

## Original Research Article

# **Hydrological Modelling of Hathmati River Watershed using HEC-HMS, Remote Sensing and Geographical Information System in Middle Gujarat, India**

### **Abstract**

Assessment of impact of climate change on water resources in river basin requires a proper estimation of availability of water and that can only be achieved by hydrological modelling of the basin. However, Hydrological modelling is a difficult task, and hydrologic models should be accurately calibrated to boost user confidence in their capacity to forecast outcomes and enable effective model application. Careful management of water resources becomes more crucial. In this investigation, the Hydrologic Modelling System (HEC-HMS) of the Hydrologic Engineering Centre is used to simulate the rainfall runoff process in the sub watershed of Hathmati river that flows into the Sabarmati situated in Sabarkantha district of Gujarat, India. The SrtmDEM 30m resolution is used as input elevation in order to produce the sub-watersheds and river characteristics. The model is calibrated using two rainfall-runoff events, and verified for the remaining third events. Two techniques, such as the Clark unit hydrograph approach and the Soil Conservation Service Curve Number (SCS-CN), are used to describe the rainfall-runoff process. Performance evaluation metrics including Nash-Sutcliffe efficiency (NSE), the Percent Bias (PBIAS), and Coefficient of Determination ( $R^2$ ) are used to evaluate the model's performance. During calibration the values of NSE, PBIAS and  $R^2$  obtained are 0.881, 9.76% and 0.913, and 0.0914, 14.8% and 0.947 for validation period, respectively. The findings imply that HEC-HMS may be used for the hydrological modelling of the basin, which will be useful for a variety of water and soil conservation measures.

**Keywords:** HEC-HMS, Hydrologic modelling, Rainfall-Runoff simulation, Events, Hathmati River, Gujarat.

### **INTRODUCTION**

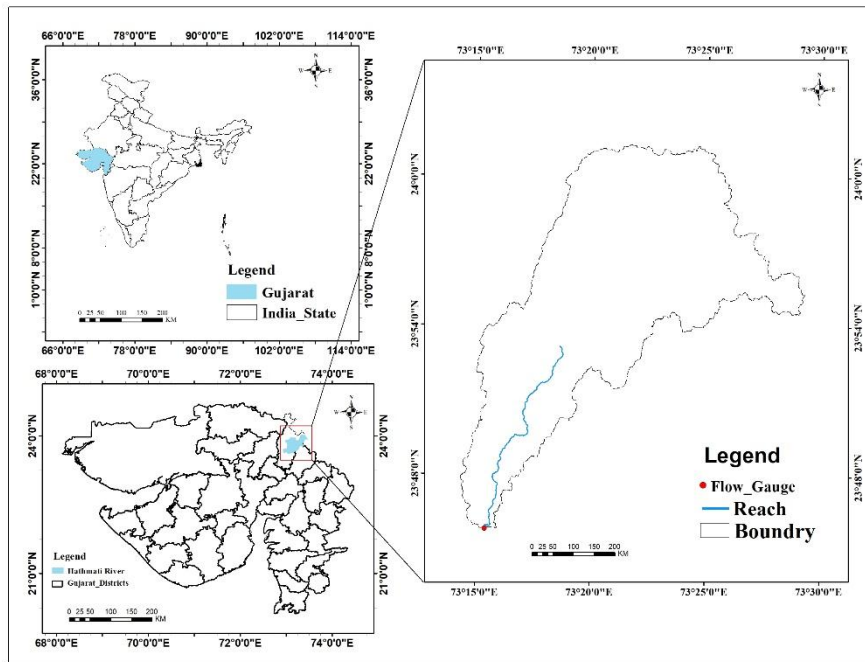
The two most crucial natural resources that are necessary for agricultural development are soil and water. (Lampurlanés et al., 2016). The production of crops is affected by the appropriate use and management of these resources. Due to rapid increase in urbanization, industrial growth, deforestation, climate change, the availability of water resources for the production of agricultural crops and their needs have become very limited (Shi et al., 2016). In order to address the issue of water shortage, care must be taken with how water resources

are used and managed (Xiubin et al., 2003). The creation of surface runoff and agricultural production have been negatively impacted by a lack of land use planning and management strategies. The design of soil and water infrastructure depends on the precise measurement and quantification of the river or channel flow produced by the individual basins in developmental action plans. (David, 1988). Conservation of land and water resources is a significant social and environmental concern now a day. Rapid demographic expansion and changing lifestyle have put tremendous pressure on the natural resources causing their degradation and posing a global threat (Lal, 1999). In India, harmful consequences of soil erosion and other types of land degradation affect around 187.8 Mha of land, or about 57% of the country's total geographical area (328.73 Mha) (Sehgal and Abrol, 1994). A major contributor to soil erosion is surface runoff, that leads to the sedimentation of reservoirs, loss of plant nutrients (agricultural watersheds), and deterioration of river water quality. Numerous research have demonstrated the HEC-HMS to be effective for hydrological modelling (Knebl et al., 2005; Mandal and Chakrabarty, 2016; Gao et al., 2018; Darji et al., 2019; Natarajan and Radhakrishnan, 2019; Yuan et al., 2019)

