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Research Article

Hydrological Modelling of Banjar River Watershed using HEC-HMS

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Abstract

In this study, Hydrologic Engineering Centre's Hydrologic Modeling System (HEC-HMS) is employed to simulate rainfall runoff process in Banjar river watershed situated in between Mandla and Balaghat district of Madhya Pradesh, India. The CartoDEM is used as input elevation to generate the sub-watersheds and river characteristics. The rainfall – runoff process is represented by the Soil Conservation Service Curve Number (SCS-CN) method. The performance of the model is assessed using performance evaluation indicators such as Nash-Sutcliffe efficiency (NSE), Percentage Error in Peak and Coefficient of Determination (R^2). During calibration the values of NSE, PEP and R^2 obtained are 0.792, 4.96% and 0.849, and 0.751, 10.51% and 0.809 for validation period, respectively. The results suggest that HEC-HMS can be utilized for the hydrological modelling of the basin that will be helpful for various soil and water conservative practices.

Keywords: HEC-HMS, Hydrologic modeling, Rainfall-Runoff simulation, Banjar Basin, SCS-CN

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Introduction

Soil and water are the two most important natural resources which are essential for agricultural production. The production of crops is affected by the appropriate use and management of these resources [1]. Due to rapid increase in urbanization, industrial growth, deforestation, climate change, the availability of water resources for the production of agricultural crops and their needs has become very limited [2, 3]. To solve the problem of water scarcity attention is needed on proper utilization and management of water resources [4]. Lack of land use planning and management practices has adversely affected the surface runoff generation and production of agriculture. In developmental action plans, accurate measurement and quantification of the river or channel flow generated by the respective basins is important for soil and water infrastructure design [5].

The understanding of hydrological phenomena such as variations in runoff with changes in climatic, geographic or physical factors are needed for the design of soil and water conservation structures [6]. It is desirable to estimate the stream flows with respect of time of occurrence and magnitude for while designing and planning soil and water conservation structures. The use of hydrological modelling becomes apparent for an ungagged and/or data scares regions [7].

There are several hydrological models available such as Soil and Water Assessment Tool, Hydrologiska Byrans Vattenavdelning model, Variable Infiltration Capacity model, etc. [8]. However, Hydrologic Engineering Centre's Hydrologic Modeling System (HEC-HMS) is found to be easy to use and can be used in data scares region [9, 10]. A number of studies were carried out by researchers using HEC-HMS model that prove its ability to simulate and predict streamflow from the basin. For example, a study conducted by [11] used HEC-HMS model to simulate rainfall runoff process in Abnama watershed in south of Iran and found that after calibration of lag time parameter, the model can be used to perform hydrologic simulation. [12] Perform hydrological modelling using HEC-HMS for flood forecasting in two subbasins with different slope and land use, in Iran. [13] used HEC-HMS and IHACRES model in an arid basin of Jordan for simulation of a single stream flow to develop framework for rainfall runoff application. The HEC-HMS model outperformed the IHACRES model. There are several studies that use the HEC-HMS for hydrological modelling and found to be performing well [14, 15, 16, 17, 18 and 19].

In this study we attempt to simulate the rainfall-runoff process using HEC-HMS hydrological model in Banjar river watershed where various watershed development and management activities are being proposed. The study will be useful to provide information to the decision makers for sustainable planning and management policies related to soil and water conservation measures and infrastructure development projects.

Study Area

The present study is being carried out in the Banjar river watershed. The Banjar River originate in Mandla district, Madhya Pradesh, India. Most of the watershed lies in Balaghat district with some part under the Mandla district of

Madhya Pradesh. Banjar River is one of the main tributary of the Narmada River. Geographically the watershed is located in between $22^0$05'N to $23^0$29'N latitudes and between $80^0$22'E to $81^0$00'E longitudes. It covers a total geographical area of around 2461 sq. km, with an elevation range of 384 to 848 m above mean sea level. The average slope of the study area is relatively flat. The normal annual rainfall of the watershed is 1400 mm. The soils of the watershed are clayey and loamy. The location of the study area is shown in **Figure 1**.

