



Simulation of surface runoff using semi distributed hydrological model for a part of Satluj Basin: parameterization and global sensitivity analysis using SWAT CUP

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Abstract

The ideal allotment of controlled water assets for diversified schemes is needed for continuous and controlled advancement. In present study SWAT (Soil and Water Assessment Tool), a physically based semi-distributed hydrological model was applied in the Satluj Basin (Suni to Kasol) for hydrologic modeling. 23 sub-basins were demarcated from the study area, which consists of 325 Hydrological Response Units (HRUs) with regard to specific slope, soil and land use combination. SWAT-CUP (SWAT-Calibration and Uncertainty Programs) is one of the new developments for calibration/sensitivity analysis of watershed models that incorporate a semi-automated approach SUFI-2 (Sequential Uncertainty Fitting) which includes both manual and automatic calibration and incorporating global sensitivity analysis. Parameters for Sensitivity Analysis used to measure statistics for goodness-of-fit. For the study area, CN2, SOIL_K, RCHRG_DP, CH_K2 were considered as the most sensitive parameters. The model Calibration (1986–1998) and Validation (1999–2011) were executed with initial 3 years considered as a warm-up period (1983–1985) at Kasol site which is considered as an outlet of the study area. The statistical performance of the model was assessed using the coefficient of variation (R^2), and Nash–Sutcliffe efficiency (NSE), during model Calibration, R^2 for the daily runoff was obtained as 0.98 with Nash–Sutcliffe of 0.96 respectively. The validation also signified satisfactory results with R^2 of 0.96 and NSE of 0.94 respectively. The results have shown excellent correlation between observed and simulated discharge on daily time steps. The results and ensuing inferences would be of immense help to the hydrological fraternity and the water resource managers.

Keywords SWAT model · Satluj Basin · Calibration · Global sensitivity analysis · SWAT-CUP · SUFI-2 algorithm

Introduction

Water resources management problem includes knotty functions from the superficial and sub-superficial level to their intertwined systems (Sophocleous 2002; Srivastava et al. 2013). The hydrological attributes confined within the water resources system are diverse in time and space that makes the water resources management very difficult and cumbersome (Bloschl and Sivapalan 1995; Strayer et al. 2003). The geographical and temporal irregularities in distribution of water resources complicate the condition further. Further, the change in climatic condition also influences both the quality and quantity of water assets (Murty et al. 2013; Ganaie et al. 2017). This also affects a change in the availability of water resources. Replicas of scattered hydrological watersheds are pragmatic and competent enough and can be used as a tool in water resources management (Patel and Srivastava 2013, 2014). As stated by the Central

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Water Commission (2005) the yearly per capita availability of water resources has decreased from 5176 to 1588 m³ in 1951 to 2015 respectively, which would further decrease to 1434 m³ in 2025. This state of affairs implicates innovating a rapid solution for better planning and operation of different programmers. This would ensure continued availability of water resources for future generations. The geomorphic and geotechnical complexities associated with a hydrologic process has led to innovation of large number of mathematical and conceptual models since the last few decades that helps in assimilating the hydrological processes (Murty et al. 2013; Dhali and Sahana 2017).

In latter times, distributed watershed models have been deployed at a fast rate for applying alternate management game plans in the sector of water resources management, flood control, impact of climate change assessments and pollution control (P. Shi et al. 2011). SWAT as a physically based, semi-distributed hydrological model was developed for prediction of discharge of any ungauged basins (Arnold et al. 1998). This hydrological model is loaded with a geographical database, which is rigorously used for filling the foster flows, sediment and nutrient of a watershed (Rosenthal and Hoffman 1999). SWAT has been proved as a well-acquired model for assessing the effect of land management practices, sediment and agricultural chemical yields on water (Shi et al. 2011), SWAT has been widely used as a discharge indicator in several countries now a days (Spruill et al. 2000; Zhang et al. 2010; Patel and Srivastava 2013). For managing the water resources in a sustainable manner SWAT proved as an effective and fruitful tool. Model developed for managing hydrological modelling and water resources management accompanying variations in climate and terrain is widely in use. Jain et al. (2010) carried out ‘Simulation of Runoff and Sediment Yield for a Himalayan Watershed Using SWAT Model’ to predict the runoff and sediment yield for the intermodal part of Satluj river (Sunni to Kasol) located in the western part of the Himalayan region. Shivhare et al. (2014) conducted a study on ‘Simulation of Surface Runoff for Upper Tapi Sub-basin Area (Burhanpur Watershed) Using SWAT’; the model was performed from the year of 1992 to 1997 on daily basis. Singh et al. (2013) evaluated the SWAT model performance on Tungabhadra Catchment for Parameterization and Uncertainty analysis using SWAT-CUP. Gyamfi et al. (2016) examined the application of SWAT on a basin named Olifants Basin in South Africa to focus on model calibration, validation and uncertainty analysis. Stehr et al. (2009) carried out a study, which was focused on the use of SWAT model in Lonquimay River basin, which is located in Chilean Andes, where snowmelt and snow accumulation has played an important role. Shi et al. (2011) have compared the Xinanjiang (XAJ) model with SWAT to understand the better performance of the model in the field of water resources. The total study area

of the intermediate basin of the Satluj River (Sunni to Kasol) is 685.15 km². As a product, the hydrologic unit, which is called watershed, produces water resource with the interaction of land surface and precipitation. The nature of the watershed management is completely based on the quality and quantity of the water, which is produced by the watershed (Jain et al. 2010). The management of the watershed varies from location to location. Somewhere the intention might be to improve the irrigation system and maintain the quality of drinking water. Another objective could be to minimize the peak rate of runoff, which helps in controlling soil erosion and sediment yield. However, for better management of water resources, the modeling of runoff is necessary (Jain et al. 2010).

The concept of watershed modeling is an assemblage of geospatial techniques and hydrometeorological data. The procedure of assembling is conducted by its own specifications and also by its correlation with other methods active in the basin area. The predominant hydrological processes are rainfall, evapotranspiration, infiltration, surface runoff, percolation, and subsurface flow (Khalid et al. 2014). The physical and chemical properties of water depend on the hydrology, and their interaction with people, living things and their surroundings. The demand for natural resources is increasing every day because of increase in consumption pattern that leads to its over-exploitation. Excess and wasteful use of water resources is a major problem nowadays that makes pertinent to store and maintain the resource properly (Srinivas. et al. 2016). Hydrological model is a dominant approach to manage the natural resources. Models are an essential tool, which can be used to manage the hydrological process and validate the risks and benefits of LULC and soil over a variable period of time (Spruill et al. 2000). SWAT was introduced by United States Department of Agriculture (USDA) as a physically based, continuous, long-term simulation agricultural model. SWAT model helps to assess the stream flow of a river, based on climate datasets. This model has been chosen to evaluate the surface runoff of an intermodal part of Satluj basin (Sunni to Kasol). The hydro-meteorological datasets were available at two different gauging (Sunni and Kasol) stations, which were used to calibrate the model. The available Spatio-temporal data (rainfall, temperature and runoff) at the gauging station were used to simulate the hydrological model parameters and extract the statistical correlation between the simulated and observed stream-flow data in a sustained manner to improve human welfare and conserve the environment.