For the purpose of designing soil and water conservation structures, it is necessary to have a grasp of hydrological phenomena such as fluctuations in runoff with changes in climatic, geographic, or physical conditions. (Refsgaard, J. C., and Abbott, M. B., 1990) 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 application of hydrological modelling becomes obvious in ungauged and/or data-scarce regions. (Sentis, 2010). There are numerous hydrological models available, including the Soil and Water Assessment Tool, the Variable Infiltration Capacity model, etc (Devia et al., 2015). However, the Hydrologic Modeling System (HEC-HMS) from the Hydrologic Engineering Centre is proven to be user-friendly and suitable for usage in areas with data scarcity (Halwatura and Najim, 2013; Chu and Steinman, 2009) Therefore, a major challenge still remaining is the accurate prediction of catchment runoff responses to rainfall events (Bürger et al., 2007). For the management of various water resources, accurate surface runoff estimation is crucial. One of the most significant hydrologic variables is runoff, and accurate estimates of the amount and rate of runoff from the land surface into streams and rivers are crucial, particularly for ungauged watersheds. Using appropriate hydrologic models for the effective management of watersheds and ecosystems is one feasible solution to this problem. We may investigate the operation of watersheds and their reaction to different inputs using hydrologic models. This helps us better understand hydrologic processes.

## **STUDY AREA AND DATA USED**

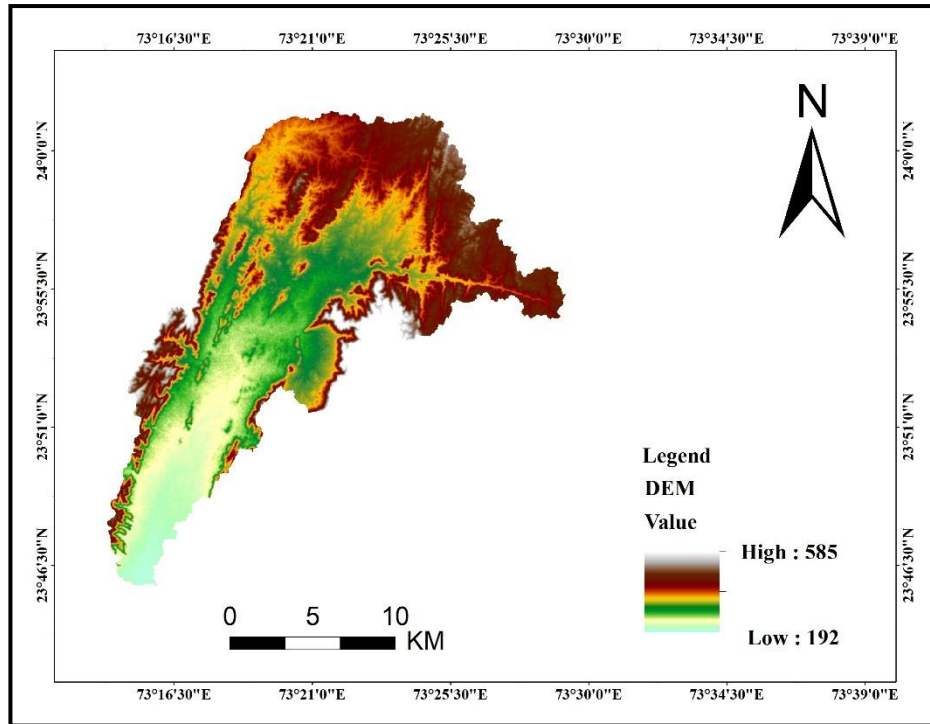
The Hathmati River is located in the Sabarkantha district of Gujarat, India, and the current study is being conducted there in its sub watershed. One of the principal tributaries of the Sabarmati River is the Hathmati River (left) (Western India). Geographically, the watershed is situated between the latitude of 23°30'49"N and the longitude of 72°49'29"E.. It lies in Bhiloda (Sabarkantha district) and rises from Gujarat Malwa Hills. After travelling a course of 98km it meets Sabarmati near village Ged. It covers a total geographical area of sub watershed around 289.75 sq.km, with an elevation range of 197 to 585 m above mean sea level. The average annual rainfall is 864mm. The soils of the watershed are clayey and loamy. The location of the study area is shown in **Figure 1**.



**Figure 1.** The location of the study area

### Terrain Data

Digital Elevation Model (DEM) is a digital representation of a topography surface. The SrtmDEM (Shuttle Radar Topography Mission) with 30meter resolution of the study area is obtained from Earth Explorer U.S. Geological Survey (<https://earthexplorer.usgs.gov/>).



