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Research Article

HYDROLOGICAL MODELLING OF BARINALLAH WATERSHED USING ARC-SWAT MODEL

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ABTRACT

In present study the hydrological simulation is carried out by using Soil and Water Assessment Tool (SWAT) model, which is integrated with Arc Gis software, for one of most important parameter of hydrology like, runoff for barinallah watershed which is located on the western hills in Chamba district, Himachal Pradesh. The model was calibrated using field-measured discharge data of watershed for two years (2002 to 2003) and validation was performed for the year 2004. The monthly simulated runoff of Barinallah watershed for the calibration and validation periods were found to match with their measured discharge value of coefficient with correlation (R^2) in both the cases 0.9385 and 0.9361 respectively. The model simulated daily runoff is corroborated by reasonably high Nash–Sutcliffe simulation coefficients of 0.8958 and 0.8229, high index of agreement (d) of 0.9755 and 0.9600 and low root mean square errors of 0.1477 and 0.2589, respectively for calibration and validation periods. The outcome of this study indicates effectiveness of the model for simulating the overflow is excellent.

***Key Words**: SWAT Model, Hilly Watershed, Runoff, Calibration and Validation*

INTRODUCTION

Water, next to the air, is the most important requirement for human life to exist. The Earth's ecosystems, societies and individuals need it. Without it, food security and human health, energy supplies and industrial production would be unobtainable. Plants and wildlife and their ecosystems need water. Water helps in regulating the global climate and as we are continuing to see, water resources themselves are affected by global climate change. The global water cycle between the sea, the atmosphere and the continents is a vital circulatory system for nature and man. This system brings about 110,000 km^3 of water to the continents every year by precipitation. Most of it evaporates back into the atmosphere from the ground and vegetation. The remaining water refills groundwater aquifers, springs, lakes and rivers.

Remotely sensed data provides valuable and near real time spatial information on natural resources and physical terrain parameters. In India, satellite based remote sensing inputs over the past two decades have been playing a key role in the management of its natural resources.

Geographical Information System (GIS) is computer-based system designed tool applied to geographical data for integration, collection, storing, retrieving, transforming and displaying spatial data for solving complex planning and management problems. GIS become an effective tool in watershed modeling as remote sensing derived information can be well integrated with the conventional database for predicting runoff and sediment yield to take up appropriate soil and water conservation measures.

Human activities have a profound impact on the environment. Alteration of the land surface for a variety of uses has changed water pathways and induced changes to natural processes (Starrett and Yunsheng 2002). The models help in evaluating and selecting the alternative land use and management practices. Implementation of these practices can help to reduce the damaging effects of storm water runoff and the landscape. Developing reliable watershed simulation models and calibrating/validating them for watersheds with measured and simulated data is a challenging issue (Borah *et al.*, 2002). The increasing

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rate of water resources development activities have focused attention on development and application of physically based hydrological models to deal with constantly changing hydrological environment. When the hydrological system is subject to change or when a realistic physical representation of flow in space and time is required to study water quality and soil erosion, the conceptual representation of traditional rainfall and runoff models with lumped approach are not suitable.

A number of simulation models have been developed to evaluate water quality parameters affected by agricultural land management at both field and watershed scale. Widely used field scale models include CREAMS (Chemicals, Runoff, Erosion from Agricultural Management Systems), EPIC (Erosion-Productivity Impact Calculator), and GLEAMS (Groundwater Loading Effects of Agricultural Management System). Watershed scale models include storm event based AGNPS (Agricultural Non-Point Source Pollution) and continuous daily time step model SWRRB (Simulator for Water Resources in Rural Basins). These models were developed for their specific reasons with some limitations for modeling watersheds. The SWAT (Soil and Water Assessment Tool) is one of the most recent models developed jointly by the United States Department of Agriculture (USDA), Agricultural Service and Agricultural Experiment Station in Temple, Texas. It is a physically based, continuous time, long-term simulation, lumped parameter, deterministic, and originated from agricultural models. The computational components of SWAT can be placed into eight major divisions: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. The application of ArcSWAT in the present study provides the capabilities to stream line GIS processes tailored towards hydrologic modeling and to automate data entry communication and editing environment between GIS and the hydrologic model. During last two decades, there has been an increase in the development and application of the hydrological and water quality models to evaluate the complex environmental processes and to assess the nonpoint source pollution of the watersheds. However, in India very little efforts have been made on the use of hydrologic models to develop management plan for such watersheds using systematic modeling approach. Application of hydrological models and adequate procedure of their calibration and validation is an important research issue. Considering hydrological behavior of the study watershed and applicability of the existing models, the current study was undertaken with the application of SWAT in integration with GIS and remote sensing to estimate the surface runoff for Barinallah watershed located in District Chamba, Himachal Pradesh. The specific objective of the present study is to calibrate and validate the Arc-SWAT model for runoff estimation in Barinallah watershed.