The main objectives of this study were to assess the stream flow of the intermodal part of the Satluj Basin (Sunni to Kasol) using SWAT hydrological model combined with calibration and global sensitivity analysis by using the SUFI-2 method and its suitability for this basin. This research contributes to the understanding on the part of

water resource community for effective planning and organizing agricultural water resources and hinders soil erosion in a sustainable manner.

Materials and methods

Study area

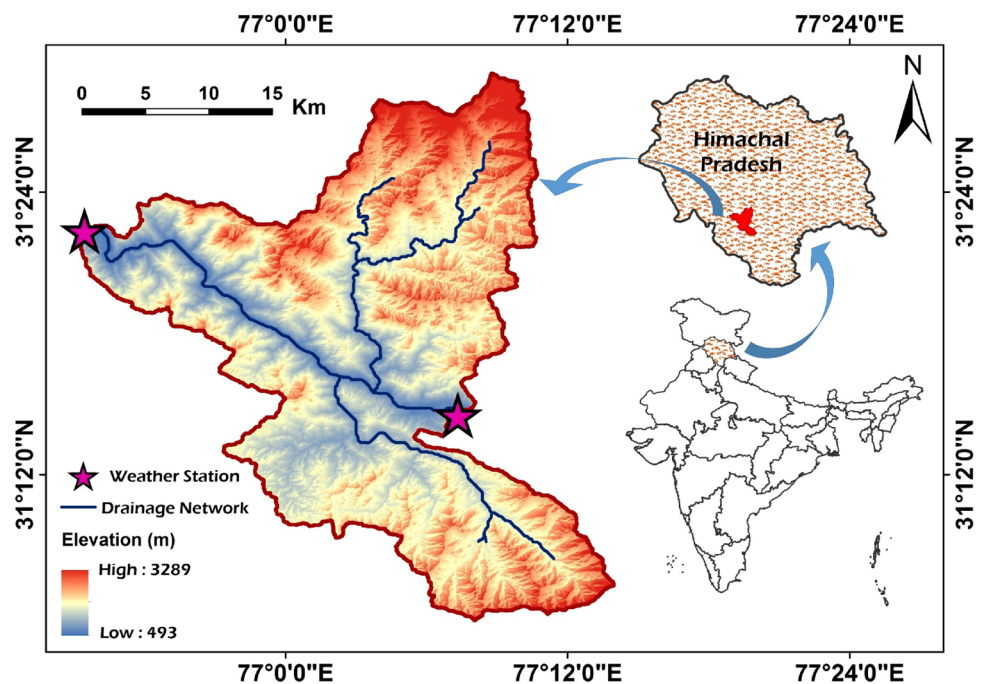
The series of mountains, the mighty Himalayas, have an enormous effect on the climate especially in the sub-continent (Sahana and Sajjad 2017). These ranges act as a barrier and help in monsoons for a large chunk in India. Also the drainage system of the Himalayan region follows a multifaceted pattern. The major water bodies originate there along with the largest stream out of the five in Himachal Pradesh. At Shipkila in Himachal the Satluj River runs through in the south-west passing by the districts of Kinnaur, Shimla, Bilaspur, Kullu, Mandi and Solan. The area in totality of the Satluj till the dam known as Bhakra is about 56,500 km² out of which over 22,000 km² falls in India which consists of the entire Spiti basin. The altitude of the catchment differs by a margin between 500 and 7000 m; and only above 6000 m there is a small part of this catchment which exist. The Satluj finally empties itself into the Indus basin which is in Pakistan. It will be worthwhile to note that Spiti, Baspa, Nogli Khad and Soan Rivers are the main branches of the Satluj River. The location of the study area is 31°5'N to 31°30'N and 76°50'E to 77°15'E (Fig. 1) with an elevation of 493–3289 m above the mean sea level, which stretches from Suni to Kasol and is an intermodal basin of

Satluj and hence selected for evaluation of surplus. In the state of Himachal Pradesh the study area covers an area of 685.15 Km². the runoff simulation of the intermodal part of the river stretch between Suni and Kasol was calculated, which flows over Western Himalayan region. The Western Himalayan belt which falls in India is present in three states i.e. Jammu Kashmir, Himachal Pradesh and Uttarakhand. Also the major rivers which include the Indus, Jhelum, Chenab, Beas, Ravi and Satluj in the Indus basin along with Yamuna, Sarada, Ramganga and Karnali in the Ganga basin all originate from this belt of mountains. Snowmelt, rainfall and groundwater flow helps in maintaining the rivers with the change of season as well (Jain et al. 2010; Sahana et al. 2018a, b).

SWAT model description

A tool for soil and water assessment, popularly known as SWAT, jointly developed by the United States Department of Agriculture–Agricultural Research Service (USDA–ARS) and the Agricultural Experiment Station is one of the newest models to help in monitoring situations on ground (Jain et al. 2010). This is a tool which is physical based, having partial distribution, better watershed range and ability for continuous hydrological modeling which processes on a day-to-day based data. This can also access the management practices in relation to land which have an impact on streams, soil and chemicals in ungauged zones (Arnold et al. 1998). The modeling helps to estimate the surface and sub-surface runoff, along with soil residues, inorganic elements and the movement

Fig. 1 Study area between Suni to Kasol (Satluj Basin)



of nutrients all the way through the hydrologic phase of the watershed system. The SWAT model itself is capable enough for uninterrupted simulation over a lengthy time interval (Narsimlu et al. 2015). The Soil and Water Assessment Tool (SWAT) also has a weather imitation model which generates daily metrological records for rainfall, solar emission, relative humidity, wind speed and temperature from average monthly variables of these records. This is an expert tool to plug the absent every day data in the observed records. This Tool splits the entire basin into sub-basins involuntarily with specific threshold area to later join the stream network. Further, these sub-divisions are divided into HRUs with the exclusive allotment of land cover gradient and soil (Patel and Srivastava 2013). These HRUs are non-spatially spread and thus report for a variety in the SWAT model. The details of selected SWAT parameters used for this study were mentioned in the Table 1. The hydrologic operations within the model consist of infiltration, percolation, evaporation, plant uptake, side flows and groundwater flows counting snowfall and snowmelt. The assessment of surface runoff volume takes place with the help of curve number method which results in a transformed Soil Conservation Number (Mishra and Singh 2003). The hydrological mechanism of the model can be tested with the assistance of the water balance equation which is represented as.

$$SW_t = SW + \sum_{i=1}^t (R_i - Q_i - ET_i - P_i - QR_i) \quad (1)$$

Where: SW_t is the final soil water content (mm), SW is the initial soil water content (mm), t is time in days, R is rainfall (mm), Q_i is surface runoff (mm), ET_i is evapotranspiration (mm), P_i is percolation (mm) and QR_i is return flow. A full model explanations and functions are introduced in Neitsch et al. (2000). SWAT use hourly and daily time steps data to evaluate surface runoff.