**Figure 2. Digital Elevation Model (DEM)**

### **Rainfall Data**

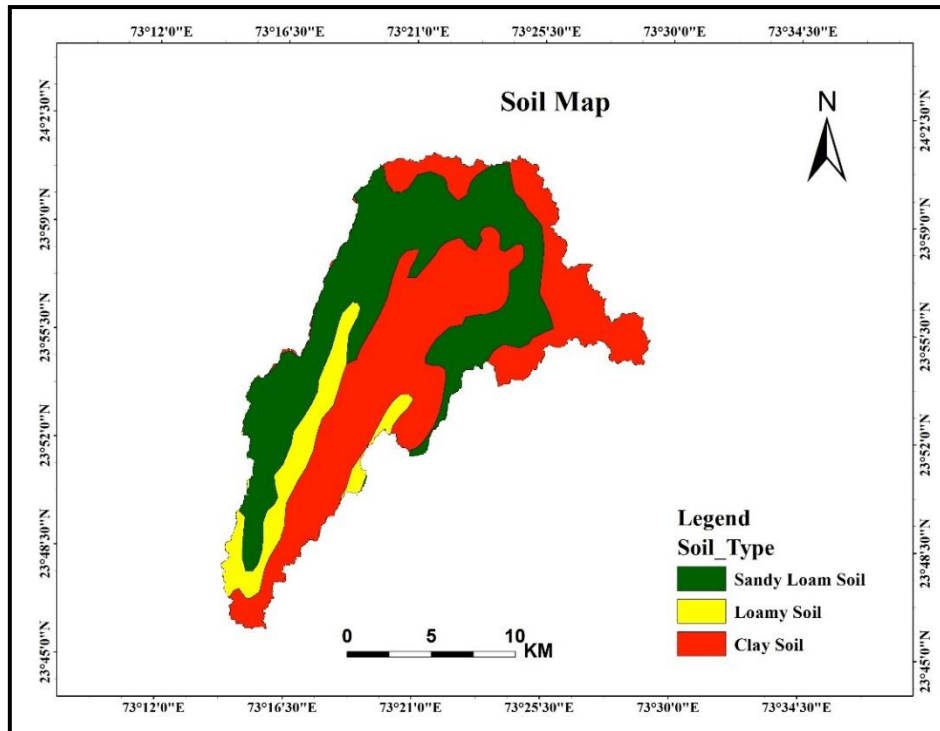
The daily rainfall data is obtained from India Meteorological Department (IMD) website (<http://imdpune.gov.in/>) with the spatial resolution of data was 0.250x0.250. In the current study, rainfall data are extracted for the study area. Using ArcGIS 10 software and the weighted rainfall from the years 2005 to 2020 prepared using the Thiessen polygon method.

### **Discharge Data**

Daily discharge data of stream gauging station at outlet Bhiloda of the watershed from 2005 to 2020 year is collected from State Water Data Center, Gandhinagar.

### **Soil Data**

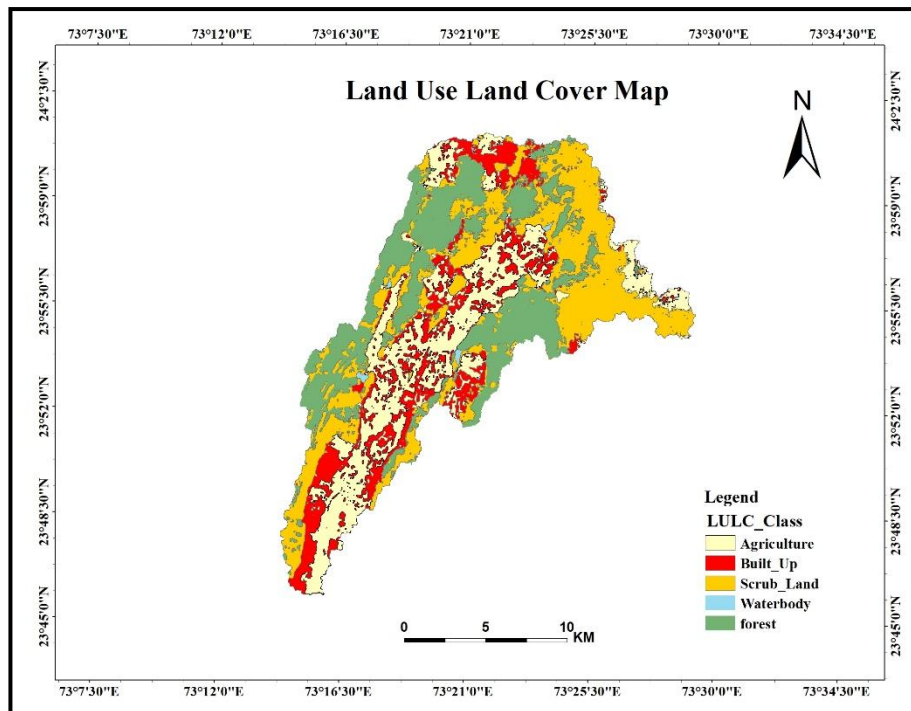
The soil map was prepared in GIS environment as a vector layer using sheet no. 3 of the soil map produced by the National Bureau of Soil Survey and Land Use Planning (NBSSLUP) at a scale of 1:500,000. And as per infiltration rate based on (Usda, 1986). Soil group with HSG of B and D are available that have the properties of low infiltration rate and more runoff. **Figure 3** shows the soil map of the research area. The majority of the study area's soil is clay at the surface (hydrological group D), sandy loam at the subsurface (hydrological group A), and silt/loam sandy soil at the bottom (i.e. hydrological group B)



**Figure 3.** The soil map of the study area

### **Land Use/Land Cover (LULC)**

The LULC map was prepared using a Landsat 8 satellite image with a spatial resolution of 30 m. Unsupervised classification was used to classify the pictures. High imagery from Google Earth is used for the validation. Figure 4 shows the LULC map of the study area.