Study Area

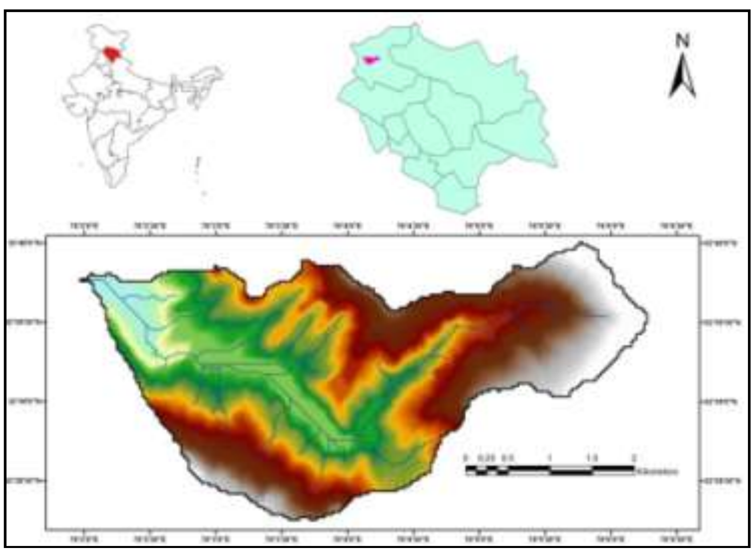

Figure 1: Location of Study area

Barinallah watershed is a part of Ravi river basin. The Barinallah watershed is located between 76°01’45’’ E to 76°06’18’’ E longitude and 32°38’00’’ N to 32°40’00’’ N latitudes on the western hills in Chamba district. This watershed has some springs and small nallahs. Water supply schemes for drinking water have been constructed to the nearby villages from these springs and nallahs. This area is characterized by elevation 760 m to 1880 m ranging mountains and valleys with drainage features**.** The location map of the study area is shown in Figure 1.

Data Acquisition

Hydro-Metrological Data

Latest daily rainfall data for eleven years (2000-2010) were collected from the rain gauge located near the watershed and analyzed to determine various statistical parameters (mean, standard deviation, skewness) for mean monthly and annual rainfall.

Other meteorological data such as maximum and minimum air temperature were collected from a meteorological observatory at Chamera Dam, located 6 km away from the outlet.

Monthly surface runoff data were collected for three years (2002-2004) from the HP Irrigation cum Public Health Department, Himachal Pradesh. The daily surface runoff data collected during the year 2002-03 were used for the calibration, whereas the data collected during the year 2004 was used for validation of the SWAT model.

Topographical Data

A digitized contour coverage at 40 m interval was developed from the topographic map. The digitized contours were given ID (identity) number representing contour elevations. The elevation of Barinallah watershed varies from 760 to 1880 m above MSL. The topography of the study area is hilly and is less suitable for agriculture and other social activities (Figure 2).