SWAT calibration uncertainty procedures (SWAT-CUP) model

A software series called the SWAT-CUP has been developed for calibration and validation of the parent model. It was created by Eawag, Swiss Federal Institute that looks into prediction ambiguity of this parent SWAT model. The factors for the representation can be chosen in accordance with the objectives of the study. With the application of explicit interface, model calibration and comprehensive sensitivity analysis can be coupled with the SWAT model. The outcome achieved after applying diverse variables with a decent blend like water content, pressure head and cumulative outflow on the estimation of hydraulic parameters by inverse modeling to investigate and bring significant analysis in the study prior to this one (Abbaspour et al. 1999). In this current study SUFI-2 algorithm was used for calibration of the model and sensitivity analysis, it is a multisite and semi-automated global search procedure.

To evaluate the model performance several statistics have been used which include Root Mean Square Error (RMSE), Co-efficient of determination (R^2) and the Nash–Sutcliffe Efficiency (NSE). The statistical techniques like the t test and p value were considered to approximate the level of significance between the datasets. In t test larger absolute value shows more sensitivity than the lower one while the value closer to zero is much more sensitive in case of the p value.

Creation of database

In the Satluj basin the Bhakra Beas Management Board (BBMB) developed a hydro-metrological network. Here the precipitation gauges are monitored at different stations which are completely maintained by BBMB. The stations are located at ten places along the basin which includes Bhakra, Berthin, Kahu, Suni, Kasol, Rampur, Kalpa, Rackchham,

Table 1 Selected SWAT parameters used for this study

SWAT parameters	Description
CN2	Soil conservation service run-off curve number
SOIL_K	Soil conductivity (mm/h)
RCHRG_DP	Deep aquifer percolation fraction
CH_K2	Hydraulic conductivity in main channel (mm/h)
ALPHA_BF	Base flow alpha factor (days)
ESCO	Soil evaporation compensation factor
GW_DELAY	Groundwater delay (days)
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)
GW_REVAP	Groundwater–revap coefficient
GWQ_MN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)

Namgia, and Kaza. Meteorological data from all these sites are available from 1983 onwards. Suni and Kasol, only two stations are located within the study area in order to assess streamflow for the simulation period (1983–2011). SWAT hydrological representation has been utilized to extract the controlled parameters on the various processes in this selected area. The Table 1 lists the various required datasets like the Digital Elevation Model (DEM), Land use and land cover (LULC), Soil, and Hydro-meteorological datasets which were downloaded from diverse sources. The details database summarization has been explained in the following sections.

Digital elevation model (DEM)

One of the dominant inputs of SWAT is the Digital Elevation Model (DEM). For the current study ASTER DEM was downloaded from the USGS Earth Explorer. Based on DEM SWAT automatically delineates a watershed into sub-watershed. The entire study basin has been divided into 23 sub-basins using Arc SWAT 2009 with the default threshold value of 2500 ha. The outlet is defined at the location of Kasol station. Flow behavior and pattern can be understood by DEM as it also plays a crucial role in runoff processes which can be fast as well as slow (Wagener and Wheeler 2006; Patel et al. 2013; Yadav et al. 2013). Figure 2 depicts the DEM of the study area.

Land use/land cover and soil classification

In order to understand the hydrological procedure, LULC is an important input parameter (Srivastava et al. 2012; Singh et al. 2014). Landsat-8 satellite imagery with 30 m spatial resolution of the study area was downloaded from the USGS Earth Explorer website to generate classified Land use/Land cover map of the study area. The maximum likelihood methods and supervised classification technique has been used to classify the satellite image (Sahana et al. 2018). The training pixel sites were used to identify the land use/land cover classes and the reclassification technique was used to reduce the error and improves the accuracy (Sahana et al. 2015, 2016). Overall classification accuracy was found to be 86.5% and the kappa coefficient values of was determined as 0.88. The classified LULC map is shown in Fig. 2. According to spectral reflectance, four land use land cover classes are introduced, these are deciduous (6.61%), forest evergreen (56.33%), water (1.49%), and barren land (35.57%). Table 2 presents the list of land use categories in the area under study. The evergreen forests cover most part of the area under observation which accounts for 56.33%.

The aid of the NBSS (National Bureau of Soil Survey) and the LUP, Nagpur (Land Use Planning) as sources for the soil map preparation were deemed significant (Sahana and

sajjad 2017; Sahana et al. 2018a, b). In Arc SWAT a variety of soil properties such as the texture of the soil and its density, hydraulic conductivity, bulk density are fundamental to make the model input. In the study area four major soil categories have been found i.e. clay-loamy/loamy-sand D (very slow rate of permeation and high rate of overspill), loamy-sand/rock-outcrop D (very slow permeation and high overspill), fine-loam/moderate C (low infiltration rate) and loamy-sand/moderate D (very slow infiltration rate and high run-off rate). Table 3 has the list of soil categories for the area under observation. The fine-loam-moderate soil has a significantly large coverage in the selected area. The soil plan of the learning area is shown in Fig. 2.

HRUs analysis has been done by overlapping the unique spatial datasets (LULC, Slope and Soil map). The threshold values which were adopted to create HRUs were assigned as 5% for land use, 10% for soil and subsequently 10% for slope. 325 HRUs have been generated all across the 23 sub-basins of the area under study. There are four class categories in the slope map i.e. from 0 to 25%, 25 to 50%, 50 to 75% and above 75%. Figure 2 has the representation of the slope map of the designated site. To calculate the stream flow using Arc SWAT, it is necessary to prepare a required database. Some statistics were generated using WGN EXCEL MACRO Software (<http://swat.tamu.edu/software/links-to-related-software/>) downloaded from SWAT website. Rainfall, temperature, and discharge which is observed data on a daily basis has been processed, on the other side relative humidity, solar emission and airstream speed data are in gridded form. Once all the required data files have been arranged, the model is set to test. The complete model was set from 1983 to 2011 from which first 3-year (1983–1985) was considered as model warm-up period, from 1986 to 1998 was run for model calibration and sensitivity analysis, rest 12 years (1999–2011) were used as model validation. The model was standardized/authenticated using discharge information on a daily basis at Kasol station which was considered as basin outlet. The soil and land use categories were specified in the SWAT database as per the Indian climatic condition.