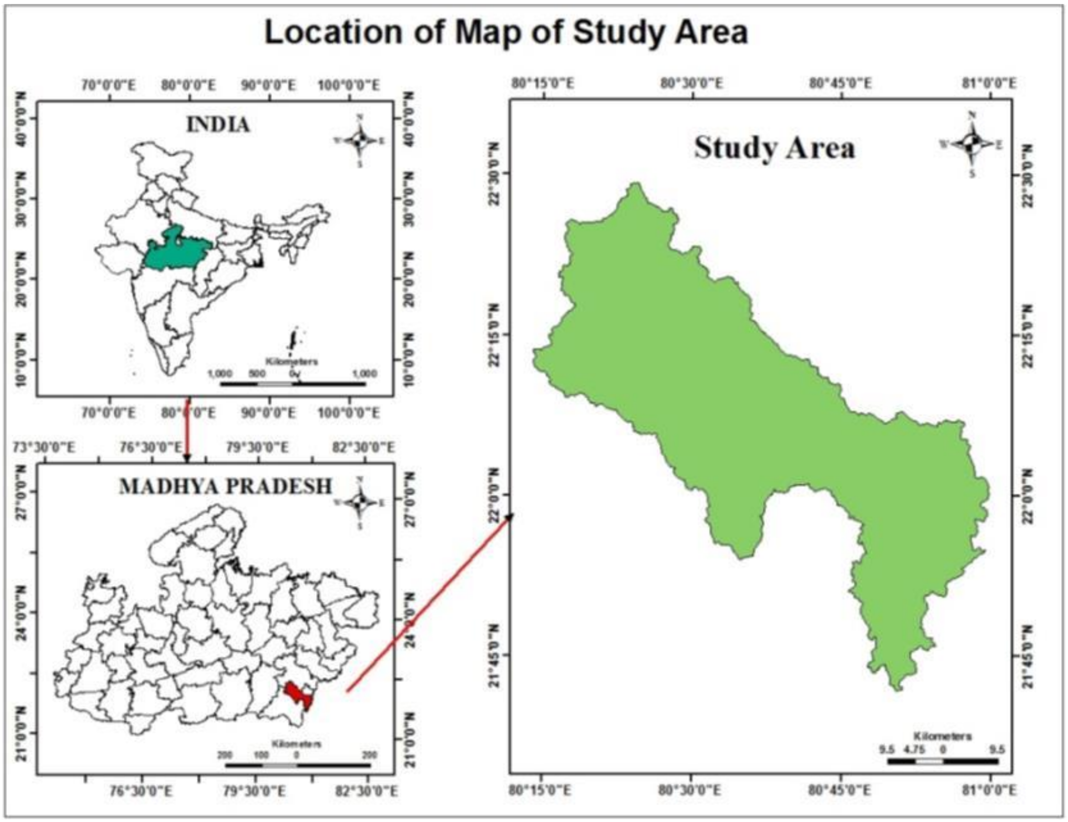

Figure 1 Location Map of Study Area

Data Availability

The following data is collected from various sources for the hydrological modelling of the watershed.

Terrain Data

Digital Elevation Model (DEM) is a digital representation of a topography surface. The CartoDEM of the study area is obtained from Indian Geo-Platform Bhuvan (https://bhuvan.nrsc.gov.in/bhuvan_links.php). Four tiles were downloaded and then mosaic together. The data was obtained in Tagged Image file (.tif) format with a spatial resolution of 30 m.

Rainfall Data

The daily rainfall data is obtained from India Meteorological Department (IMD) website (http://imdpune.gov.in/Clim_Pred_LRF_New/Grided_Data_Download.html). The spatial resolution of data was 0.25^0x0.25^0. The rainfall data is extracted for the study are that covered six grid points.

Discharge Data

Daily discharge data of stream gauging station at outlet Bamhani banjar of the watershed is collected from central water commission (CWC).

Soil Data

The soil map was constructed in GIS environment in form of vector layer using sheet no. 5 of the soil map generated by National Bureau of Soil Survey and Land Use Planning (NBSSLUP) at a scale 1:500000. Soil map is further classified into A, B, C and D hydrologic soil groups (HSGs) as per infiltration rate based on [20]. Soil group with HSG of B and D are available that have the properties of low infiltration rate and more runoff. The soil map of the study area is shown in **Figure 2**. In most part of the study area, surface soil is loamy and the subsurface soil is sandy clay loam except in alluvial deposits that have relatively heavy texture of clay.

Land Use/Land Cover (LULC)

Landsat 8 satellite image with a spatial resolution of 30 m is used to make LULC map. The imagery was classified using unsupervised classification. The validation is performed using high resolution imagery from Google Earth. The LULC map of the study area is shown in **Figure 3**.