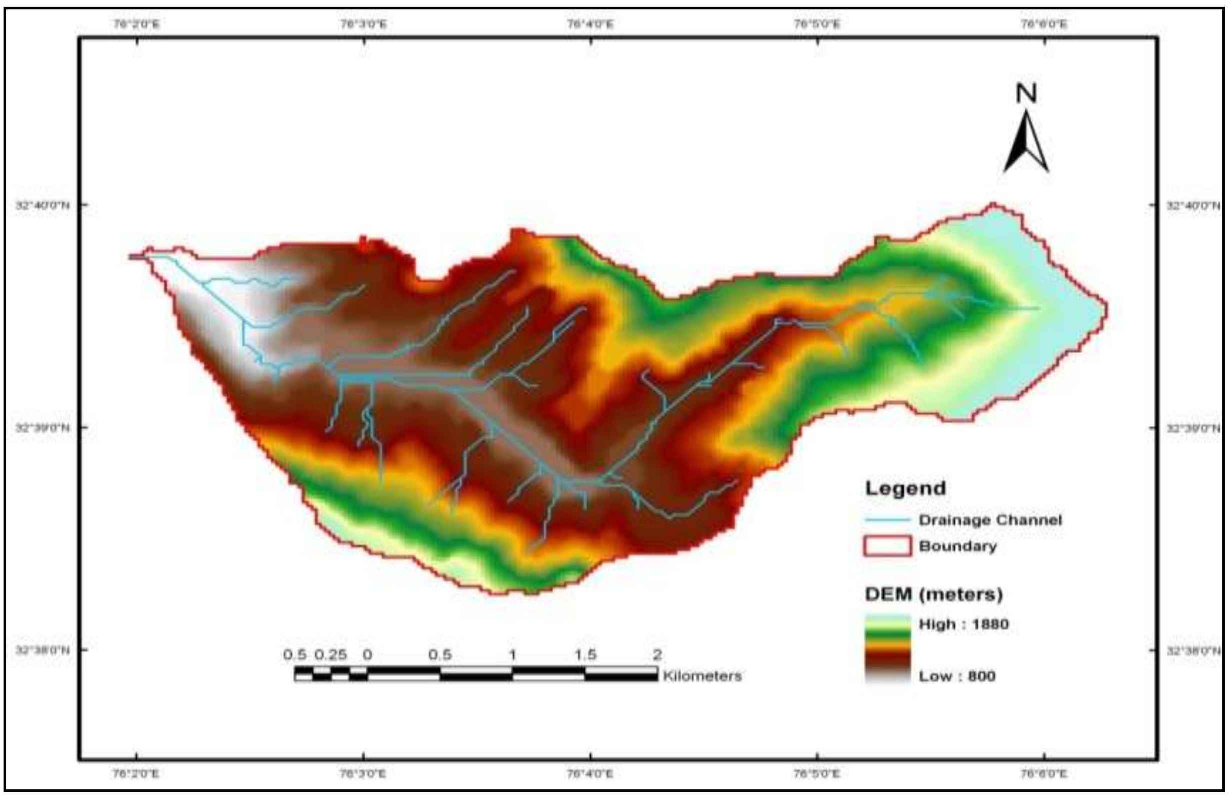

Figure 2: Digital Elevation Model (DEM)

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Soils

The soil map was collected from The Department of Agriculture, Himachal Pradesh. Soils vary in texture, color and depth depending upon the topography and land use. The main soils in the study area are sandy loam, loam and sandy clay loam (Figure 3). And (Table.1) shows the distribution of soil types with their corresponding covered area.

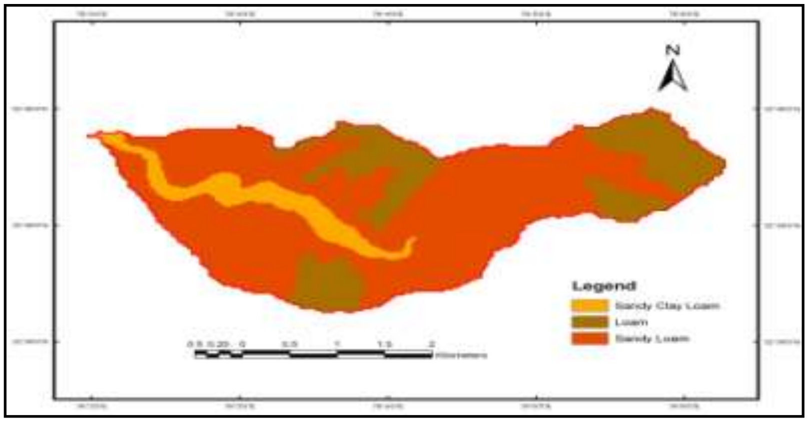

Figure3: Soil Map of the study area

Table1: Distribution of soil types with their corresponding covered area

S. No.	Soil Type	Area (Km^2)	% Area
1	Loam	2.96	24.61
2	Sandy Clay Loam	0.99	8.23
3	Sandy Loam	8.07	67.16

Land use/ Land cover

The dominant land use in the region is forest land and fallow land. The main food crops include maize, wheat vegetables, beans, potatoes. Dairy farming is also practiced together with traditional livestock keeping. The watershed provides water for domestic water supply, agriculture through springs, nallahs etc (Figure 4). And (Table 2) shows the description of land use with their corresponding covered area.

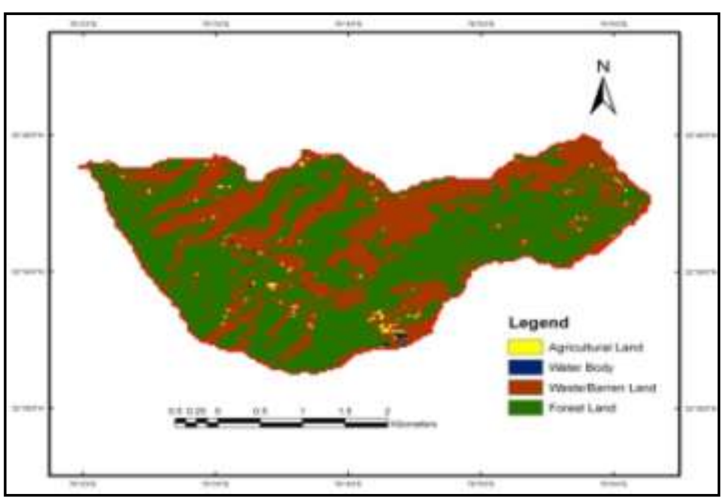

Figure 4: Land Use Map

Table 2: Description of land use with their corresponding covered area

S. No.	Land Use	Area (Km^2)	% Area
1	Agricultural Land	0.10	0.84
2	Water	0.04	0.29
3	Fallow Land	4.51	37.50
4	Forest	7.37	61.37