Model setup

The required database has been arranged for area under observation (Intermodal part study basin—from Suni to Kasol). The model has setup to establish hydrological simulation for the study area. The following steps have been followed to set up the model: SWAT project setup, Automatic watershed delineation, Land use and soil characterization (HRUs analysis), Climate data definition (Write input tables), Editing input information, SWAT simulation. The detail steps have explained in the methodology

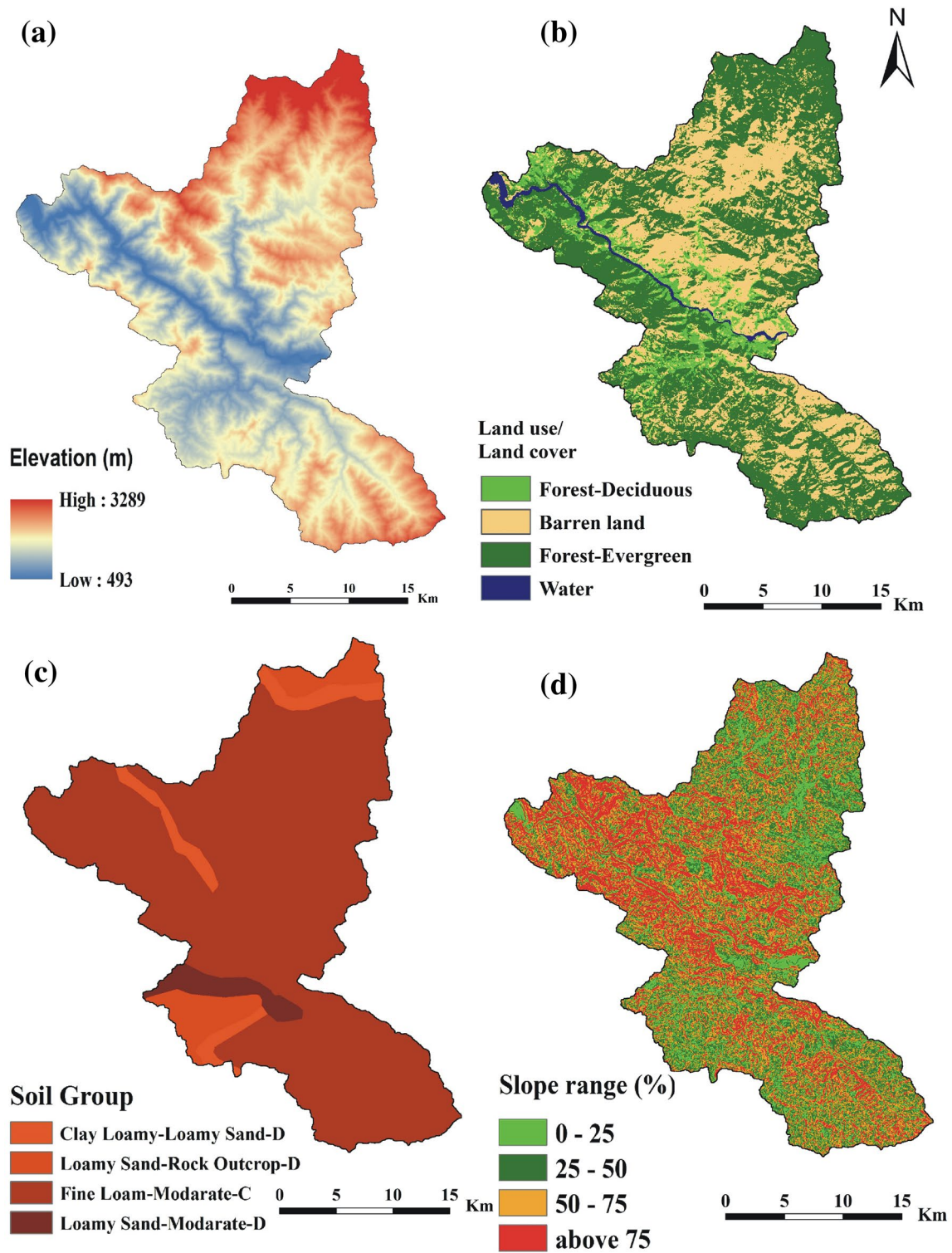


Fig. 2 Selected indicator for this study **a** elevation, **b** land use/land cover map, **c** soil map, **d** slope

flowchart Fig. 3. Arc SWAT 2009 automatically delineated watersheds into multiple sub-watersheds on the basis of DEM and the river's exhaust arrangement. ASTER DEM has been clipped with respect to the size of the study area,

and then it was introduced in the model features. A cover of the polygon has generated manually in the Grid format, which was inserted in the model to extort the area of

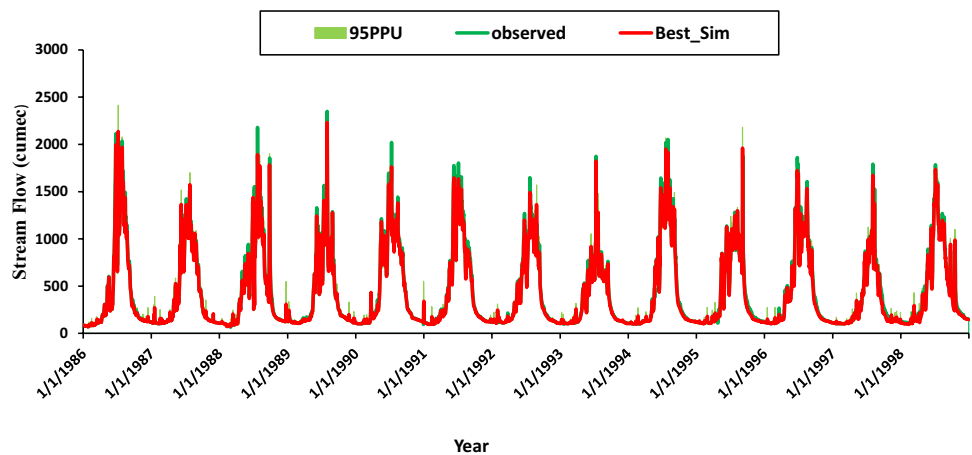
Table 2 Sources and Description of the input Data for the Study

Data type	Source	Spatial/temporal resolution	Description
Topography	USGS earth explorer	30 m	ASTER digital elevation model
Land use/land cover	Landsat-8 satellite imagery (Earth Explorer)	30 m	Land use classification
Soils	NBSS and LULP, Nagpur (Hardcopy of soil map was converted into digital form)	–	Soil classification
Weather data	BBMB, India http://globalweather.tamu.edu/	Daily	Rainfall, minimum and maximum temperature
		Daily	Solar radiation, relative humidity, wind speed
Stream flow data	BBMB, India	Daily	Daily stream flows measured at the gauging stations

Table 3 Area coverage of the land use categories

Land use/land cover types	Classes	Reclassified classes according to SWAT geodatabase	Area (%)
Land use/land cover types	Forest deciduous	FRSD	6.61
	Barren land	BARN	35.57
	Forest evergreen	FRSE	56.33
	Water	WATR	1.49

Fig. 3 Methodological framework adopted for SWAT Model of Satluj Basin (Sunj to Kasol)



concern. DEM has to be pre-processed for the determination of the size and number of sub-watersheds based on the threshold area. Once the watershed and sub-watershed boundaries are delineated a specific outlet for the study area has defined at Kasol site (585 m elevation) to generate the whole watershed. As the area under observation is not the complete basin of the Sutlej, it is a part of it so the concept of inlet became necessary to bring here. The Sunj station has been considered as an inlet for the study area. The watershed delineation and sub-basin parameters calculation have been done successfully. The delineated study area by the model was found 685.15km². Weather stations of the study area are shown in Fig. 4.