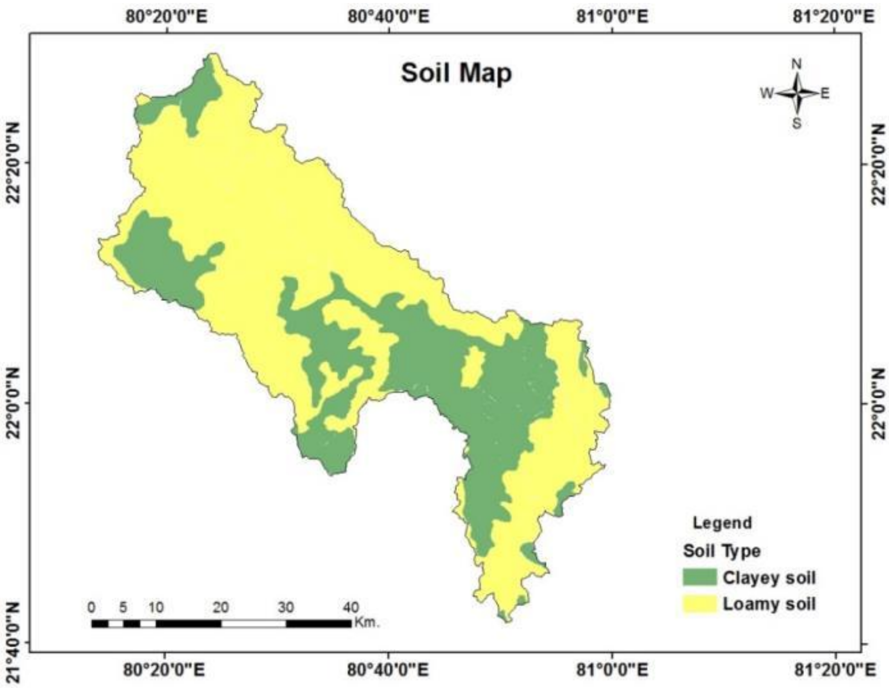

Figure 2 Soil Map of Study Area

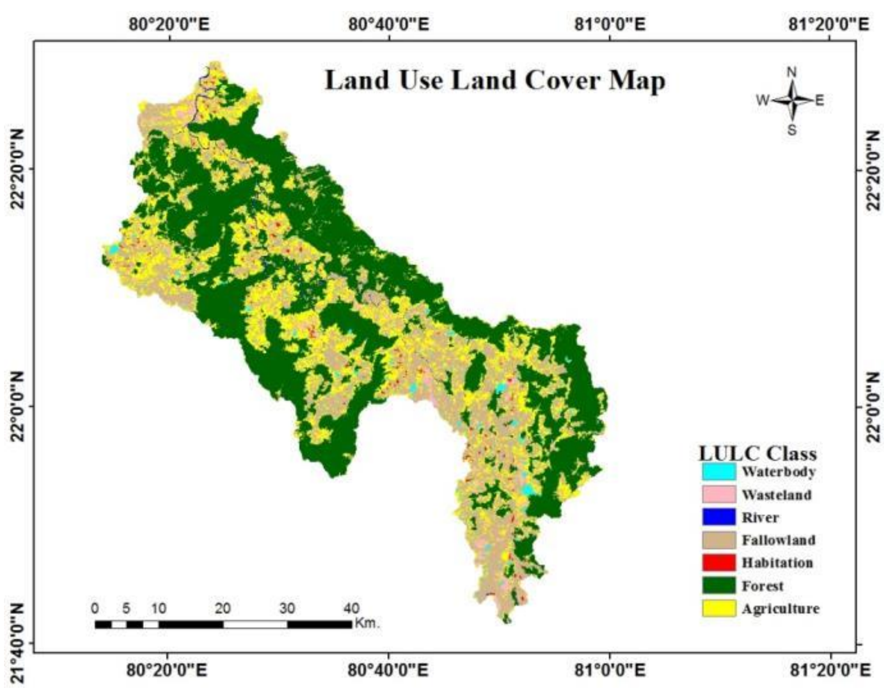

Figure 3 LULC Map of Study Area

Model Description

HEC-HMS is a physics based, semi-distributed hydrological model that simulates the hydrological processes of watershed systems in a wide range of geographic areas such as large river basins and small urban or natural watersheds. HEC-HMS is developed by the US Army Corps of Engineers, Hydrologic Engineering Center (HEC). The software used for the present study is HEC-HMS (v4.6.1) and was downloaded from the USACE website (https://www.hec.usace.army.mil/software/hec-hms/downloads.aspx). The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is an extension and integrating tool between HEC-HMS and GIS. HEC-GeoHMS uses ArcGIS and the Spatial Analyst extension tool to process geospatial data and develop hydrologic modeling inputs for HEC-HMS model.