**Figure 4.** The LULC map of the study area

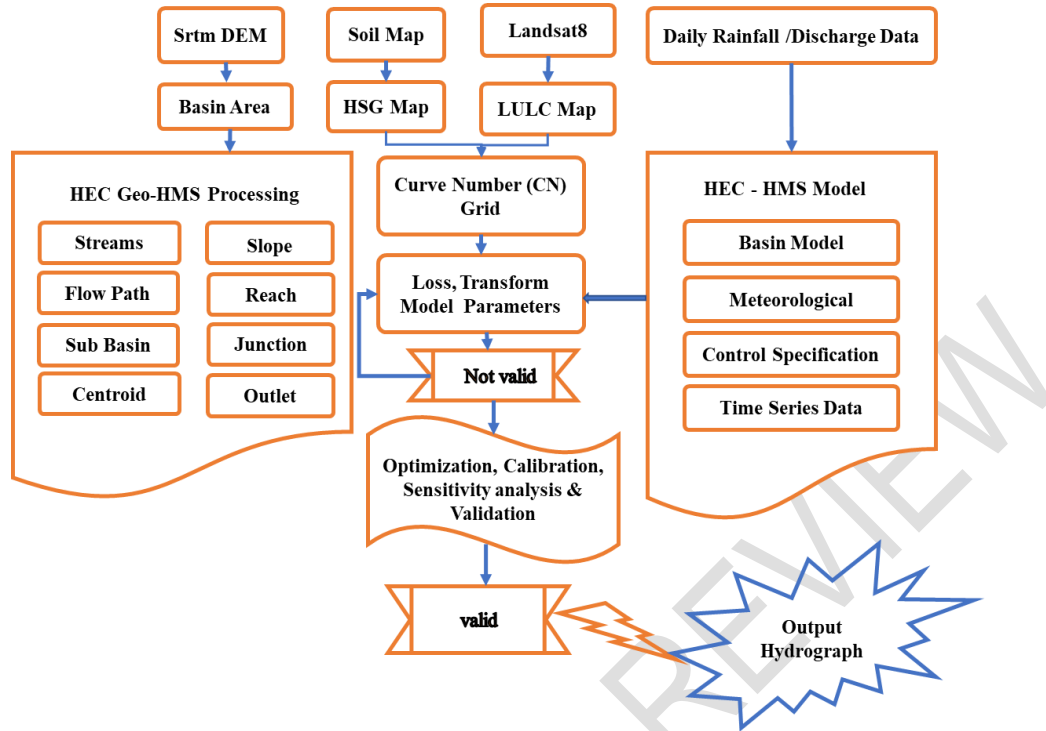
## OVERVIEW OF HEC-HMS MODEL

A physics-based, semi-distributed hydrological model called HEC-HMS can simulate the hydrological functions of watershed systems in a variety of geographic settings, including both larger 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 (v4.10) and was downloaded from the USACE website (<https://www.hec.usace.army.mil/software/hec-hms/downloads.aspx>).

The HEC-GeoHMS, a tool for merging HEC-HMS with GIS, is the Geospatial Hydrologic Modeling Extension. HEC-GeoHMS processes geospatial data and creates hydrologic modelling inputs for the HEC-HMS model using ArcGIS and the Spatial Analyst extension tool.

## Methodology

The overall Methodology presented in Figure 5. In order to extract the 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 (Usda, 1986). The curve number grid is shown in **Figure 6**. In the present study, two methods were used such as the Soil Conservation Service Curve Number (SCS-CN) and deficit and constant loss as loss method and Soil Conservation Service Unit Hydrograph method and Clark unit hydrograph as transform method



**Figure 5** Shows the Flow Chart of Methodology

The basin models, meteorological models, control simulations, and input data are the four essential parts of the HEC-HMS model. Precipitation, evapotranspiration, and snowmelt data are included in the meteorological model, and the basin model maintains the physical datasets detailing the catchment features. Control specifications that include a simulation's beginning date and time, ending date and time,

### **Loss Method**

The SCS-CN approach takes into account the majority of the runoff-producing watershed variables, including soil type, land use, hydrologic soil group, and antecedent moisture condition. (Mishra & Singh, 2004; Abushandi & Merkel, 2013; Yuan et al., 2019). The formula for calculating loss through the SCS-CN method is

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

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. 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)

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

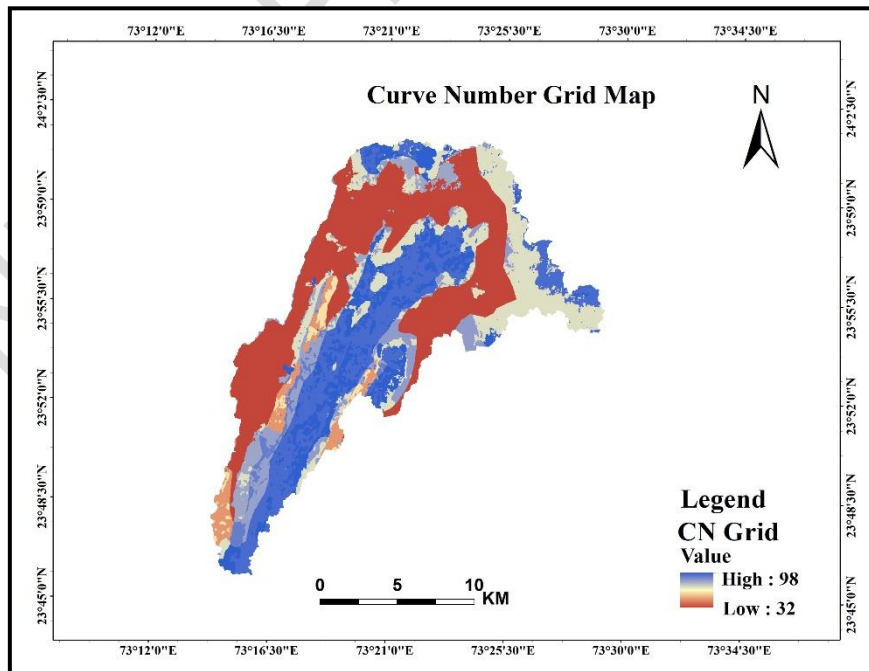
Therefore, the cumulative excess at time t is given as