Evolution of the model performance

The performance of the model was evaluated by comparing the model simulated value with the ground observed discharge data. The model performance widely depends on the statistical method namely coefficient of determination (R²) (Eq. 2), Nash–Sutcliffe (NSE) (Eq. 3), Percent bias (Eq. 4), and RMSE-observations standard deviation ratio (RSR) (Eq. 5) were used to evaluate the model performance. R² indicates the goodness of fit of any model. It’s measure how well the simulated data approximated with the ground observed discharge data. The efficiency or the acceptability of the model depends on the R². It ranges from 0 to 1. An R² closer to 1 is indicated the high degree

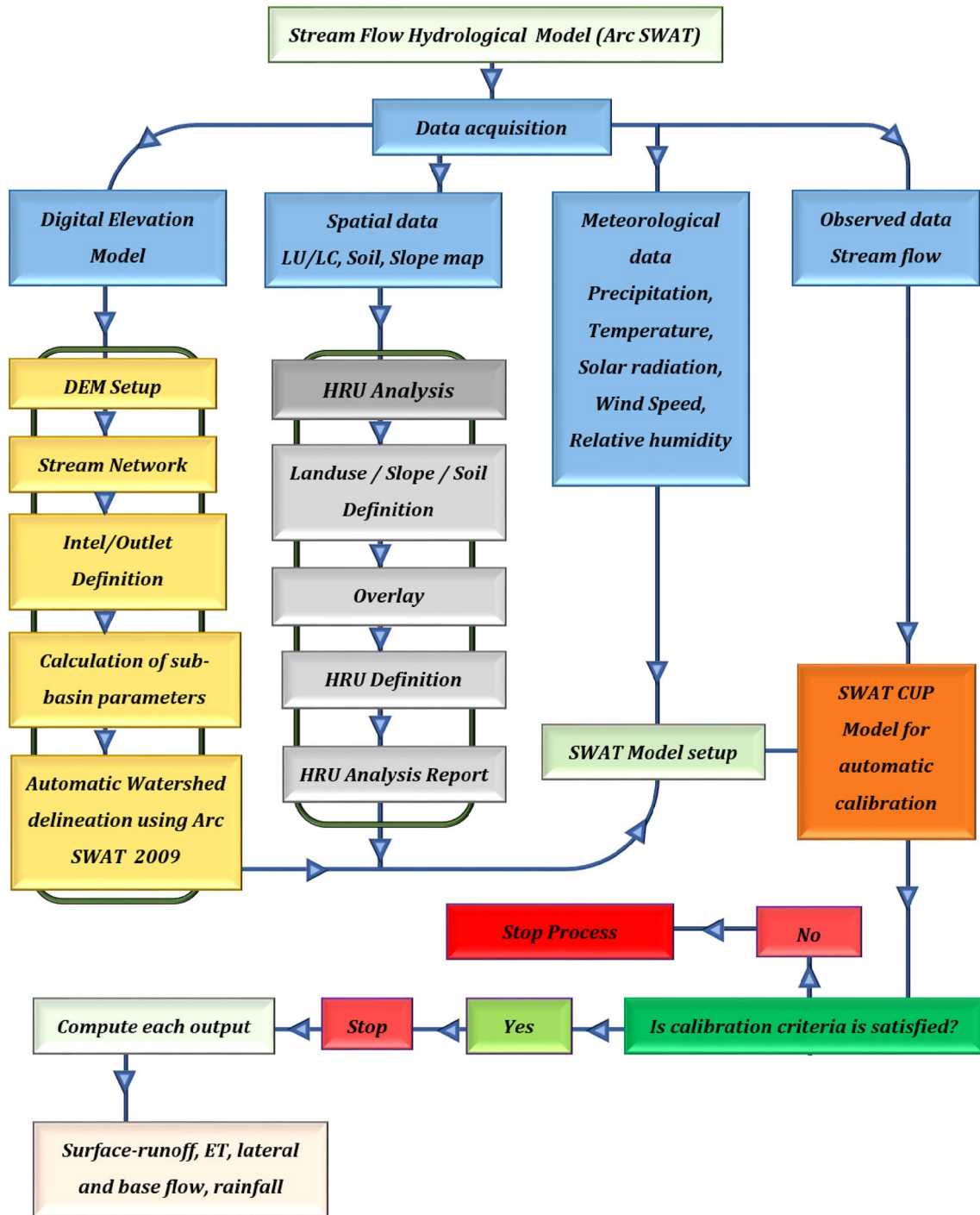


Fig. 4 Sub-basin map (a) and weather-location map (b) of the study area

of model efficiency or the simulated value is perfectly fitted with the observed data.

$$R^2 = \left[\frac{\sum_{i=1}^n (O_i - S_i)(S_i - \bar{S})}{\left(\sum_{i=1}^n (O_i - \bar{O})^2 \right)^{0.5} \left(\sum_{i=1}^n (S_i - \bar{S})^2 \right)^{0.5}} \right]^2 \quad (2)$$

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (3)$$

$$PBIAS = \frac{\sum_{i=1}^n (O_i - S_i) \times 100}{\sum_{i=1}^n O_i} \quad (4)$$

$$RSR = \frac{\sqrt{\sum_{i=1}^n (O_i - S_i)^2}}{\sum_{i=1}^n (O_i - \bar{O})^2} \tag{5}$$

Where; O_i = observed variable, S_i = simulated variable, O = mean of observed variable, S = mean of simulated variable, n = number of observations under consideration (Gyamfi et al. 2016).

Result and discussion

In this study, we have used an acute calibration based comprehensive sensitivity investigation of model parameters (Abbaspour et al. 2007) with the help of the SWAT-CUP documentation (Neitsch et al. 2005). The model calibration predictions for stream flow were done with the aid of 11 SWAT sensitive parameters.