Methodology

The overall methodology is represented in the **Figure 4**. The CartoDEM is processed using HEC-GeoHMS to generate sub-watersheds and channel characteristics. The curve number is generated using based on the LULC and the HSG provided by the Natural Resources Conservation Service [20]. The curve number grid is shown in **Figure 5**. The loss method used is Soil Conservation Service Curve Number (SCS-CN), the transform method is Soil Conservation Service Unit Hydrograph, and channel routing method is Muskingum-Cunge.

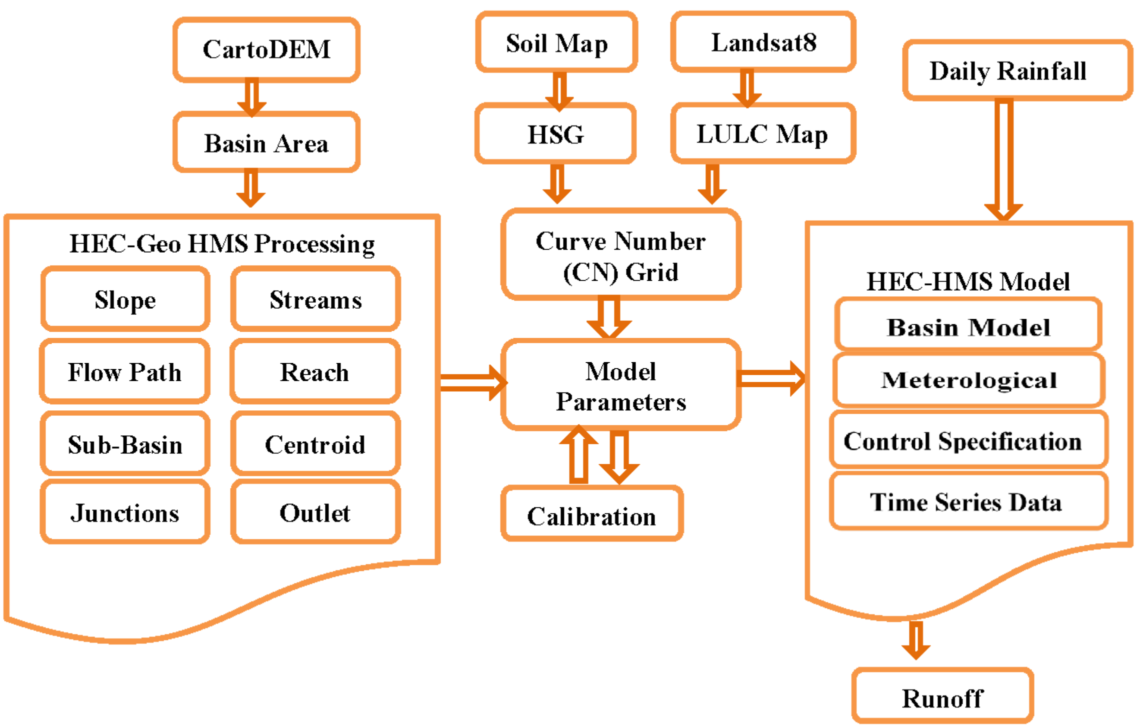

Figure 4 Flow Chart of Methodology

The HEC-HMS model includes four basic components, i.e., the basin models, meteorological models, control simulations and input data. The basin model stores the physical datasets describing the catchment properties and the meteorological model includes precipitation, evapotranspiration, and snowmelt data. The time span of a simulation is controlled by control specifications including a starting date and time, ending date and time, and computation time step. Input data stores boundary and parameter conditions for basin and meteorological models.

Loss Method

The SCS-CN method accounts for most of the runoff-producing watershed characteristics, such as soil type, land use, hydrologic soil group, and antecedent moisture condition [13, 19 and 21].