ArcSWAT Model

The major goal of the ArcSWAT model development is to predict the impact of management measures on water, sediment and agricultural chemical yields in large ungauged basins. The ArcSWAT model simulates the surface runoff using the SCS curve number method (USDA-SCS, 1972). Sediment yield is computed for each sub-basin with the Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977). The model predicts sub-basin nutrient yield and nutrient cycling using EPIC model (Williams *et al.*, 1984). The ArcSWAT model uses a command structure for routing runoff and chemicals through a watershed similar to the structure of HYMO model (Williams and Hann, 1973). The crop model is a simplification of the EPIC crop model (Williams *et al.*, 1984). Crop yield is estimated in the model using the harvest index concept. The ArcSWAT tillage component was designed to incorporate surface residue into the soil. Fertilizer applications can also be scheduled by the user or automatically applied by the model.

Generation of Discharge Using the SWAT Model

The ArcSWAT is a graphical user interface for the SWAT model (Arnold *et al.*, 1998). Basically, ArcSWAT is a long term, physically based, continuous simulation watershed model developed to quantify the impact of land management practices in large, complex catchments. A large number of inputs are required for running the model to obtain modeled discharge. DEM, Landuse/Landcover map and Soil map of the study watershed are three spatial inputs required for the model. Other inputs required for the model are long term weather data, soil properties and discharge data.Finally, the ArcSWAT model required discharge data at representative outlets of the streams for calibration and validation of the model. Discharge data recorded at the outlet of the study watershed during 2002-2004 have been taken for these purposes.

Criteria for Model Evaluation

Haan *et al.*, (1982) suggested that the graphical representation of the result could easily be interpreted if the calibration is done for only one watershed at one stream gauging location. Time series of the recorded and simulated data and a scatter gram of recorded data plotted against simulated data were used in this study. Although scatter gram method does not preserve the flow sequence contained in the time series plots, but the difference between a linear regression line through the plotted points and the equality line of scatter gram helps to identify errors that can be used with these graphical displays. Several statistical techniques provide useful numerical measures of the degree of agreement between the simulated model and recorded quantities. Basically one can compute and display comparison for each item or develop and use summary statistics for a group of items. Selection requires a choice on how to aggregate groups of measured differences in a single statistics. Hydrological models are used most frequently to simulate or predict flow either on a continuous basis or for a particular event. In all cases the model computed flow is compared with the measured flow. The model performance can be evaluated using established indices like (i) coefficient of determination (R2), (ii) Index of agreement (d), (iii) Nash and Sutcliffe efficiency, and (iv) Relative Error (RE).

(i) Coefficient of determination is given by:

$$R^2 = \left\{ \frac{n(\sum Q_{mod} . Q_{obs}) - (\sum Q_{mod}).(Q_{obs})}{\sqrt{[n(Q_{mod}^2) - (\sum Q_{mod})^2].[n(Q_{obs}^2) - (\sum Q_{obs})^2]}} \right\}^2 \quad \ldots\ldots\ldots\ldots\ldots.. \quad (1)$$

R^2 is most often used in linear regression. Given a set of data points, linear regression gives a formula for the line most closely matching those points. It also gives an R-Squared value to say how well the resulting line matches the original data points. The value of R^2 ranges from 0 to 1, a value between 0.6 to 1.0 indicates a good correlation.

(ii) Index of agreement is given by:

$$d = 1.0 - \left[\frac{\sum_{i=1}^{n}(Q_{mod} - Q_{obs})^2}{\sum_{i=1}^{n}\left[|Q_{mod} - Q_{avg}| + |Q_{obs} - Q_{avg}|\right]^2}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

The value of d ranges from 0 to 1.0, nearer the value is to 1.0 better is the flow prediction.

(iii) Nash and Sutcliffe model performance coefficient is given by:

$$NR = 1.0 - \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{mod})^2}{\sum_{i=1}^{n}(Q_{obs} - Q_{avg})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The value of Nash and Sutcliffe model coefficient ranges from 0 to 1.0 and higher is the value better is the model prediction output.