Sensitivity analysis of model parameters

Water balance components have been calculated based on the 1st equation of the SWAT model; the calculated outcomes have been resolved in the Check tool of the software. Primary parameters and the water balance ratios are shown

in Table 4. The stability of water proportion through the base flow and total flow was calculated as 0.62. Sensitivity analysis has been executed to identify the variability of the output of the model with respect to relative modification to the input parameters of the model. In order to know the most sensitive parameters we analyzed the sensitivity comparative parameters which were carried out during model calibration using the SUFI-2 algorithm. Eleven parameters were found to be most sensitive according to their statistical ranking. Highest, lowest along with fitted standards of the consideration for daily calibration using SUFI-2 techniques has presented in Table 5. The global sensitivity assessment has been dealt with for stream flow measurement based p value and t test (Table 6; Figs. 5, 6) of the parameters. These eleven parameters showed high level of sensitivity to model calibration with the parameter changes of the fitted value during the iteration process. Other parameters were not seen to have as much of a considerable effect on the flow of the stream simulation. Relative amendment in model input parameters also resulted in no major change in the output. In present study CN2 was noted to be most responsive parameters toward the output and SOIL_K, RCHRG_DP, CK_K2 respectively. Where else the least sensitive parameters were GW_REVAP, GWQ_MN, and REVAPMN respectively. For measuring the stream flow in the study area sensitivity analysis has been played a great role in determining the

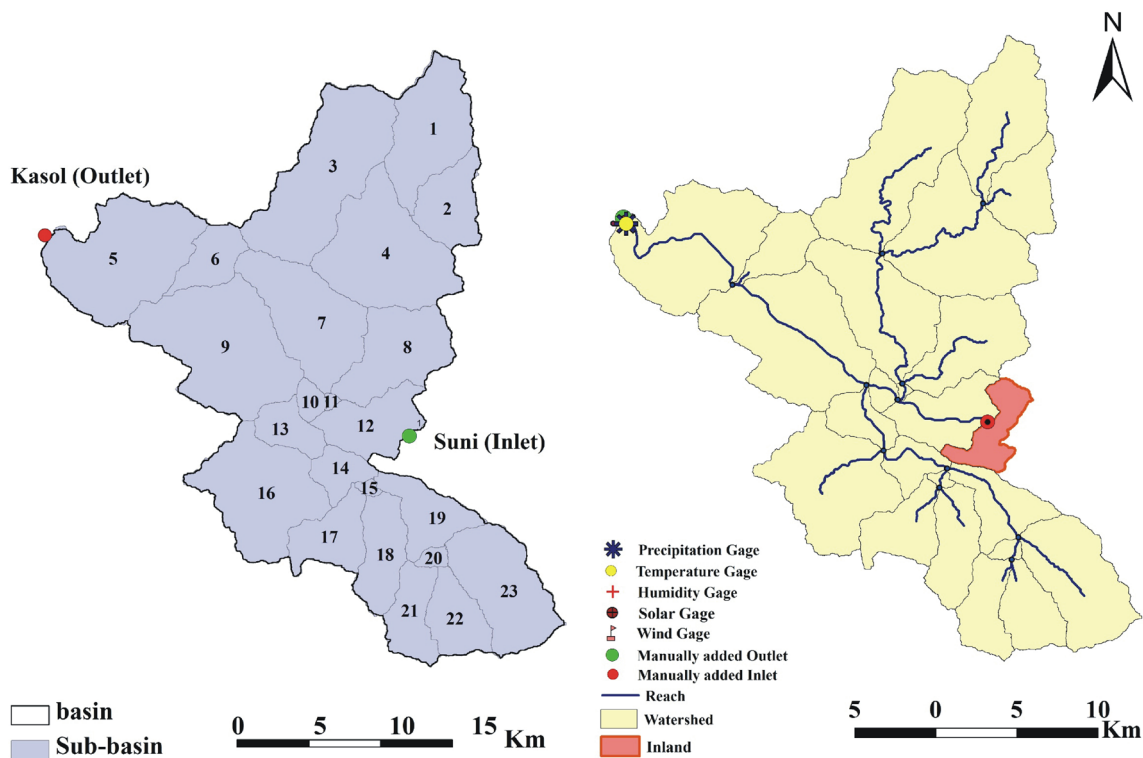


Fig. 5 Graphical representation of p value

Fig. 6 Graphical representation of *t* test

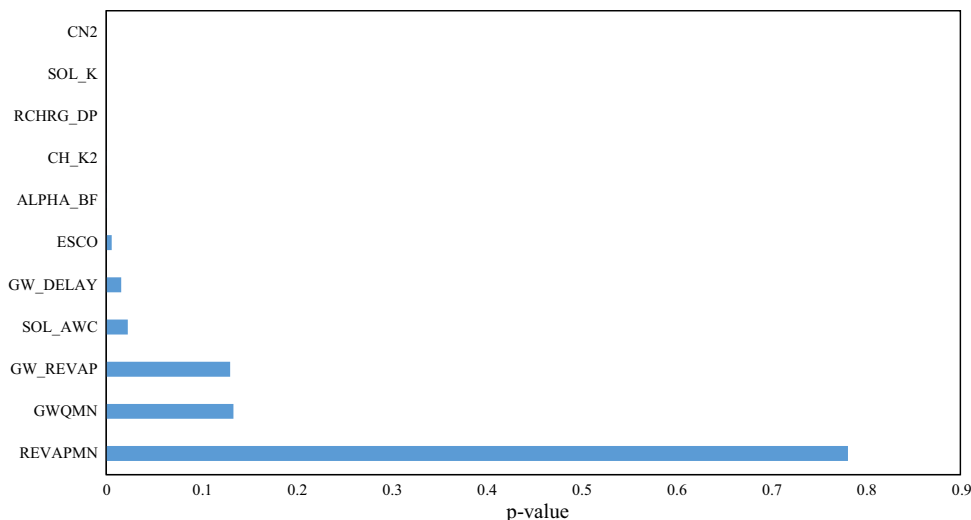


Table 4 Area coverage of the soil categories

	Classes	Reclassified classes according to SWAT geodatabase	Area (%)
Soil types	Clay loamy–Loamy sand D	CL-LS-D	4.98
	Loamy sand–rock outcrop D	LS-RO-D	6.55
	Fine loam–moderate C	FL-MD-C	85.34
	Loamy sand–moderate D	LS-MD-D	3.13

Table 5 Simulation details of the SWAT model

Simulation details		
General details	Simulation Length (Years)	29
	Warm up (Years)	3
	Hydrological Response Units (HRU)	325
	Sub-basins	23
	Precipitation method	Observed
	Watershed area (km ²)	685.15
Hydrology (Water balance ratio)	Stream flow/precipitation	0.50
	Base flow/total flow	0.62
	Surface run-off/total flow	0.38
	Percolation/precipitation	0.15
	Deep recharge/precipitation	0.05
	ET/precipitation	0.45

importance parameters. The intermodal part of the Satluj basin has a curve number near about 70 which offer ample amount of run-off. It depends on the soil moisture condition which had its basis on the fractional average of the basin gradient.