The formula for calculating loss through the SCS-CN method is

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \qquad (1)$$

Where Q is the runoff value (mm), P is the precipitation (mm), I_a is the initial abstraction (mm), S is the potential maximum retention.

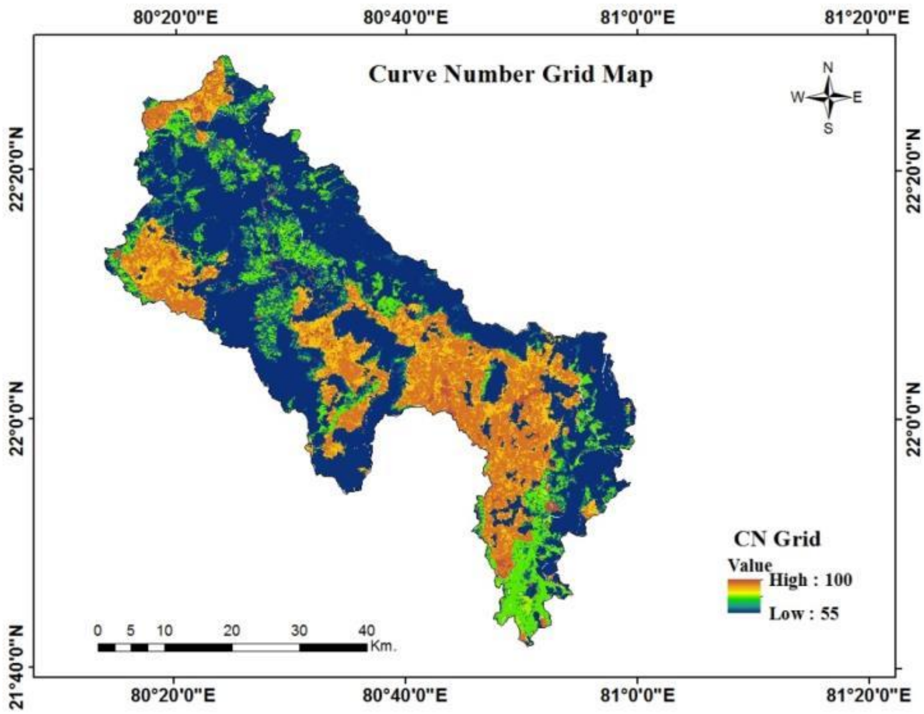

Figure 5 Curve number map

The potential maximum retention (S) is a measurement of the capacity of a catchment to abstract and retain storm precipitation. There will be no precipitation excess until the accumulated rainfall exceeds the initial abstraction. As shown in equation (2)

$$I_a = 0.2S \quad (2)$$

Therefore, the cumulative excess at time t is given as

$$Q = \frac{(P-0.2S)2}{P+0.8S} \quad (3)$$

Soil retention is calculated using CN values with the formula as

$$S = \frac{25400-254CN}{CN} \quad (4)$$

CN = SCS curve number for the watershed.

In this study the values of CN can be obtained for different land uses, treatment, and hydrologic conditions from the standard table are found in the Technical Release Number 55 (TR-55) [20]. The CN values vary from 100 to 55. The value of 100 is assumed for water bodies and 55 for permeable soils of moderate infiltration rates.

Model Calibration and Validation

Model calibration is a systematic process and is performed to obtain the best fit between model calculations and observed data by adjusting or changing the selected parameters in the model [22]. These calibration parameters were estimated using a trial and error method in the HEC-HMS model until an appropriate match was obtained between observed and simulated daily flow data at the gauging station. The next step after the model setup and calibration is the validation of the model. The process of comparing the model to the real system is validation. Validation is achieved without any additional adjustment to the model parameters by running the model using data covering an alternative period. In this study only one extreme event September 2005 and was selected for model calibration and other extreme event August 2014 were used for validation.

Model performance evaluations

The HEC-HMS model performance evaluation involved assessing the goodness of fit between the observed and simulated stream flow using through visual examination of the simulated and observed hydrograph, and through statistical indicators such as Nash and Sutcliffe efficiency (NSE), Coefficient of determination (R^2), Percent error peak flow (PEPF) and Root mean square error (RMSE). The values of NSE, R^2, and PEPF were calculated using the following equations

1. The percentage Error in Peak Flow (PEPF).

$$PEPF = \left| \frac{Q_{O(Peak)} - Q_{S(Peak)}}{Q_{O(Peak)}} \right| \times 100$$

Where $Q_{O(Peak)}$, $Q_{S(Peak)}$ are the observed and simulated flows, respectively.

