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Calibration and Validation of HEC-HMS Model for Baitarani river basin

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ABSTRACT - Prediction of flood-prone areas in a river basin and evaluation of the impact of climate change on water resources require an accurate estimation of water availability, which can be effectively achieved through hydrological modeling of the basin. However, modeling the hydrology of a basin is a complex process, and the models must be carefully calibrated and validated to enhance user confidence in their predictive abilities. This, in turn, ensures the effective application of the model in decision-making. In this study, a rainfall-runoff simulation model, the Hydrologic Modeling System (HEC-HMS) developed by the Hydrologic Engineering Centre, USA, has been calibrated and validated for the Baitarani River Basin **in Odisha, Eastern India, to predict its hydrologic response. The results indicate that** Curve Number (CN)**,** Lag Time**, and** Initial Abstraction (Ia) **are the most sensitive parameters influencing the simulated streamflow. The performance evaluation of the model was carried out using statistical criteria such as the** Nash-Sutcliffe Efficiency (NSE)**, the** percentage error in peak discharge**, the** percentage error in runoff volume**, and the** net difference in observed and simulated time to peak**. The results of the analysis demonstrate that the NSE values ranged from 0.818 to 0.882, the percentage error in peak discharge ranged from** -0.108 to -16.8**, the percentage error in runoff volume ranged from** -0.182 to -7.47**, and the time to peak difference was observed to range from** 0 to 6 days**, indicating very good model performance in simulating streamflow.**

I. INTRODUCTION

Globally, floods are among the most devastating natural disasters, impacting human life more than any other calamity. According to Jha & Jessica (2012) **(1)**, in 2010 alone, 178 million people were affected by floods. Additionally, the Department for International Development (DFID) reports **(2)** that one-sixth of the global population—approximately one billion people, primarily low-income earners—live in areas at risk of a 1-in-100-year flood. In India, extreme precipitation and floods are significant hydro-climatic events that recur annually during the monsoon season, causing extensive damage to infrastructure, agriculture, and human lives. Studies (**3**) **(4)** (**5**) indicate an increase in extreme precipitation events over the past few decades, with projections of further intensification under a warming climate. India has witnessed several severe flood events in recent decades, such as the 2005 Mumbai floods that affected over 20 million people and caused more than 1,000 deaths **(6)**, the 2013 Uttarakhand floods that resulted in over 6,000 fatalities and $3.8 billion in economic losses **(7)**, and the 2015 Chennai floods with over $3 billion in economic damages (**8**) **(9)**.

Odisha, located on the eastern coast of India, is highly vulnerable to extreme precipitation and recurrent flood events. The Baitarani River Basin, covering a total area of 13,482 km², is one of the major river systems in the state, frequently experiencing severe floods during the monsoon season. The basin was significantly impacted during extreme flood events in 2008, 2011, and 2014, causing widespread damage to infrastructure, agriculture, and human lives. These floods highlight the urgent need for improved water resource assessment and flood management in the region.

In this study, the modeling of flood flows has been carried out for the Baitarani River Basin using the Hydrologic Modeling System (HEC-HMS), developed by the Hydrologic Engineering Center, USA. The model was calibrated and validated to simulate rainfall-runoff processes and hydrologic responses in the basin. This approach enables the assessment and effective

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management of water resources in the basin, providing critical insights for mitigating flood impacts and enhancing the region's resilience to extreme precipitation events.

II. STUDY AREA

The Baitarani River is one of the major rivers in Odisha, India, and flows through the districts of Kendujhar, Mayurbhanj, Jajpur, Bhadrak, and Balasore. The Baitarani River Basin (BRB) lies between 21°02' to 22°15' North Latitude and 85°10' to 87°03' East Longitude. The river originates from the Guptaganga hills of the Gonasika region in the Kendujhar district at an elevation of approximately 900 meters above mean sea level and flows eastward before draining into the Bay of Bengal **(10)**. The basin encompasses varied physiographic and geological terrains, with its upper reaches characterized by hilly and forested landscapes, while the lower reaches predominantly consist of alluvial plains. The basin receives an average annual rainfall of about 1,200–1,600 mm, primarily during the monsoon season **(11**). The total length of the river is approximately 360 km, and the catchment area is about 13,482 km²**,** spanning across Odisha and parts of Jharkhand **(12)**. The basin plays a crucial role in the agricultural and hydrological landscape of the region, supporting livelihoods and ecosystems.