Evaluation of the model performance

Using observed daily discharge data the selected model for the area under observation was regulated and authenticated

respectively. In order to evaluate between the observed and simulated discharge value on a daily basis of 28 years of observed discharge data has been used. The entire simulation period was from 1983 to 2011. From this, 3 year records (1983–1985) were kept as model preparation period, the remaining time scale was used to calibrate the model i.e. 1986–1998 as well as for validation i.e.1999–2011. To check the model calibration efficiency five objective functions has chosen namely coefficient of determination (R^2), p-factor (which has a range between 0 and 100 percent), the R-factor

Table 6 Parameter uncertainties during Stream flow calibration on daily basis

Parameters	Rank	Maximum value	Minimum value	Fitted value	Process
CN2	1	0.01	−0.20	−0.20	Run-off
SOIL_K	2	0.80	−0.80	−0.19	Soil
RCHRG_DP	3	0.40	0.00	0.10	Soil
CH_K2	4	50.00	30.00	47.50	Channel
ALPHA_BF	5	0.80	0.23	0.60	Groundwater
ESCO	6	1.00	0.80	0.88	Evaporation
GW_DELAY	7	100.00	45.00	33.56	Groundwater
SOL_AWC	8	0.40	0.12	0.39	Soil
GW_REVAP	9	0.20	0.02	0.09	Groundwater
GWQ_MN	10	2.00	0.89	0.99	Groundwater
REVAPMN	11	200.00	60.00	126.22	Groundwater

Fig. 7 Daily flow calibration plot (SUFI-2) using SWAT-CUP for the period of 1986–1998

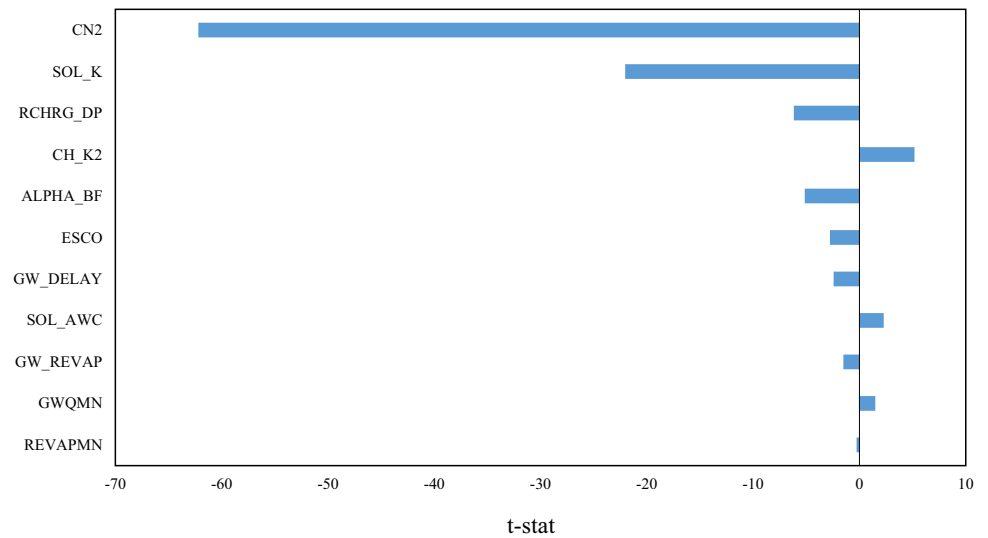
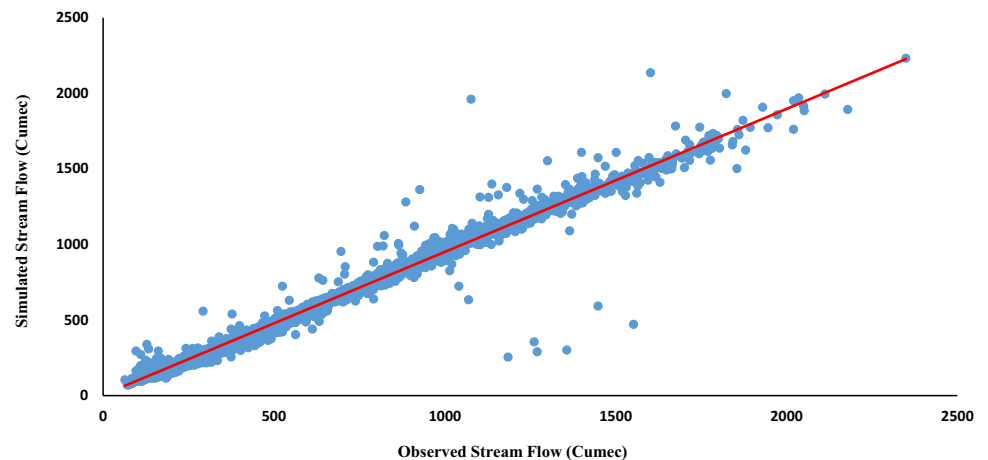


Fig. 8 Correlation between daily observed and simulated stream flow measured Kasol during calibration (1986–1998)



(which ranges between zero to infinite value), Nash–Sutcliffe coefficient (NS) and RMSE-observations standard deviation ratio (RSR) for the catchment of the intermodal part of Sutlej. The Nash–Sutcliffe coefficient (NS) and the coefficient

of determination (R^2) help in obtaining the quantified details of the goodness of the model. On the basis of Nash–Sutcliffe in 1970, the results were considered of good quality when the value of NS was greater than 0.75, and when it is greater

Fig. 9 Daily flow validation plot (SUF2) using SWAT-CUP for the period of 1999–2011

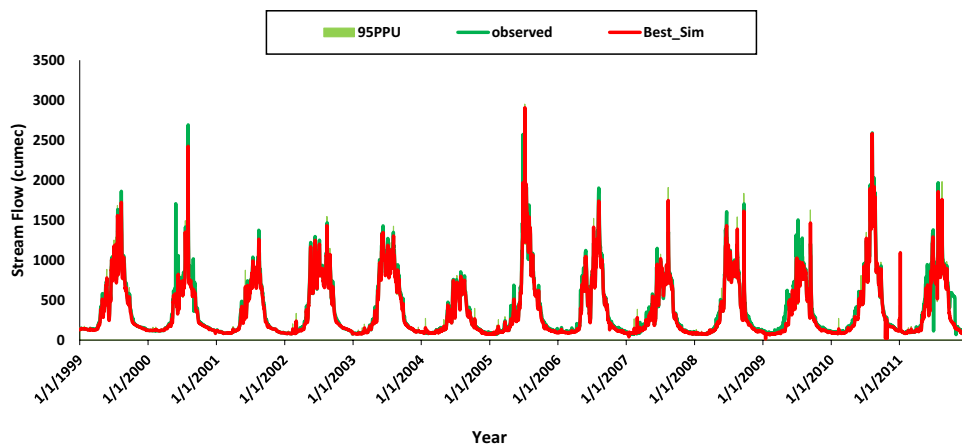


Fig. 10 Correlation between daily observed and simulated stream flow measured Kasol during validation (1999–2011)