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

Soil retention is calculated using CN values with the formula as

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

Where, 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) (Soil conservation service engineering division, 1986). The CN values var from 98 to 32. The value of 98 is assumed for water bodies and 32 for permeable soils of moderate infiltration rates. The Curve number map of the study area as shown in **Figure 6**.



**Figure 6.** Curve number map

### ***Model performance evaluations***

The performance evaluation of the HEC-HMS model was done by 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 ( $R^2$ ), the Percent Bias (PBIAS) and Root mean square error (RMSE). The values of NSE,  $R^2$ , and PBIAS were calculated using the following equations

1. the Percent Bias (PBIAS).

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

Where,  $O_i, P_i$  are the observed and simulated flows, respectively.

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

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

$R^2$  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) (Nash & Sutcliffe, 1970)[23].

$$E = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \times 100$$

Nash-Sutcliffe efficiencies can range from  $-\infty$  to 1.

Where;  $O_i$ = observed discharge,  $P_i$ = simulated discharge,  $\bar{O}$  = mean of observed discharge,  $\bar{P}_i$  = mean of simulated discharge. The general performance ratings of interpreted results as

shown in **Table 1** were used as a guide (Santhi et al., 2001; Moriasi et al., 2007, 2015; Gebre, 2015 and Ouédraogo et al., 2018)

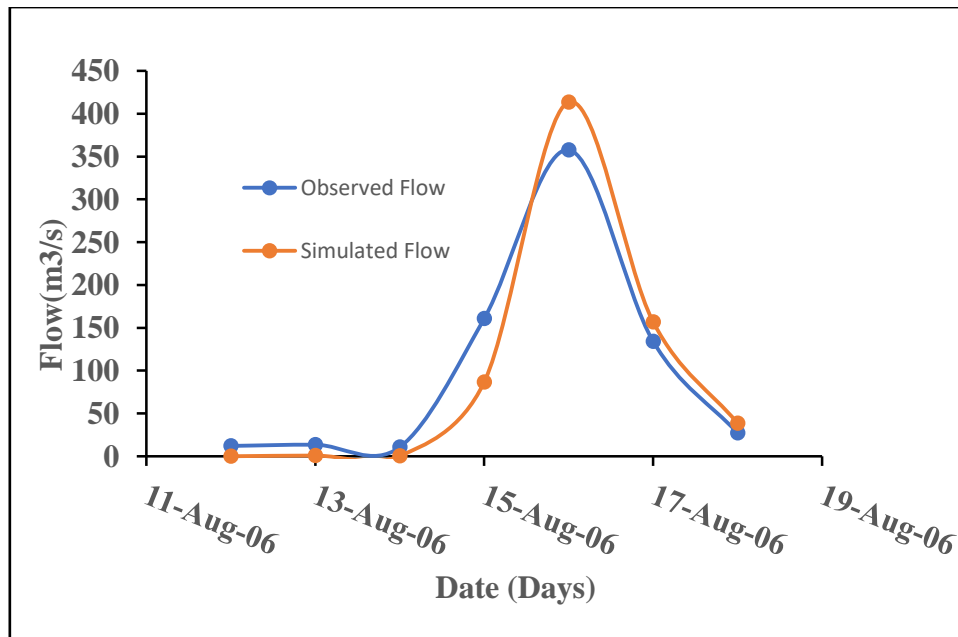
**Table 1** Performance indicator for various evaluation criteria

Performance Rating	PBIAS (%)	R2	NSE
Very good	PBIAS < ±10	0.75 to 1	0.75 to 1
Good	±10 < PBIAS < ±15	0.65 to 0.75	0.65 to 0.75
Satisfactory	±15 < PBIAS < ±25	0.50 to 0.65	0.50 to 0.65
Unsatisfactory	PBIAS > ±25	<0.50	<0.50