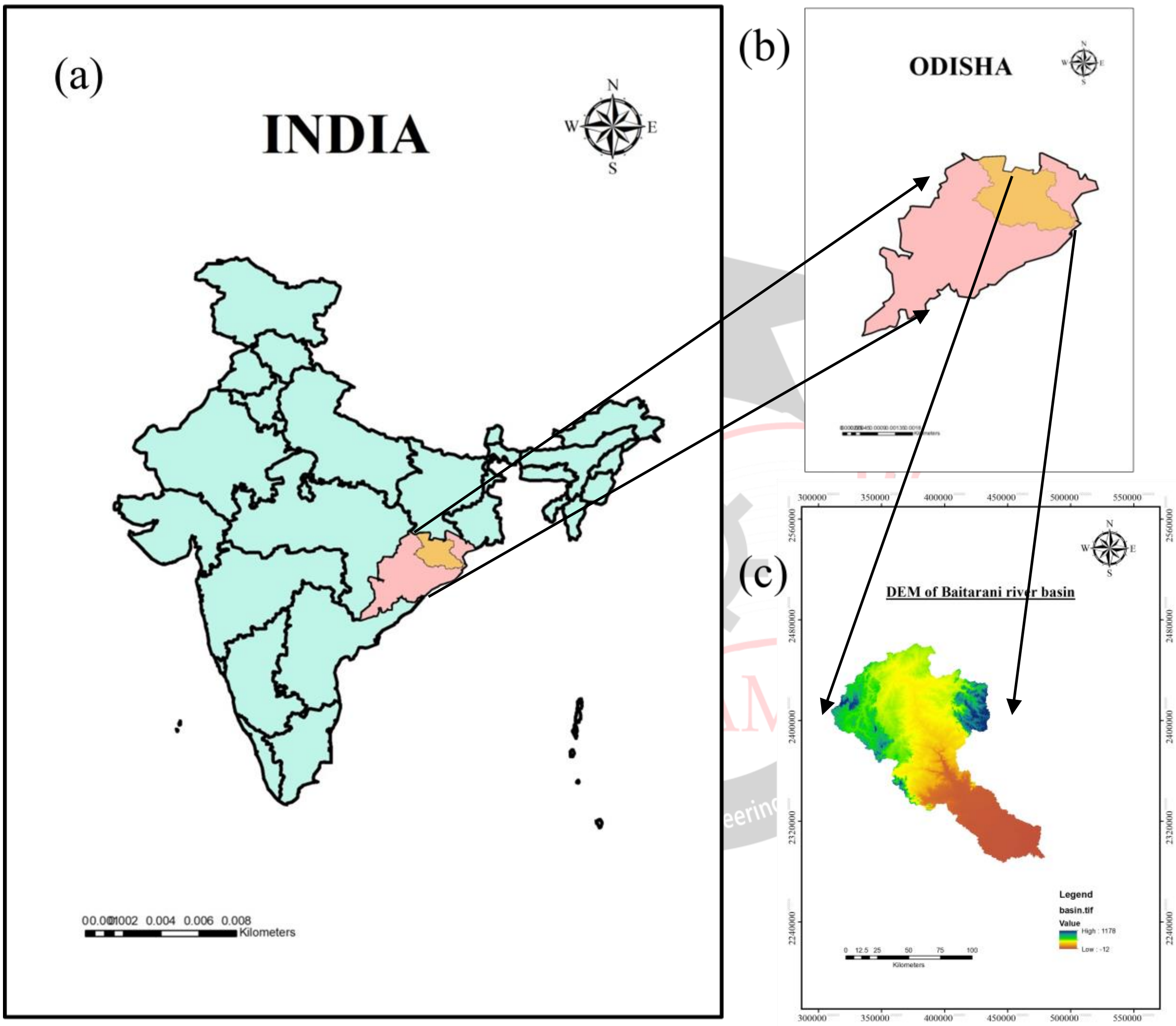

Fig. 1. Location map of Baitarani river basin

III. METHODOLOGY

The hydrological simulation modeling for the Baitarani River Basin was performed using HEC-HMS, a semi-distributed hydrologic model capable of conducting both continuous and event-based simulations in dendritic watershed systems. HEC-HMS, an advanced version of the HEC-1 model developed in 1968 by the US Army Corps of Engineers, has been extensively used for modeling rainfall-runoff processes, flood forecasting, system planning, and assessing the impact of land-use changes and runoff simulations in ungauged basins [2]. In HEC-HMS, the catchment is constructed by decomposing the hydrological cycle into manageable components, such as precipitation, initial abstraction, evapotranspiration, infiltration, surface runoff, and base flow. The watershed is described physically using elements such as sub-basins, reaches, junctions, reservoirs, diversions, sources, and sinks. Computations proceed in an upstream-to-downstream direction, and runoff calculation occurs sequentially,

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starting from canopy storage through surface or depression storage, infiltration, and transformation into base flow or surface flow hydrographs. Rainfall, along with spatially distributed watershed characteristics like land use, soil type, and topography, forms the primary input for the model, while the output is represented as flow hydrographs.

The key components of HEC-HMS applied to the Baitarani River Basin are as follows:

Basin Models: The physical representation of the Baitarani River Basin, including hydrologic elements (sub-basins, junctions, reaches, and reservoirs) and its drainage network, is incorporated into the basin models.

Meteorological Models: Meteorological data, such as precipitation, temperature, evapotranspiration, sunshine, humidity, and snowmelt (if applicable), are defined in the meteorological model. HEC-HMS offers multiple options to specify these meteorological elements.

Control Specification: This component defines the simulation's starting date and time, ending date and time, and the computational time step.

Time-Series Data: Real-time series data for meteorological elements, including discharge data for calibration and simulation, are inputted. These can be manually supplied or uploaded using HEC-DSS, the Hydrologic Engineering Center Data Storage System.