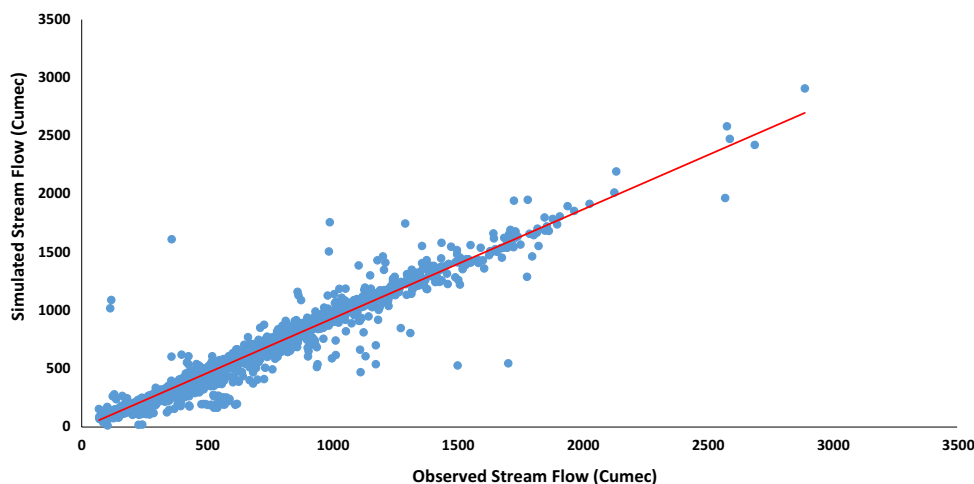


Table 7 Parameters Sensitivity ranking using SUFI-2 technique

Parameters	<i>t</i> stat	p value	Sensitivity ranking
CN2	−62.19	0.00	1
SOIL_K	−22.04	0.00	2
RCHRG_DP	−6.17	0.00	3
CH_K2	5.18	0.00	4
ALPHA_BF	−5.14	0.00	5
ESCO	−2.77	0.01	6
GW_DELAY	−2.42	0.02	7
SOL_AWC	2.28	0.02	8
GW_REVAP	−1.51	0.13	9
GWQMN	1.50	0.13	10
REVAPMN	−0.28	0.78	11

than 0.36 the results were acceptable. Daily flow calibration plot (Fig. 7) between observed and simulated discharge was plotted for the period of 1986–1998 for visual comparison to explore the similarity of the peak values between the observed and simulated discharge. Correlation among daily

simulated and observed discharge is shown in Fig. 8 during calibration. The recommended model evaluation parameters i.e. R^2 , NSE, RSR and PBIAS have been computed for the observed and computer-generated watercourse to standardize and authenticate phases which are as represented in the Table 7. As we can understand from the daily flow hydrograph of every day experiential and replicated flow values, it can be seen that the model forecasts daily flows almost has a similar trend as that of practical/observed values. Coefficient of determination (R^2) for the daily runoff values for 1986–1998 was observed 0.98 and 0.96 for the validation the statistical performance is presenting a superior relationship between the practical and virtual flows. On similar lines, the values of the statistical function were found to be 0.96 (NSE), PBIAS (4.2) and 0.13 (RSR) respectively during calibration and 0.94 (NSE), 7.6 (PBIAS) and 0.20 (RSR) respectively during validation. Daily flow validation plot is shown in Fig. 9. The correlation between daily observed and simulated discharge throughout validation episode has been represent in the Fig. 10. The probable reasons for the excellent performance of the model could be the inlet concept which was added here another reason could be the size of the

Table 8 Evaluation of SWAT model performance (Daily time steps)

Model Stage	Evaluation Statistics			
	NSE	R ²	PBIAS (%)	RSR
Calibration (1986–1998)	0.96	0.98	4.2	0.13
Validation (1999–2011)	0.94	0.96	7.6	0.20

watershed area. The value of the coefficient of determination (R^2) exhibiting satisfactory results. To wrap up, it can be suggested to adopt the SWAT model for upcoming forecasts to be made for the water balancing components of the study basin (Table 8).

Conclusion

An effective model calibration is needful for an effective output in case of hydrological prediction. In this research, Arc SWAT model has been applied to estimate the stream flow in a part of Satluj Basin with the default threshold value (2500 ha.), 23 sub-basins were created. HRUs have been generated in each subbasin from the spatial data (LULC map, Soil and Slope map) of the study area. The hydro-meteorological data sets on a daily basis at two different gauging stations (Suni and Kasol) were used as input data to run the model. Suni was considered as an inlet and Kasol was defined as an outlet. The SWAT simulated runoff was compared with the observed discharge data at Kasol point. SWAT model was calibrated and validated to examine its applicability for simulating daily data. For this study, the model setup has been arranged for 28 years (1983–2011) of datasets, the first 3 years were kept for model initialization (1983–1986). Out of these 28 years, 12 years (1986–1998) were used for calibration and rest of the years (1999–2011) for validation of model respectively. The Global Sensitivity Analysis has been chosen for the stream-flow calibration indicates the variation between the parameter ranges and identified the most sensitive parameters for the study basin. For this analysis, advanced software, namely SWAT-CUP (calibration and uncertainty analysis programs) has been chosen. Eleven most sensitive parameters (CN2, SOIL_K, RCHRG_DP, CH_K2, ALPHA_BF, ESCO, GW_DELAY, SOL_AWC, GW_REVAP, GWQMN, and REVAMP) were found for the intermodal part of the Satluj basin. For daily simulation, the statistical values of NSE, PBIAS, RSR, and R^2 were established to be 0.96, 4.2, 0.13, and 0.98 respectively for the time of calibration. Similarly, the statistical values of NSE, PBIAS, RSR, and R^2 were established to be 0.94, 7.6, 0.20, and 0.96 respectively for the time of validation. The statistical values of the model signify a good indicator of the high accuracy of model performance. These study results are useful in agricultural sector, and soil and

water conservation divisions. SWAT model could be a great guidance for controlling natural calamities like drought and flood. Future assessments of climatic change and LULC cover impact assessment on water resources are done using this calibrated model.

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Compliance with ethical standards

Conflict of interest All the authors declare that they have no conflict of interest.

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