8.1332587	0.0000000
5	SMFMN.bsn	2.3517122	0.0190904
6	RCHRG_DP.gw	-1.4169676	0.1571411
7	GW_REVAP.gw	1.3402635	0.1807937
8	CH_K2.rte	1.2491841	0.2122066
9	SMFMX.bsn	0.9486074	0.3432977
10	ESCO.bsn	-0.9360012	0.3497432
11	TIMP.bsn	-0.765846	0.4441443
12	TLAPS.sub	0.7275455	0.4672466
13	GWQMN.gw	-0.6446097	0.5194881
14	SOL_AWC(1).sol	0.4582262	0.6469973
15	SMTMP.bsn	-0.2867777	0.7744063
16	ALPHA_BF.gw	-0.2308854	0.8175022
17	GWQMN.gw	0.1477808	0.8825778
18	REVAPMN.gw	0.0444354	0.9646407
19	PLAPS.sub	-0.0327383	0.9738969

Then the model with the optimized parameters has been calibrated and validated for data from 1996-2005 and 2006-2007. First four parameters are most sensitive for the simulation of streamflow. SOL_K.sol, soil hydraulic conductivity is the most sensistive parameter. Once the sensitive parameters have been identified they can be used for better convergence of simulation during calibration of the model.

4. Discussion

The model has been calibrated by using the values of 19 parameters that are identified as highly sensitive to streamflow. The fitted, minimum and maximum values of the selected parameters for streamflow are given in Table 5. The optimized values of the parameters have been obtained with 1000 iterations. The observed and simulated streamflow have been compared for the calibration and is presented in Fig. 9. The scatter plot of observed and simulated streamflow for the calibration is given in Fig. 10. The coefficient of determination (R^2) and NSE for the calibration are 0.78 and 74 % respectively. The validation of the parameters has been done with the streamflow data for the period from 2006 to 2007 and the coefficient of determination (R^2) and NSE are 0.74 and 69 % respectively. The observed and simulated streamflow have been compared for the validation and is presented in Fig 11. The scatter plot of observed and simulated streamflow is given in Fig. 12. The results for the calibration and validation of the streamflow are given Table 6.

Table 5 Best fitted values of parameters for SWAT

Parameter	Min	Max	Fitted value
CN2.mgt	-0.2	0.2	0.07
ALPHA_BF.gw	0	1	0.34
GW_DELAY.gw	30	450	377.48
GWQMN.gw	0	2	0.18
TLAPS.sub	-10	10	-0.76
SOL_AWC(1).s	-0.2	1	0.90
SOL_K(1).sol	-0.8	0.8	-1.23
REVAPMN.gw	0	500	436.24
RCHRG_DP.gw	0	1	0.06
GW_REVAP.gw	0	0.2	0.26
PLAPS.sub	-1000	1000	475.71
SMTMP.bsn	-5	5	-0.59
SMFMN.bsn	0	10	3.66
SMFMX.bsn	0	10	5.24
SFTMP.bsn	-5	5	1.77
TIMP.bsn	0	1	1.10
SNOCOVMX.bsn	0	500	163.94
CH_K2.rte	0	500	429.56
ESCO.bsn	0	1	0.46