IV. DATA COLLECTION AND ANALYSIS

a) Digital Elevation Model (DEM)

For the present study, a DEM with a 30 m resolution, downloaded from the USGS Earth Explorer, was utilized for delineating the Baitarani River Basin and determining its basin characteristics, such as elevation, slope, slope length, flow direction, and drainage features.

b) Land Use Land Cover Map

The land use and land cover (LULC) map was prepared using ERDAS Imagine 2014 software, available in the Geo Spatial Lab of MPUAT, Udaipur. Cloud-free Sentinel satellite data (geo-coded with UTM projection, spheroid and datum WGS 1984, Zone 45 North) with a 30 m spatial resolution for the year 2020 was downloaded from the USGS Earth Explorer website (http://earthexplorer.usgs.gov/).

The LULC classification method adopted for this study was unsupervised classification. Eight land use classes were identified for the Baitarani River Basin: water body, forest, urban area, barren land, tea, paddy, oil palm, and coffee/cardamom. Ground truthing and data collection were carried out prior to classifying different land use categories in the basin. Cross-verification of the basin area was conducted using Google Earth Pro for better accuracy in identifying various classes. After classification, each pixel was inspected and appropriately categorized, assigning meaningful names to each class.

c) Soil Map

The soils of the Baitarani River Basin fall into six broad categories:

1. **Lateritic Soil:** Predominantly found in the basin's upland and midland regions.
2. **Hydromorphic Saline Soil:** Confined to low-lying areas susceptible to water stagnation and salinity.
3. **Brown Hydromorphic Soil:** Found in valley bottoms of undulating topography, formed due to deposition from adjacent hills and slopes.
4. **Riverine Alluvium:** Distributed along the riverbanks, formed by river deposits, and fertile for agriculture.
5. **Coastal Alluvium:** Found near the basin's estuarine areas, supporting specific vegetation types.
6. **Forest Loam:** Covers a significant portion of the forested areas, characterized by a surface layer rich in organic matter.

d) CN Grid Map

The Curve Number (CN) grid was calculated in Arc GIS by integrating land use and soil cover layers for the Baitarani River Basin. The CN grid serves as a critical input for determining lag time in the HEC-HMS model's transform method. The following steps were employed to generate the CN grid for the catchment:

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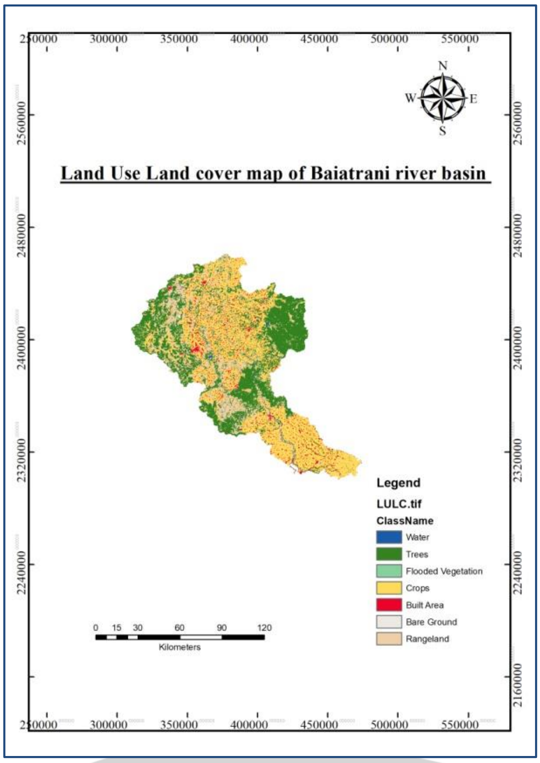

Fig. 2 Land use land cover map of Baitarani river basin

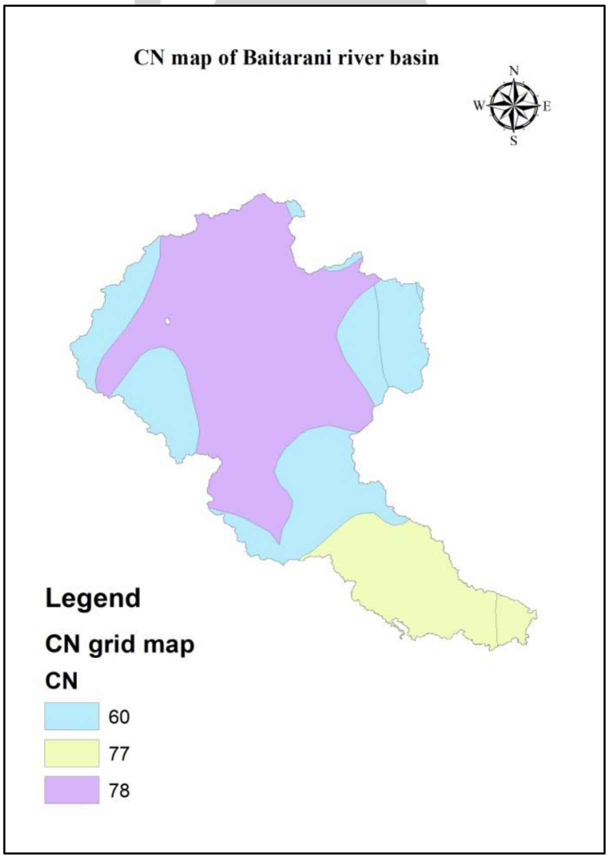

Fig. 3 CN map of Baitarani river basin

i. Integration of LULC and soil maps in ArcGIS.

ii. Assignment of appropriate CN values based on hydrological soil groups and land use types.

iii. Generation of a CN grid map using raster calculations.

iv. Optimization of CN values during the HEC-HMS calibration process to improve model accuracy.

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This systematic approach to data collection and analysis ensured accurate hydrological characterization of the Baitarani River Basin and provided reliable inputs for the HEC-HMS model.