(iv) Relative Error:

$$RE = \frac{\sum_{i=1}^{n} Q_{mod} - \sum_{i=1}^{n} Q_{obs}}{\sum_{i=1}^{n} Q_{obs}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The range of RE is -1 to α, and zero is the perfect match. When the RE value near 0 the prediction of the model is more acceptable.

where, Q_{mod} is Model discharge,
Q_{obs} is observed discharge,
Q_{avg} is average value of observed discharge, n is numbers of data being considered.

Model Calibration

Model calibration is the modification or adjustment of model parameters, within recommended ranges, to optimize the model output so that it matches with the observed set of data. The calibration tool of ArcSWAT provided several different parameters for adjustment through user intervention. These parameters can be adjusted manually or automatically until the model output best matches with the observed data. The discharge data recorded during the years 2002 and 2003 were used for the calibration of the model. The model calibration was done manually by changing the various ArcSWAT parameters one by one until the simulated model output matches the observed discharge data.

Sensitivity Analysis

Sensitivity analysis is the determination of the most influential independent parameter of the model in predicting the flow. The ArcSWAT model has various inbuilt parameters affecting the flow with a prescribed range of value. The process involves varying the various values of parameter of model to see the effect on the output value.

The analysis was done based on the hydrological simulation at the catchment outlet by varying the various parameters one by one and comparing the percentage deviation in the flow simulated. This helps the ArcSWAT user in calibrating the model and choosing the right and minimum parameter for calibration. The sensitivity of parameters varies from basin to basin due to physical properties, landuse, and different climatic conditions.

Validation of the Model

Proper validation of the calibrated model is essential to understand its performance without change in input files except climatic parameters. After proper calibration, the model was validated for daily runoff. Model validation for daily runoff was performed using the data of year 2004.

RESULTS AND DISCUSSION

Model Calibration and Validation

Model Calibration

Model calibration was performed for the year 2002-2003 (Figure 5) and graphically compared the model output with observed discharge data recorded during these years. It is observed that the model discharge closely matched the observed discharge consistently in both the calibrated years. The calibration was done with the average daily discharge in a month for the whole year.

The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown for the calibrated years 2002 and 2003. The coefficient of correlation (R^2) is 0.9385 and which shows a close relationship between the observed and simulated discharge.

Further, the efficiency of the model for simulating the runoff was also tested using established index (Table 3). It is observed from the overall standard deviation and mean that the model over predict during the years 2002 and 2003. A high value of Nash–Sutcliffe efficiency and index of agreement shows that there is a good relationship between the model and observed discharge during the calibration. The linear correlation of coefficient of the observed and simulation mean monthly discharge in scatter plot is shown in Figure 6.

Table 3: Statistical analysis of model and observed monthly discharge during calibration

Parameters	Discharge	
	Model	Observed
Mean	0.0112	0.0098
Standard Deviation	0.0087	0.0082
Maximum	0.0303	0.0285
Total	0.2690	0.2344
Coefficient of correlation (R^2)	0.9385	
Nash-Sutcliffe efficiency (NSE)	0.8958	
d	0.9755	
RE	0.1477	