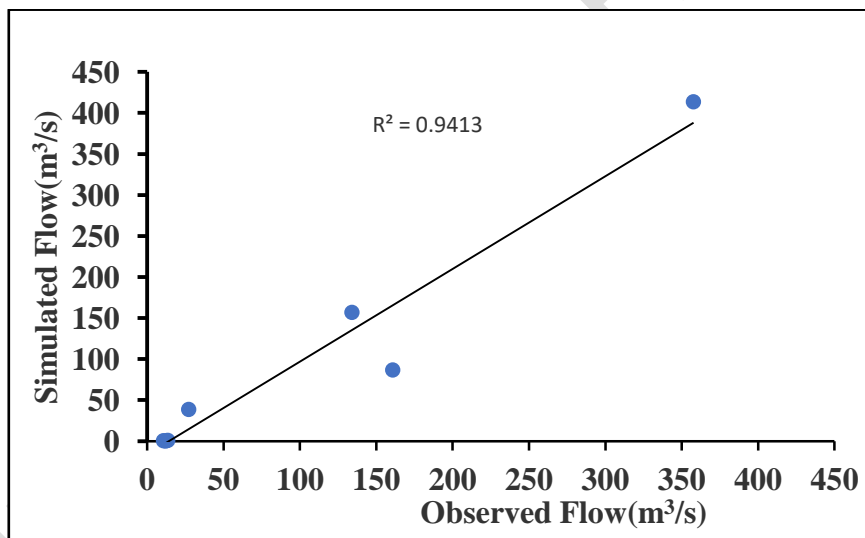
## Results and Discussion

### Calibration and Validation Results using HEC-HMS Model

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 2006 (August) and 2007 (August) in the Hathmati river watershed using scs unit hydrograph and Clark unit hydrograph method respectively, as shown in **Figure 7-8&9-10**. From the results of the calibration run on event dated 16th August 2006 using the SCS unit hydrograph method the computed peak discharge was found to be 410.0 m<sup>3</sup>/s higher than the observed peak discharge of 357.7 m<sup>3</sup>/s, with an acceptable values of the Percent Bias (PBIAS) 11.65%. In terms of model efficiency, the NSE was 0.881, which means there was an acceptable agreement produced by the rainfall-runoff model. Whereas, by using Clark unit hydrograph method the computed peak discharge was found to be 321.5 m<sup>3</sup>/s lower than the observed peak discharge of 357.7 m<sup>3</sup>/s. whereas, the computed peak discharge during the validation period for the event 2007 using both the method were found to be 31.8 m<sup>3</sup>/s and 45.7 m<sup>3</sup>/s respectively, with an acceptable value of the NSE and R<sup>2</sup> was found to be 0.69 and 0.9794 and 0.7461 and 0.9794 respectively, during calibration period the optimized parameter such as curve number, lag time(min), initial abstraction (I<sub>a</sub>) are found to be 89.92, 230 and 5.09 mm respectively. It is observed that the curve number value is found to be very high compare to the initial value, which indicate high runoff potential generated in the watershed it is due to the change in land use land cover and the most dominated land use type in the study area is found to be scrub/waste land and soil type is clay . It can be observed that the model is able to simulate the peak value satisfactorily, Since the parameters utilised here are those that were optimised for event 1, it can be seen that the majority of the values are not very accurately simulated. It could be made clear that the first event was observed in the year 2006, whereas the second event was noticed in the year 2007 and the optimised parameters were used. It is possible that some of the geographical parameters are altered, making the larger discrepancy in the simulation of event

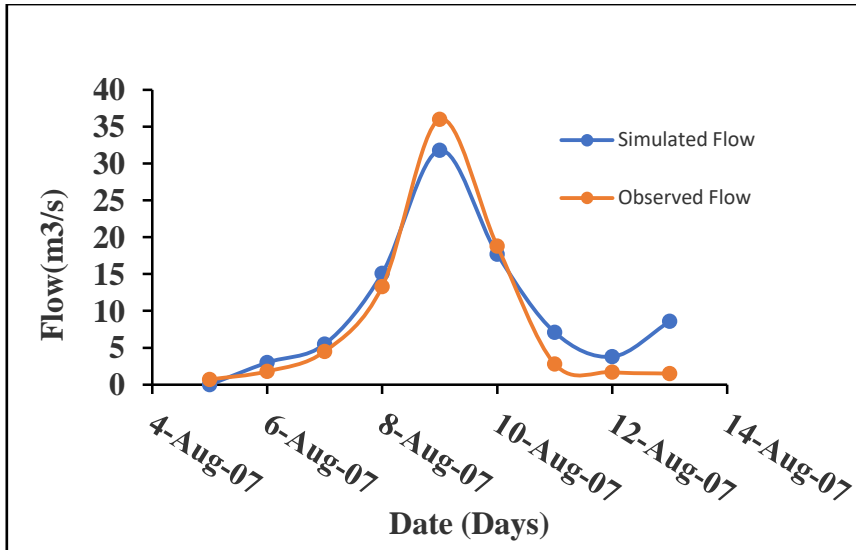


(a)

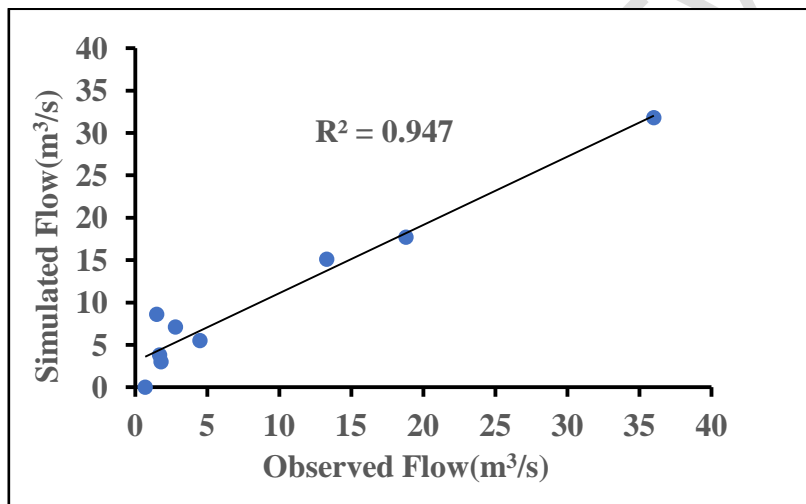


(b)