Table 1. Areal Distribution of different Land use/land cover classes of the Baitarani riverbasin

Landuse class	Area(km²)	Area(%)
Water	164.71	1.47
Trees	2441.31	21.76
Crops	3561.14	31.75
Built area	1106.44	9.86
Bare ground	2.43	0.02
Range land	3940.18	35.12
Total	11217.69	100

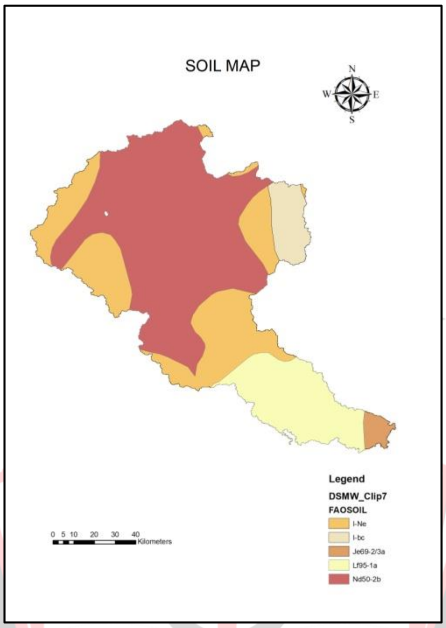

Fig. 4 Soil map of Baitarani river basin

e) Climate Data

The Baitarani River Basin is characterized by a tropical monsoon climate with three distinct seasons: summer (March to May), monsoon (June to October), and winter (November to February). The higher elevations of the basin experience a relatively cooler climate compared to the low-lying areas. The region receives an average annual rainfall of approximately 1500-2000 mm, varying spatially across the basin.

About 60-70% of the total rainfall occurs during the southwest monsoon (June to September), while the northeast monsoon (October to November) contributes around 15-20% of the total rainfall. The remaining precipitation is scattered across the pre-monsoon (March to May) and winter months. The basin experiences around 110-120 rainy days annually, with the majority occurring during the southwest monsoon.

Relative humidity remains high during the monsoon months, contributing to a humid environment. Wind speeds typically peak in the pre-monsoon period, with May recording the highest wind speed, averaging 10-12 km/h. Temperatures remain relatively uniform throughout the year, with the highest temperatures recorded in May and the lowest in December and January.

Daily rainfall data from seven meteorological stations along with other climatic parameters such as maximum and minimum temperature, relative humidity, sunshine hours, and wind speed have been collected from the CWC, Bhubaneswar for the calibration and validation of the hydrological model.

HEC-HMS Hydrological Modelling

HEC-HMS uses separate models to represent each component of the runoff process, including models that compute runoff volume, models of direct runoff, and models of base flow. Each model run combines a basin model, meteorological model and control specifications with run options to obtain results.

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Following methods were selected for each component of runoff process such as runoff depth, direct runoff, base-flow and channel routing in event based hydrological modelling. These methods were selected on the basis of applicability and limitations of each method, availability of data, suitability for same hydrologic condition, well established, stable, widely acceptable, researcher recommendation etc.

I. SCS Curve Number (CN) method

In SCS-CN method, accumulated precipitation excess is estimated as a function of cumulative precipitation, soil cover, land use, and antecedent moisture and is:

$$P_e = \frac{(P-Ia)^2}{(P-Ia+S)}$$

Where, P_e = Accumulated precipitation excess attime t; P = Accumulated rainfall depth at time t;

Ia= Initial abstraction and S = Potential maximum retention. I_a and S are calculated from following equations:

$$I_a = 0.2S$$

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

For a watershed that consists of several soil types and land uses, a composite CN is calculated as suggested by Panigrahi (2013)**(13)**.

I. SCS unit hydrograph method

SCS unit hydrograph method is applied for estimating direct runoff. The basin lag time (T_{lag}) is the parameter of SCS UH model which is 0.6 times the time of concentration (Tc), Value of T_c is computed as suggested by Panigrahi (2013).

II. Recession method

It is used to represent watershed base flow. It is given by:

$$Q_t = Q_o^{Rt}$$

Where, Q_0 = Initial base flow at time t = 0, Q_t = Threshold flow at time t, and R = Exponential decay constant.