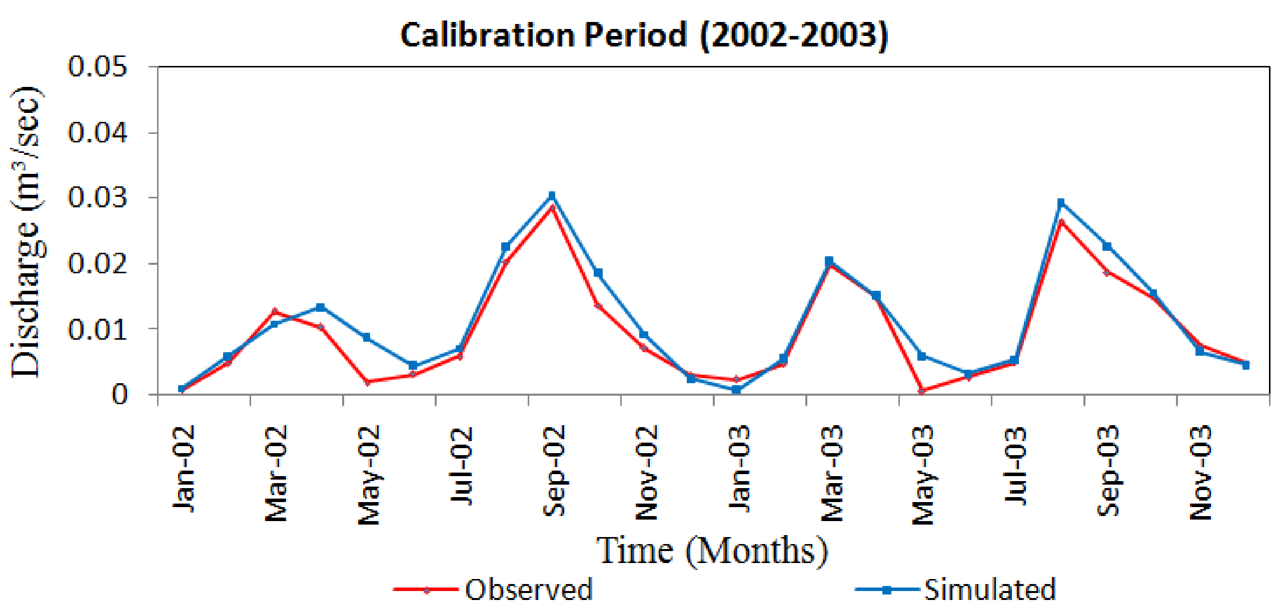

Figure 5: Mean monthly simulated and observed discharges in Barinallah watershed for calibration period

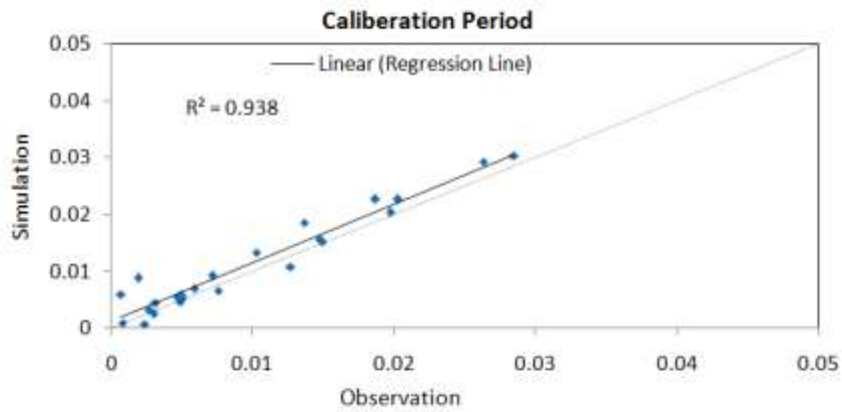

Figure 6: Scatter plot of monthly simulated and observed discharge during the calibration

Model Validation

Validation of a model is required to evaluate the performance of the model and is achieved by running the model without changing any parameter and with a different set of input data. Calibrated model was validated using the discharge data recorded. For this purpose the model was continuously run from 2000 to 2004 and for evaluation, results of 2002 to 2004 were used as the observed discharge data is available for these years. The validation was tested for the year of 2004 and also for the combined period of three years (2002 to 2004). Model validation was performed for the year 2004 (Figure7) and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown. The model slightly over predicted the high value of discharge (Figure 8). The coefficient of correlation (R^2) is 0.9361 shows a close relationship between the observed and simulated discharge.

Further, the efficiency of the model for simulating the runoff was also tested using the efficiency index (Table.4). A few high value of discharge during the monsoon were slightly over predicted. The value of Nash-Sutcliffe value (0.8229), index of agreement‘d’ (0.9600) and a lower value of relative error ‘RE’ (0.2589) indicates that there is a good relationship between the observed and simulated discharge during the validation. (Figure 7) describes the scatter plot of monthly simulated and observed discharge during the validation period.

Table 4: Statistical analysis of model and observed monthly discharge, 2004

Parameters	**Discharge**	
	Model	**Observed**
Mean	0.0141	0.0112
Standard Deviation	0.0104	0.0096
Maximum	0.0400	0.0345
Total	0.1693	0.1345
Coefficient of correlation (R2)	0.9361	
Nash-Sutcliffe efficiency (NSE)	0.8229	
d	0.9600	
RE	0.2589	