2. The Coefficient of correlation (R^2).

$$R^2 = \left(\frac{\sum(Q_{obs} - \overline{Q_{obs}})^2 - \sum(Q_{sim} - \overline{Q_{sim}})^2}{\sum(Q_{obs} - \overline{Q_{obs}})^2} \right)$$

R^2 is indicates how the simulated data correlates to the observed values of data. The range of R^2 is extends from 0 (Unacceptable) to 1(best)

3. Nash-Sutcliffe efficiencies (NSE) [23].

$$NSE = 1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \overline{Q_{obs}})} * 100$$

Nash-Sutcliffe efficiencies can range from -∞ to 1.
Where: Q_{obs} = observed discharge, Q_{sim} = simulated discharge, $\overline{Q_{obs}}$ = mean of observed discharge, $\overline{Q_{sim}}$ = mean of simulated discharge.

To interpret the results, general performance ratings shown in **Table 1** were used as a guide [24, 25, 26 and 27]

Table 1 Performance indicator for various evaluation criteria

Performance Rating	PEPF (%)	R^2	NSE
Very good	<15	0.75 to 1	0.75 to 1
Good	15 to 30	0.65 to 0.75	0.65 to 0.75
Satisfactory	30 to 40	0.50 to 0.65	0.50 to 0.65
Unsatisfactory	>40	<0.50	<0.50

Results and Discussion

The HEC-HMS rainfall-runoff model for the Banjar river watershed is shown in **Figure 6**. The Banjar river watershed is divided into 57 sub-watersheds.

Calibration and Validation

The model is calibrated in order to determine the best fit between the model and observation. HEC-HMS has a trail optimization function that can be used to match the simulated flow with observed flow. The HEC-HMS model is calibrated and validated using two different events of 2005 (September) and 2014 (August) in the Banjar river watershed respectively, as shown in **Figure 7-8**.

From the results of the calibration run on event dated 15th September 2005, the computed peak discharge was 1528.1 m^3/s lower than the observed peak discharge of 1455.9 m^3/s, with an acceptable percent error of peak flow 4.96 %. In terms of model efficiency, the NSE was 0.792, which means there was an acceptable agreement produced by the rainfall-runoff model.