**Figure 7** (a) hydrograph and (b) Scatter plots of observed discharge versus simulated discharge for the calibration period. Using SCS unit hydrograph

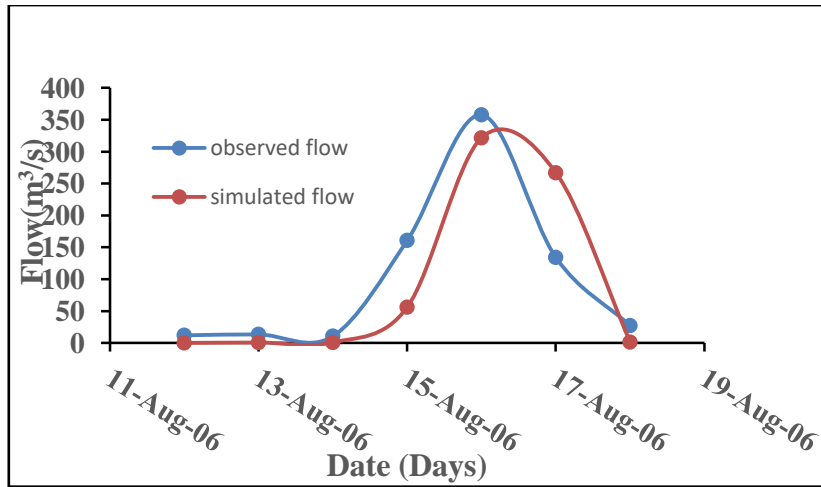


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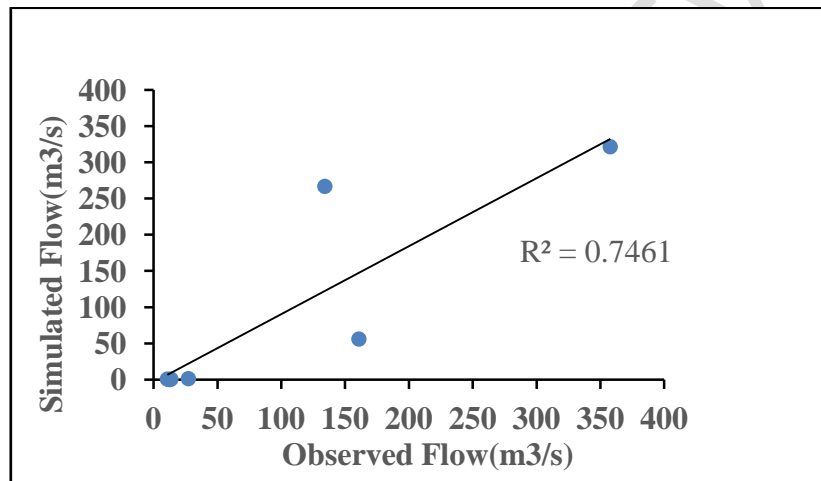


(b)

**Figure 8** (a) hydrograph and (b) Scatter plots of observed discharge versus simulated discharge for the validation period. using SCS unit hydrograph