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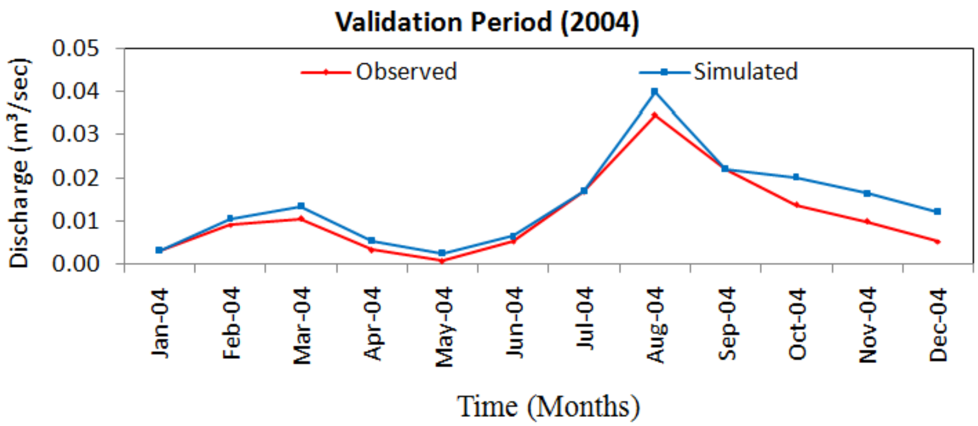

Figure 7: Mean monthly simulated and observed discharges in Barinallah Watershed for validation period

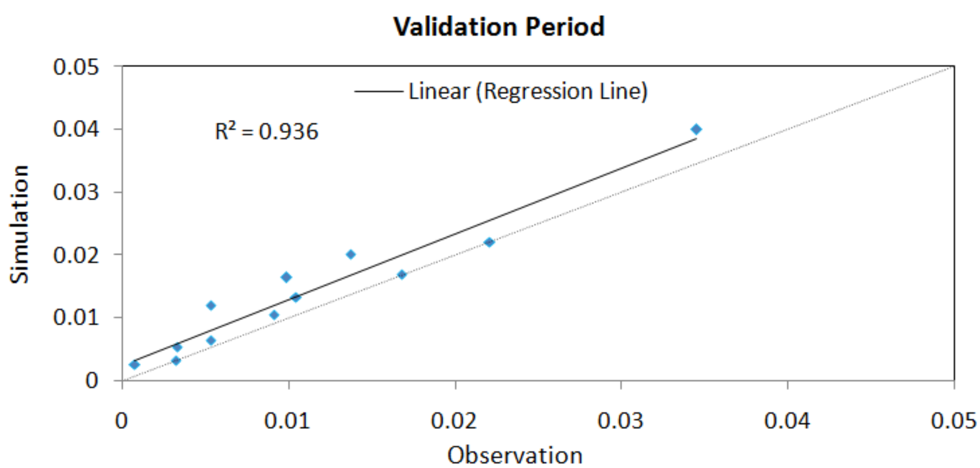

Figure 8: Scatter plot of monthly simulated and observed discharge during the validation

The high R^2 and NSE in the calibration and validation suggest that the calibrated model can describe the stream flow of the watershed. Thus we can be confident the calibrated model with set of optimized parameters can be applied to examine the hydrological responses of the basin under the land-cover change and climate change scenario.

Validation with Discharge Data of 2002 to 2004 Combined

The performance of the model was checked by statistical analysis (Table. 5). Model validation was performed for the year 2002-2004 (Figure 9) and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. A regression analysis was performed between the observed and simulated discharge and the best fit line is also shown (Figure10).

0It is observed that the model discharge data are distributed uniformly along the 1:1 line. The efficiency of the model for simulating the runoff was also tested using the efficiency index (Table. 5). A high value of coefficient of determination (0.9337) indicates a close relationship between the observed and model discharge data exist. A close relationship between the means and standard deviation of the observed and model data shows that the frequency distribution is similar. The value of Nash-Sutcliffe value (0.8424), index of agreement'd' (0.9636) and a lower value of relative error 'RE' (0.1882) indicates that there is a good relationship between the observed and simulated discharge during the calibration and validation period.

Table 5: Statistical analysis of model and observed monthly discharge, 2002-2004

Parameters	**Discharge**	
	Model	**Observed**
Mean	0.0122	0.0103
Standard Deviation	0.0093	0.0086
Maximum	0.0400	0.0345
Total	0.4383	0.3689
Coefficient of correlation (R2)	0.9337	
Nash-Sutcliffe efficiency (NSE)	0.8676	
Index of agreement 'd'	0.9695	
Relative Error 'RE'	0.1882	

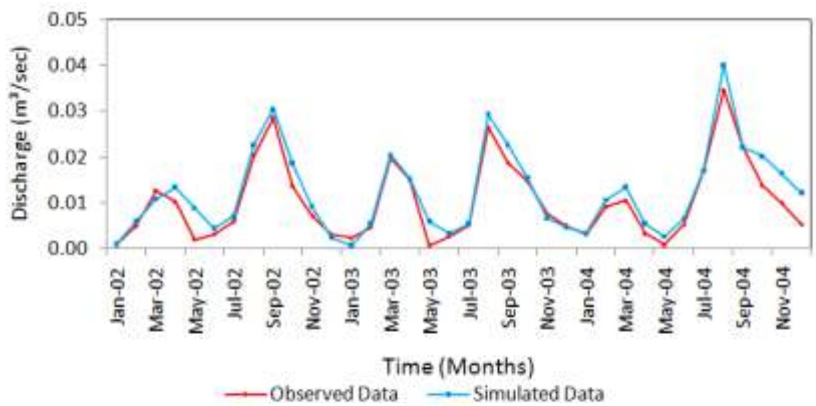

Figure 9: Mean monthly simulated and observed discharges in Barinallah watershed for calibration and validation period