Initial base flow (Q_o) is estimated by field inspection. The recession constant (R) is estimated from observed flow hydrograph which depends upon the source of base flow. The threshold flow (Qt) is estimated from observed flows hydrograph, wherein the flow at which recession limb is approximated well by a straight line (USACE –HEC, 2008) **(14)**

III. Muskingum method

Muskingum method for channel routing was chosen. In this method X and K parameters must be evaluated. Theoretically, parameter K is the time of passing of a wave in reach length and parameter X is a constant coefficient whose value varies between 0 - 0.5. Therefore parameters can be estimated with the help of observed inflow and outflow hydrographs. Parameter K is estimated as the interval between similar points on the inflow and outflow hydrographs. Once K is estimated, X can be estimated by trial and error.

Result and Discussion

Calibration and Validation of ModelParameters

In the calibration procedure all the parameters involved were balanced in order to reduce the error between the observed values and the simulated values obtained for the basin **[15].** It was mainly done to minimize the deviation between the observed and obtained values from the model and to get the best set of parameters in calibrating and validating the model **[16].** The process was completed either by repeated manual adjustment of the parameters, computation and inspecting goodness of fitbetween the computed and observed hydrographs or automatically by using the iterative calibration procedure called optimization [**17**]. Daily available rainfall and discharge data from the year 2011 to 2013 were used for model calibration whereas the data from 2014 to 2015 were used for validation. The same parameters, obtained after calibration, were used for validation and thus the flood hydrographs of the catchment were generated.

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Optimization of model parameters

Using the optimization tool in HEC-HMS, the model parameters were adjusted to match the simulated and observed discharge. Sub basin and reach parameters included Initial Abstraction (Ia), Curve Number (CN), and Lag Time (LT), among several others. Optimization trials were used to automatically optimize these parameters. The optimization was carried out in such a way that the output hydrograph computed at the outlet matched with the simulated/observed hydrograph closely. Minimization of the function, i.e., minimization of the difference between computed and observed discharge, was selected as the objective function for optimization. To analyze the minimization function, 'first lag auto correlation statistics' was used.

Table 2 Initial and optimized parameter values for different Subbasins

Subbasin	Initial abstractions (I_a)		Basin CN		Lag time (min)	
	I	O	I	O	I	O
Subbasin 1	15	188.77	72	98.606	2950	374.03
Subbasin 2	15	55.341	72	98.536	2950	137.69
Subbaisn 3	15	34.848	87	81.274	2950	25831
Subbaisn 4	15	18.665	68	20.054	2950	563.8
Subbaisn 6	15	0.001	80	71.875	2950	645.76
Subbaisn 8	15	38.252	74	81.048	2950	559.2
ZZ5	15	188.77	69	57.619	2950	481.32
ZZ7	15	103.44	71	69.965	2950	530.02

Table 3 Initial and optimized parameter values of coefficients in Muskingumequation

River	X		K	
	I	O	I	O
ZZ 37	0.25	0.15	22	59.735
ZZ 35	0.25	0.16	22	33.543
ZZ 34	0.25	0.17	22	22.644
ZZ 33	0.5	0.345	22	12.578
ZZ 32	0.5	0.228	22	21.998
ZZ 31	0.5	0.355	22	35.830
ZZ 30	0.5	0.5	22	27.989
ZZ 29	0.5	0.449	22	23.621
ZZ 28	0.5	0.261	22	25.78
ZZ 27	0.5	0.5	22	21.578
ZZ 26	0.5	0.378	22	14.788

The NSE values slightly increased after using the optimized parameters, as shown in Table 4, indicating that the model generated satisfactory results for the simulation of rainfall-runoff for the sub basin.

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Table 4 NSE values before and after optimization

Year	N.S.E value	
	Before optimization	After optimization
2011	0.231	0.864
2012	0.603	0.818
2013	0.401	0.882

Calibration of HEC-HMS model

Daily rainfall and other hydro-meteorological data from 2011 to 2013 were used for calibration. The model's calibration input was initially set to the estimated initial parameters, as shown in Table 4. The discharge hydrograph, peak runoff, total volume, time to peak, and total volume were all simulated. When observed discharge values were compared to model simulated discharge values, it was found that there was a significant difference between observed and predicted values in all sub basins. The initial parameters were optimized using the model's automatic optimization tool to obtain satisfactory results. The model was re-calibrated using optimum parameters (Table 4) to ensure peak discharge, total volume, and time to peak. It was found that the optimized value generated a simulated hydrograph that was nearly identical to the observed one. As a result, for model calibration and accurate simulation, optimized parameter values were chosen.