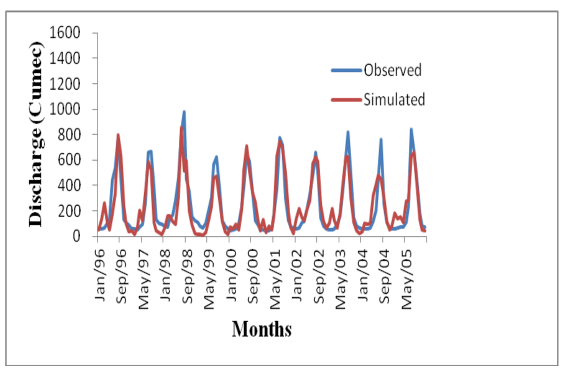

Fig. 9 Monthly discharge for calibration period from 1996 to 2005

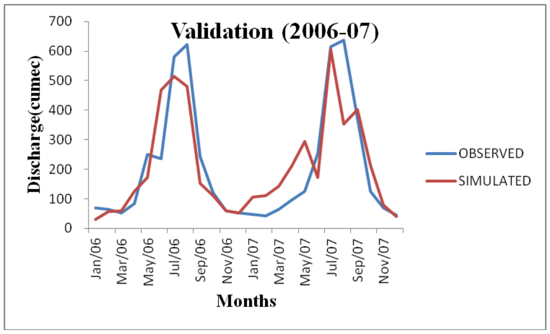

Fig. 11 Monthly discharge for validation period from 2006 to 2007

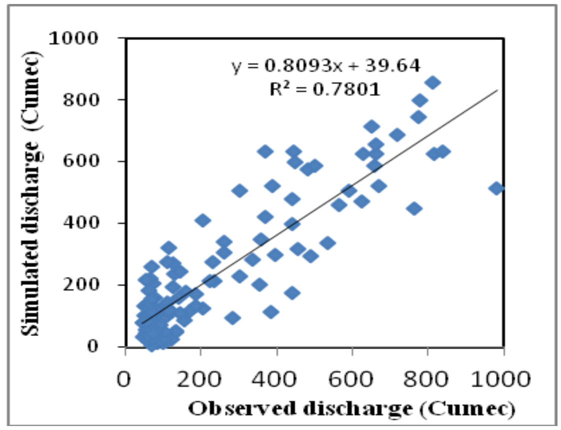

Fig. 10 Scatter plot for monthly discharge for calibration period from 1996 to 2005

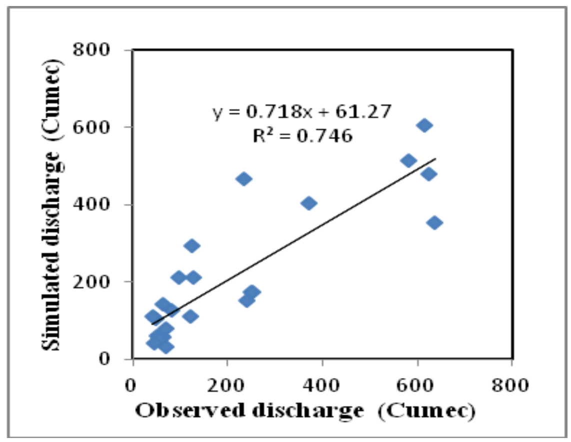

Fig. 12 Scatter plot for monthly discharge for validation period from 2006 to 2007

Table 6. Results of simulation for streamflow during calibration and validation

Statistical parameters	Calibration (1996-2005)	Validation (2006-07)
R^2	0.78	0.74
NSE	0.74	0.69

From the results it has been observed that the discharge has been been simulated fairly good. The low stramflow values are simulated better than the peak flow values during the calibration and validaiton of the the model. The optimized parameters of SWAT can be used to simulate the discharge for future climate scenarios such as RCP2.6, 4.5 and 8.5 with the generated series of rainfall, maximum and minimum temperature for the climate scenarios such as RCP2.6, 4.5 and 8.5.

5. **Conclusion**

In this study, SWAT (Soil and Water Assessment Tool) has been used to simulate the runoff from the catchment of Bhagirathi up to Tehri dam. The input data such as DEM, LULC and soil type have been generated from different sources such as NASA, BHUVAN, NRSC, National Bureau of Soil Survey and Land Utilisation Planning (NBSSLUP) and Harmonised World Soil Database (HWSD). The meteorological (rainfall, maximum and minimum temperature, relative humidity and wind speed) and hydrological data (discharge) from 1994-2007 have been obtained from IMD and THDC India Ltd. The model has been calibrated using the data of streamflow for the period from 1994 to 2005 and validated with data for the period from 2006 to 2007. SWAT-cup is run to find out the sensitive parameters for the simulation of streamflow. The sensitive parameters for streamflow have been optimized by SUFI2 algorithm (Sequential Uncertainty Fitting version 2). The streamflow has been simulated with the sensitive parameters. The coefficient of correlation (R^2) between observed and computed streamflow during calibration and validation are 0.78 and 0.74 respectively. The Nash-Sutcliffe Model efficiency (NSE) during calibration and validation are 74 and 69 % respectively. The results clearly indicate that the SWAT simulated the streamflow fairly well. The optimized parameters of SWAT can be used to simulate the discharge for future climate scenarios such as RCP2.6, 4.5 and 8.5.