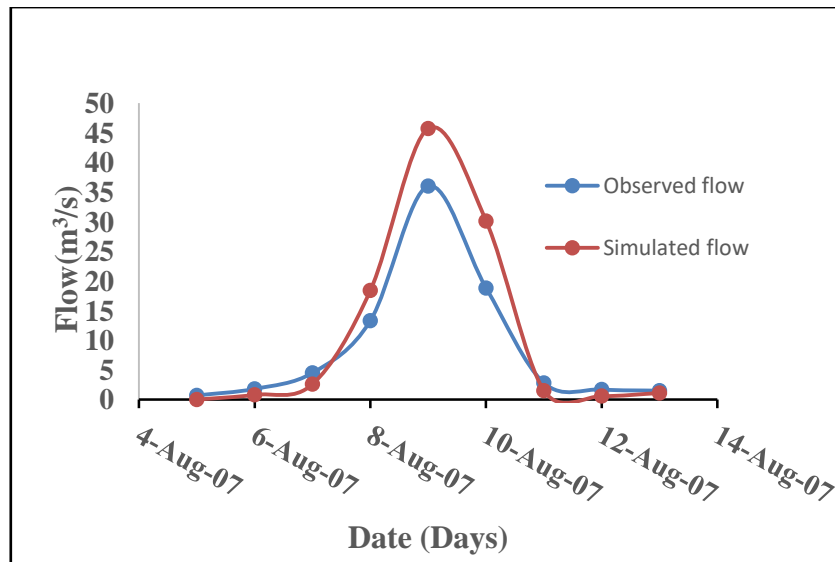


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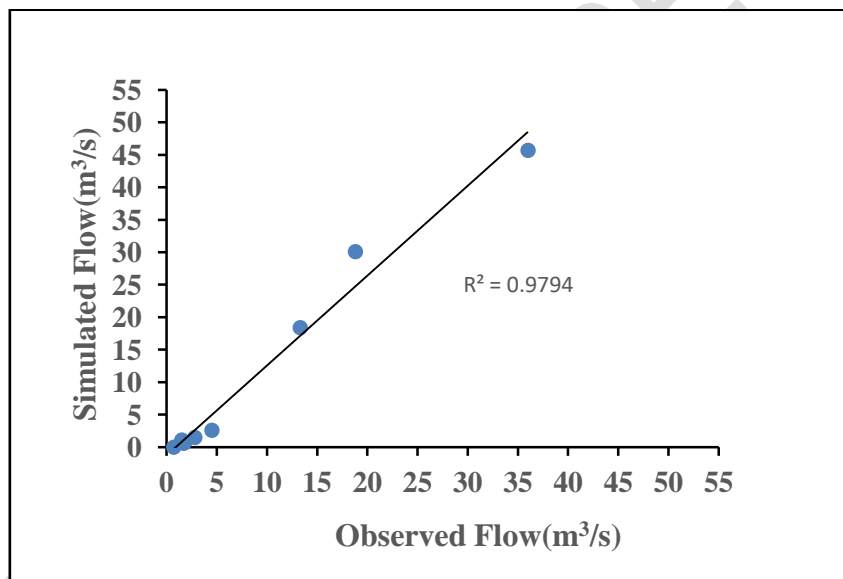


(b)

**Figure 9** (a) hydrograph and (b) Scatter plots of observed discharge versus simulated discharge for the calibration period, using Clark unit hydrograph



(a)



(b)

**Figure 10** (a) hydrograph and (b) Scatter plots of observed discharge versus simulated discharge for the validation period. using Clark unit hydrograph

The Percent Bias (PBIAS), 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 2007 for the model validation. The validated results of 2007 events are as shown in **Figure 8**. The coefficient of determination ( $R^2$ ), the Percent Bias (PBIAS) and Nash Sutcliffe efficiency (NSE) values are obtained as 14.8%, 0.947 and 0.914 respectively for 2007 event. This is resulted closely and good correlation between the observed and simulated

flow. The Model performance statistics during calibration and validation period as shown **Table 2**. And Initial and optimized Parameters using HEC-HMS Model for Events 1 for SCS CN and Clark unit hydrograph transform method during Model calibration as shown in **Table 3&4**. The calibrated and validated results of 2006 and 2007 events using Clark unit hydrograph method presented in **Figure 9&10**. The coefficient of determination ( $R^2$ ) was found to be 0.7461 and 0.9794. from the statistical performance analysis of the model, it is observed that there is closely and good correlation the between observed and simulated flow.

**Table 2.** Model performance statistics during calibration and validation period

Period	Objective function		$R^2$
	PBIAS (%)	NSE	
Calibration	9.76	0.869	0.901
Validation	14.8	0.914	0.947

**Table 3.** Initial and optimized Parameters using HEC-HMS Model for Events 1 for SCS loss and transform metho

Method	Parametrs	Initial Parameter	Optimized Parameter
Loss method	Initial abstraction (Ia), mm	10	5.09
	Curve number (CN)	62	89.92
Transform	Lag time(min), min	226.09	230

**Table 4.** Initial and optimized Parameters using HEC-HMS Model for Events 1 for Deficit and constant loss and Clark unit hydrograph transform method

Method	parameters	Initial parameter value	Optimized parameter value
Deficit and constant loss method	<b>Loss Parameter</b>		
	Initial Deficit (MM)	5	2.8425
	Constant (MM/HR)	0.01	0.29059

	Impervious (%)	10	--
Clark unit hydrograph Transform method	<b>Transform Parameter</b>		
	Time of Concentration (Tc)	3.76	--
	Storage Coefficient (Sc)	7.11	7.1046

## CONCLUSIONS

In the present study, hydrological modelling of sub watershed Hathmati river is carried out using HEC-HMS. The SCS-CN is used to represent loss method, the transform method is Soil Conservation Service Unit Hydrograph method. The model is evaluated using Nash-Sutcliffe efficiency, coefficient of determination and Percent Bias. Daily timescale calibration and validation results over the study area shown good performance with NSE,  $R^2$  and Percent Bias PBIAS (%) 0.881, 0.913 and 9.76% respectively for calibration and 0.914, 0.947 and 14.8% respectively for validation. Whereas, The Nash-Sutcliffe efficiency, coefficient of determination, and statistical performance indicators for the Clark unit hydrograph transform method were found to be 0.69, 0.77, 0.7461, and 0.9794, respectively. Based on these results, the model shows a strong correlation between simulated and observed peak flows during the calibration validation period. correlation between simulated and observed peak flows during the calibration validation period. It is concluded that, the 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. Based on the statistical and graphical indicators used in this study, The results of this study's statistical and geographical parameter indicators revealed that the HEC-HMS distributed technique successfully reproduced daily stream flow satisfactorily and its performance was found to be reliable to estimate more desired peak values. The simulation results can be used directly or in conjunction with other software for different hydrological and environmental studies and for flow forecasting, future urbanization impact assessment, flood damage reduction, reservoir design studies, and overall systems operation. 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

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