Fig. 4-6 represents the plot of hydrograph of simulated outflow and observed flow during the calibration. The graph showed that there is a close similarityof trend between the simulated and observed hydrograph in all the years including thecalibration period. It was also seen that the peak of the hydrographs for calibration was not matching with the peak of observed hydrographs. This might be due to the fact that watershed physical characteristics change both spatially and temporarily.

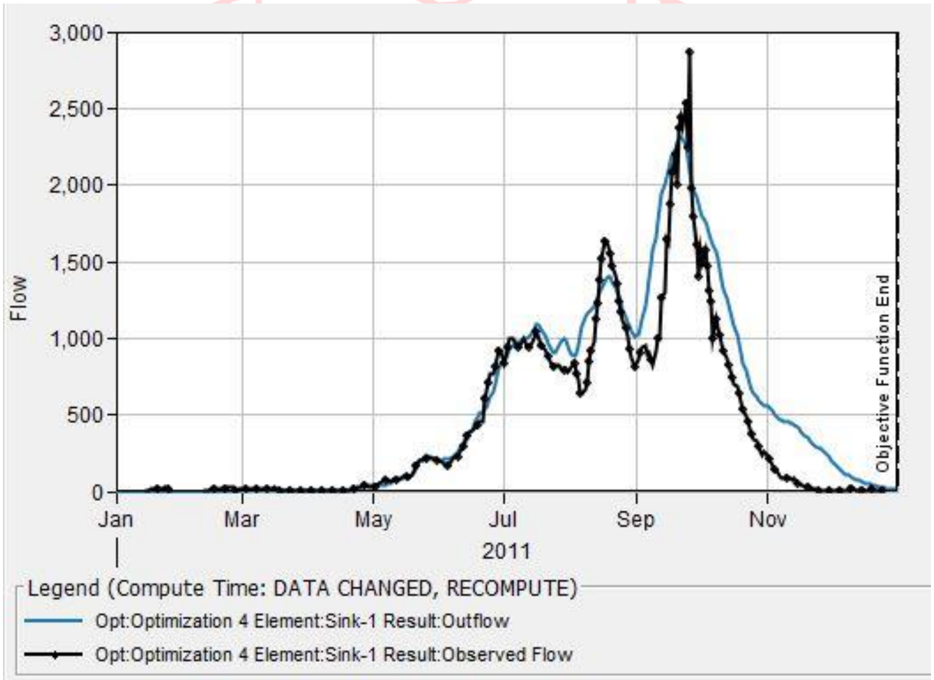

Fig. 5 Simulated and observed hydrograph for the year 2011

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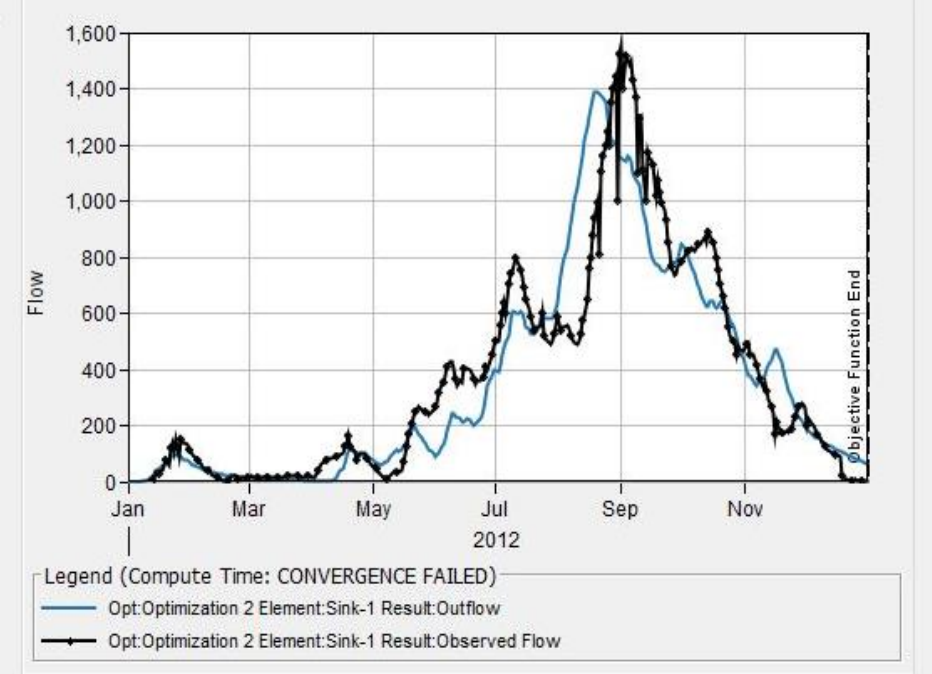