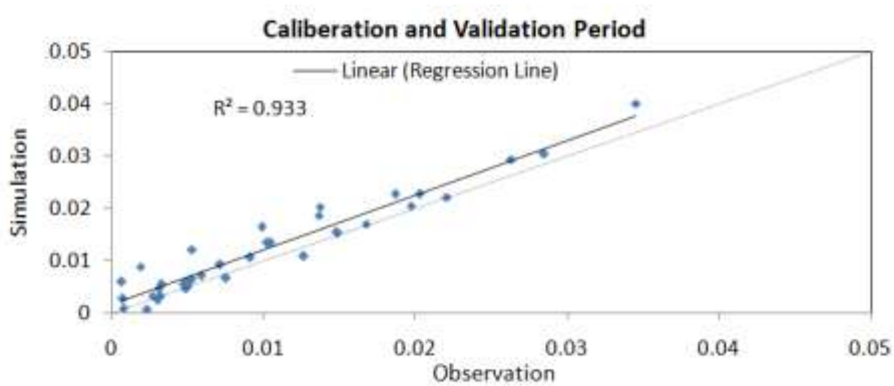

Figure 10: Scatter plot of monthly simulated and observed discharge during calibration and validation

Sensitivity Analysis

The sensitivity analysis in ArcSWAT of different parameters was carried out to know how different parameters of ArcSWAT influence the model output. The analysis was done, based on the hydrological simulation at the catchment outlet by varying the various parameters one by one and comparing the deviation in the flow simulated.

Sensitivity analysis was carried out using those model parameters which were used for calibration of the watershed within their recommended range. The calibrated value of each parameter is selected as the base value for the sensitivity analysis. The base value of the each parameter is varied by replacing the values of the parameters within their recommended range.

The parameters considered for sensitivity analysis are: Threshold depth of water in shallow aquifer required for return flow to occur (Gwqmn), Soil evaporation compensation factor (Esco), Channel effective hydraulic conductivity, Ch_K_2, Base flow recession alpha (Alpha_Bf), Manning's coefficient 'n' for channel (Ch_N2). The various parameters and their range considered for sensitivity analysis are present in table (Table.6).

Table 6: Input parameter for sensitivity analysis for Barinallah watershein in ArcSWAT

S. No.	Parameters	Short form	Range
1	Threshold depth of water in shallow aquifer required for return flow to occur	Gwqmn	0 - 5000
2	Soil evaporation compensation factor	Esco	0.01 - 1
3	Channel effective hydraulic conductivity	Ch_K_2	0 - 150
4	Base flow recession alpha	Alpha_Bf	0 - 1
5	Manning’s coefficient ‘n’ for channel	Ch_N_2	0 - 1

Conclusion

Based on the present study the following conclusions can be drawn:

1) Satellite image was regenerated into land use map for the region using supervised classification algorithm. The land use in the region is predominantly covered by forest (61.37%) followed by fallow land (37.50%), agricultural land (0.84%) and water bodies (0.29%) out of the total area of 12.02 km^2.
2) Average monthly discharge data for three years (2002, 2003 and 2004) was calibrated and validated using ArcSWAT model. It is observed from the overall standard deviation and mean that the model over predict during the year 2002-2003. A high value of Nash–Sutcliffe efficiency and index of agreement shows that there is a good relationship between the model and observed discharge during the calibration.
3) Model validation was performed for the year 2004 and graphically compared the model output with observed discharge data recorded. It is observed that the model discharge closely matched the observed discharge consistently. The regression analysis was performed between the observed and simulated discharge and the best fit line is also shown. The model slightly over predicted the high value of discharge. The coefficient of correlation (R^2) is 0.9361 showing a close relationship between the observed and simulated discharge.
4) The efficiency of the model for simulating the runoff was also tested using the efficiency index in the study. A few high value of discharge during the monsoon were slightly over predicted. The value of Nash-Sutcliffe value (0.8229), index of agreement‘d’(0.9600) and a lower value of relative error ‘RE’ (0.2589) indicates that there is a good relationship between the observed and simulated discharge during the validation.

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