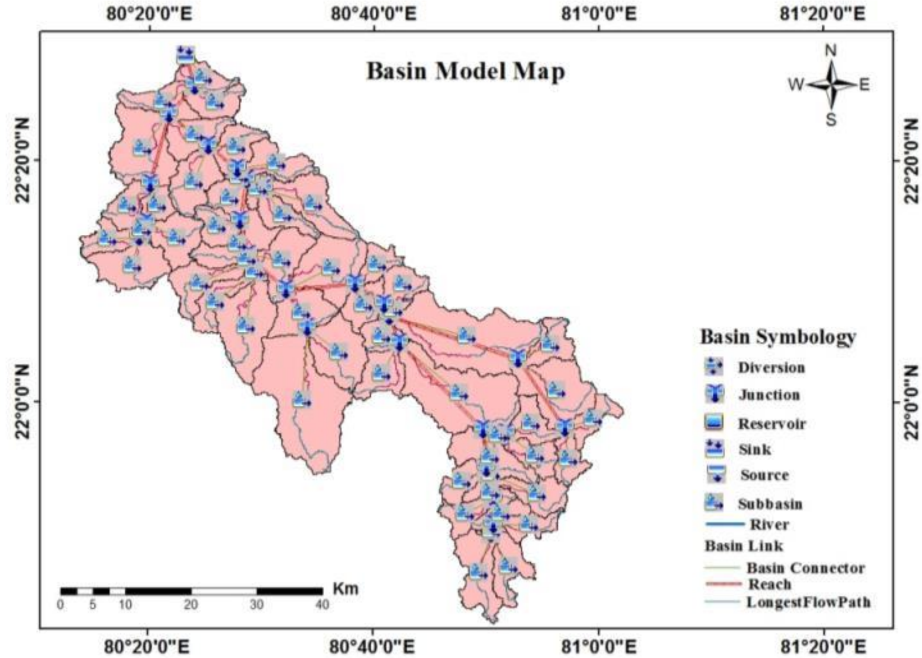

Figure 6 Basin Model Map of Study Area

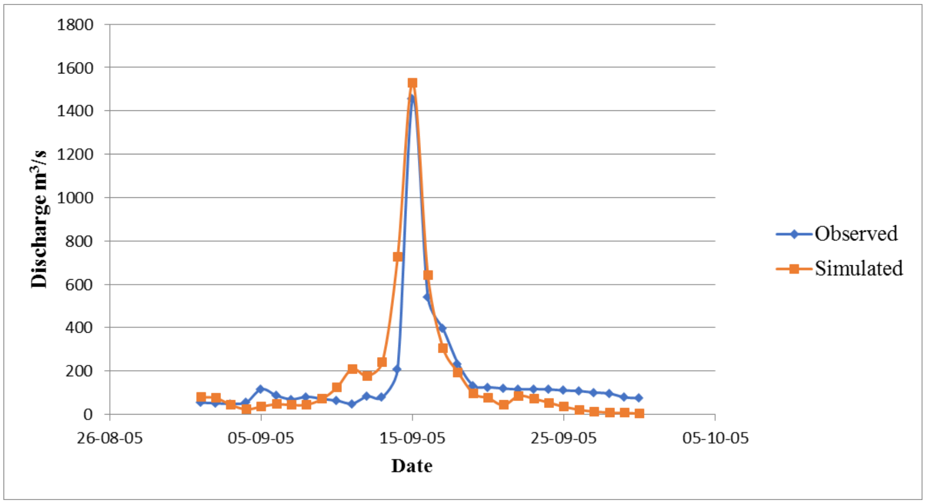

Figure 7 (a) Observed and Simulated discharge for the calibration period

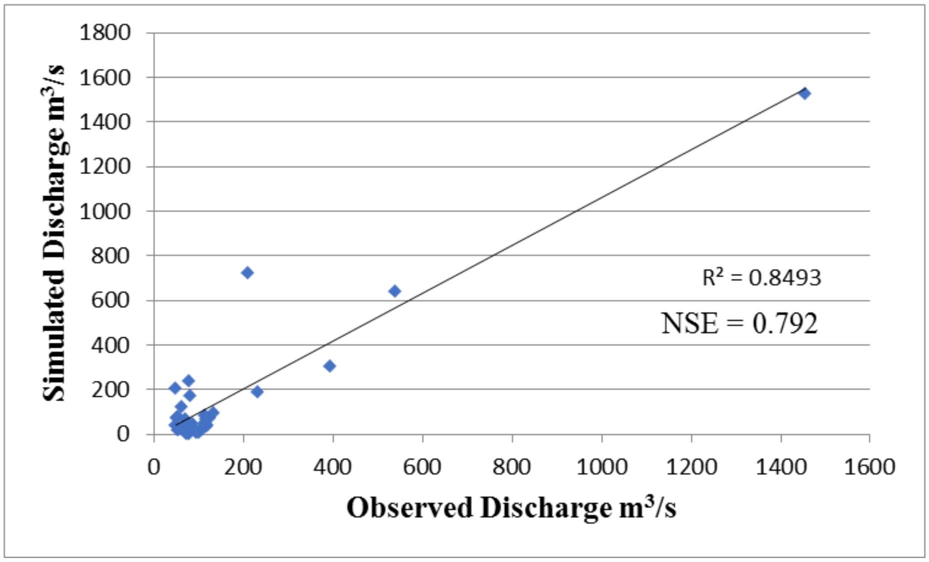

Figure 7 (b) Scatter plots of observed discharge versus simulated discharge for the calibration period