Acknowledgements

The authors acknowledge the support provided by Department of Science and Technology (DST), Ministry of Science and Technology, India Meteorological Department (IMD), Tehri Hydro Development Corporation (THDC) India Ltd., National Institute of Hydrology, Roorkee. The funding support received from DST for the study “National Mission for Sustaining the Himalayan Ecosystem (NMSHE)” is duly acknowledged.

References

Arnold, J. G., Srinivasan, R., Muttiah, R. S., & Williams, J. R. (1998). Large area Hydrologic modeling and assessment part I: Model development. *Journal of the American water resources association*, 34(1), pp. 73-89.

Gassman , P., Jha, M., Secchi, S. and Arnold, J. (2003). Initial calibration and validation of the SWAT model for the upper Mississippi riven basin. *7th International Conference on Diffuse Pollution and Basin Management*, Dubli, pp. 1-40.

Tripathi, M. P., Raghuwanshi, N. S., and Rao, G. P. (2006). Effect of watershed subdivision on simulation of water balance components. *Journal of Hydrological processes*, 20(5), pp 1137-1156.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, T. L., and Veith, R. D.(2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Soil & Water Division of American Society of Agricultural and Biological Engineers*, 50(3), pp. 885−900.

Setegn, S. G., Srinivasan, R., and Dargahi, B. (2008). Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. *The Open Hydrology Journal*, 2(2008), pp. 49-62.

Mengistu, G., and Mccray, J. E. (2008). “Effects of Soil Data Resolution on SWAT Model Streamflow and Water Quality Predictions” *Journal of Environmental Management* 88(3):pp 393-406.

Xu, Z., Pang, J. P., Liu, C. M., and Li. J. Y. (2009). Assessment of runoff and sediment yield in the Miyun Reservoir catchment by using SWAT model. *Hydrological Processes,* 23(25), pp. 3619 – 3630

Lin, S., Jing, C., Chaplot, V., Yu, X., Zhang, Z., Moore, v., and Wu, J. (2010). Effect of DEM resolution on SWAT outputs of runoff, sediment and nutrients. *Journal of Hydrology and Earth System Sciences.* 7, pp. 4411– 4435.

Raneesh, K., Surya, T.V., and Santhosh, G.(2010). Prediction of Stream flow and Sediment Yield in the Chaliyar River Basin, Kerala, India. *International Journal of Earth Sciences and Engineering*, 3(5), pp. 654 – 661.

Nagraj, S. P., Rajkumar, V. R., and Manoj, S. (2014). Runoff Modelling for Bhima River using Swat Hydrological Model. *International Journal of Engineering Research & Technology* (IJERT) ISSN: 2278-0181.

Tyagi, J. V., Rai, S. P., Qazi, N., and Singh, M. P. (2014). Assessment of discharge and sediment transport from different forest cover types in lower Himalaya using Soil and Water Assessment Tool (SWAT). *International Journal of Water Resources and Environmental Engineering*, 6(1), pp. 49-66.

Omani, N., Tajrishy, M and Abrishamch, A. (2000). Modeling of a River Basin Using SWAT Model and SUFI-2. *Fourth International Conference of SWAT Model*, Delft, Netherlands.

Tomas D. Reyes, JR. (2017). Application of Soil and Water Assessment Tool (SWAT) Model to predict streamflow and sediment yield in Wahig-Inabanga watershed, Bohol, Philippines. *International Journal of Environmental and Rural Development*, 8(1), pp. 104-110.

Williams, J.R. (1969). Flood routing with variable travel time or variable storage coefficients. Trans. ASAE, 12, pp. 100–103.

Agarwal, N. K., Lohani, A. K., and Goel, N. K. (2019). Physiographic Analysis of Tehri Dam Catchment and Development of GIUH Based Nash Model for Ungauged Rivers. *Current World Environment*, 14(2), pp. 215-230.

Soil and Water Assessment Tool Theoretical Documentation, Version 2009. (2011). TR-406, Texas A&M University, USA.

Soil Conservation Service (SCS) (1972) National Engineering Handbook, Section 4: Hydrology. Department of Agriculture, Washington DC, p.762.

Green, W.H., and G. Ampt. (1911). Studies of soil physics, part I – the flow of air and water through soils. Journal Agricultural Science, 4, pp. 1-24.