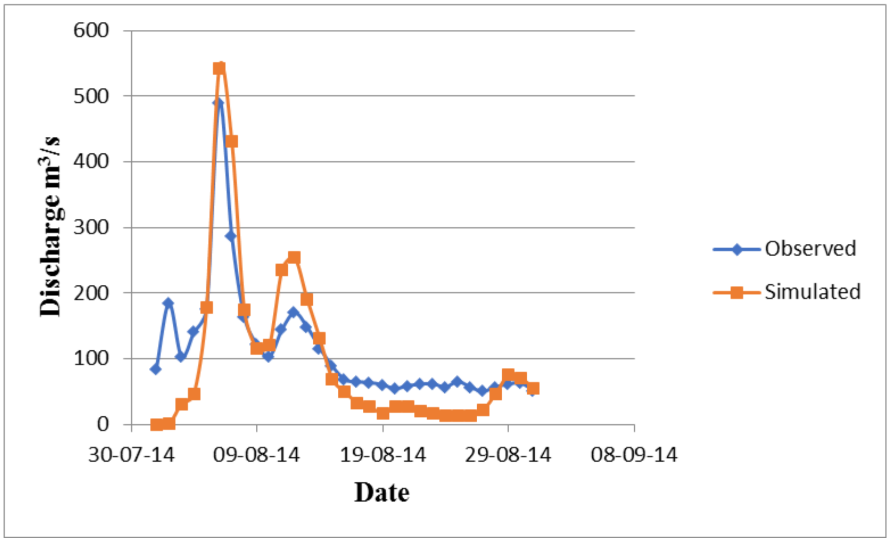

Figure 8 (a) Observed and Simulated discharge for the validation period

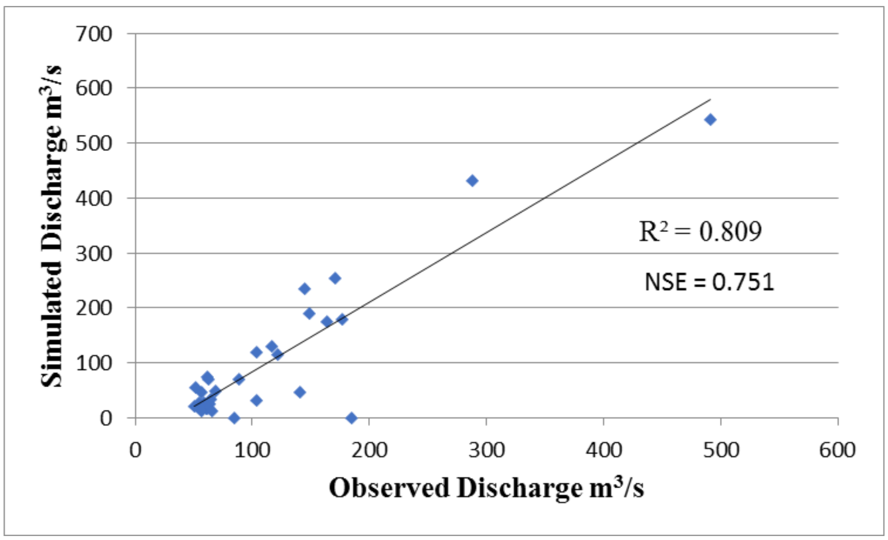

Figure 8 (b) Scatter plots of observed discharge versus simulated discharge for the validation period.

Table 2 shows the percent error peak (PEPF), the coefficient of determination (R^2), and the Nash-Sutcliffe efficiency (NSE) for calibration events. It indicates a close relationship between the observed and simulated flow and the model performance is very good. Once the calibration was completed, then the calibrated final parameters were taken as input in the selected other events of August 2014 for the model validation.

The validated results of 2014 events are as shown in Figure 8. The coefficient of determination (R^2), the percent error peak flow (PEPF), and Nash Sutcliffe efficiency (NSE) values are obtained as 0.809, 10.51% and 0.751 respectively for 2014 event. This is resulted closely and good correlation between the observed and simulated flow.

Table 2 Model performance statistics during calibration and validation period

Period	**Objective function**		
	PEPF (%)	**NSE**	**R^2**
Calibration	4.96	0.792	0.849
Validation	10.51	0.751	0.809

Conclusion

In the present study, hydrological modelling of Banjar river watershed is carried out using HEC-HMS. The SCS-CN is used to represent loss method, the transform method is Soil Conservation Service Unit Hydrograph, and Muskingum-Cunge as channel routing method. The model is evaluated using Nash-Sutcliffe efficiency, coefficient of determination and percentage error in peak flow. Daily timescale calibration and validation results over the study area show good performance with NSE, R^2 and PEPF (%) 0.792, 0.849 and 4.96% respectively for calibration and 0.751, 0.809 and 10.51% respectively for validation. The developed hydrologic model is found to be a good fit for the basin. The calibrated model is very much useful for better planning and management practices of water resources in the study area or for the basin having similar characteristics. In future, the simulation can be done for other rainfall events.

Acknowledgment

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