Fig. 6 Simulated and observed hydrograph for the year 2012

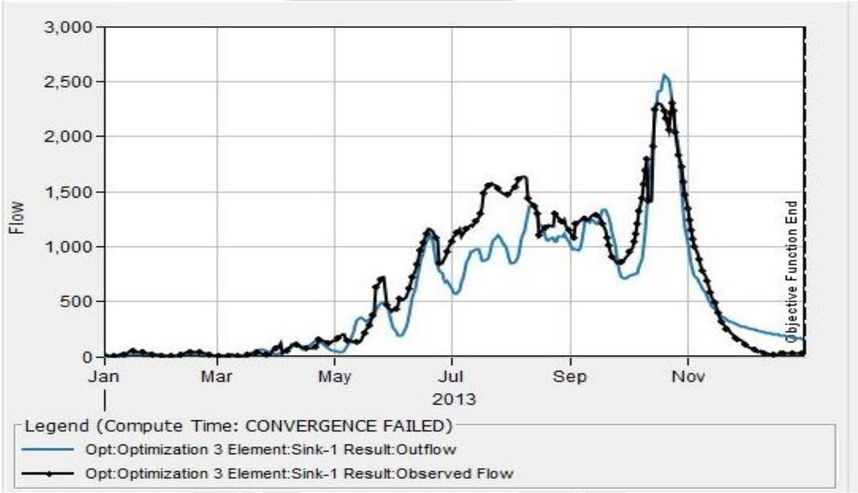

Fig. 7 Simulated and observed hydrograph for the year 2013

Referring to above hydrographs, it was clear that only base flow contributed to the discharge at outlet during the summer season, when there was no or little precipitation over the watershed. However, during the monsoon season, the maximum precipitation that occurred in the watershed caused a large discharge at the exit, resulting in a peak flow in the basin. During the calibration period, the largest peak discharge occurred in 2011, with a peak flow of 2312 m^3/s.

During particular time periods in the graphs, it was also visible that the peakof the observed and simulated hydrographs of flow was not matching. This could be due to the fact that the actual basin physical parameters may not be exactly as has been simulated by the model. In addition, initial loss, imperviousness and curve number of the sub basin areas may also create some effect on the runoff in the watershed. In some parts of the watershed, areas with higher imperviousness resulted in less infiltration and thus greater surface runoff. This had an impact on the volume of discharge, the peak discharge, and the time it took to reach the peak discharge. The time of peak was influenced by imperviousness and curve number, resulting in an increase in peak discharge and volume. That is, variations in hydrological indicators, such as time to peak, peak discharge, and volume, were highly correlated with the basin's imperviousness. In addition to these considerations, the catchment soil was predominantly clayey resulting in a large amount of storm water draining quickly intothe streams. However, the initial losses including surface depressions and interceptionloss reduced the surface runoff at some stages of flow because of more resistance caused in flow path and the availability of more opportunity time for initial loss.

The respective R^2 values were also in the acceptable range in a scatter plot of actual and simulated flow (Fig. 7) for different time periods (i.e. greater than 0.7). The simulation overall results were represented as an objective function and a

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summary results table that provides a comparison between observed and computed flow is given. The estimation has an excellent performance rating when the RSR (Root mean square error-standard deviation ratio) is less than 0.5. Moreover, Nash SutcliffeEfficiency (NSE) value for calibration period was obtained in the range of 0.75-0.81, which was also found satisfactory. (Table 5)

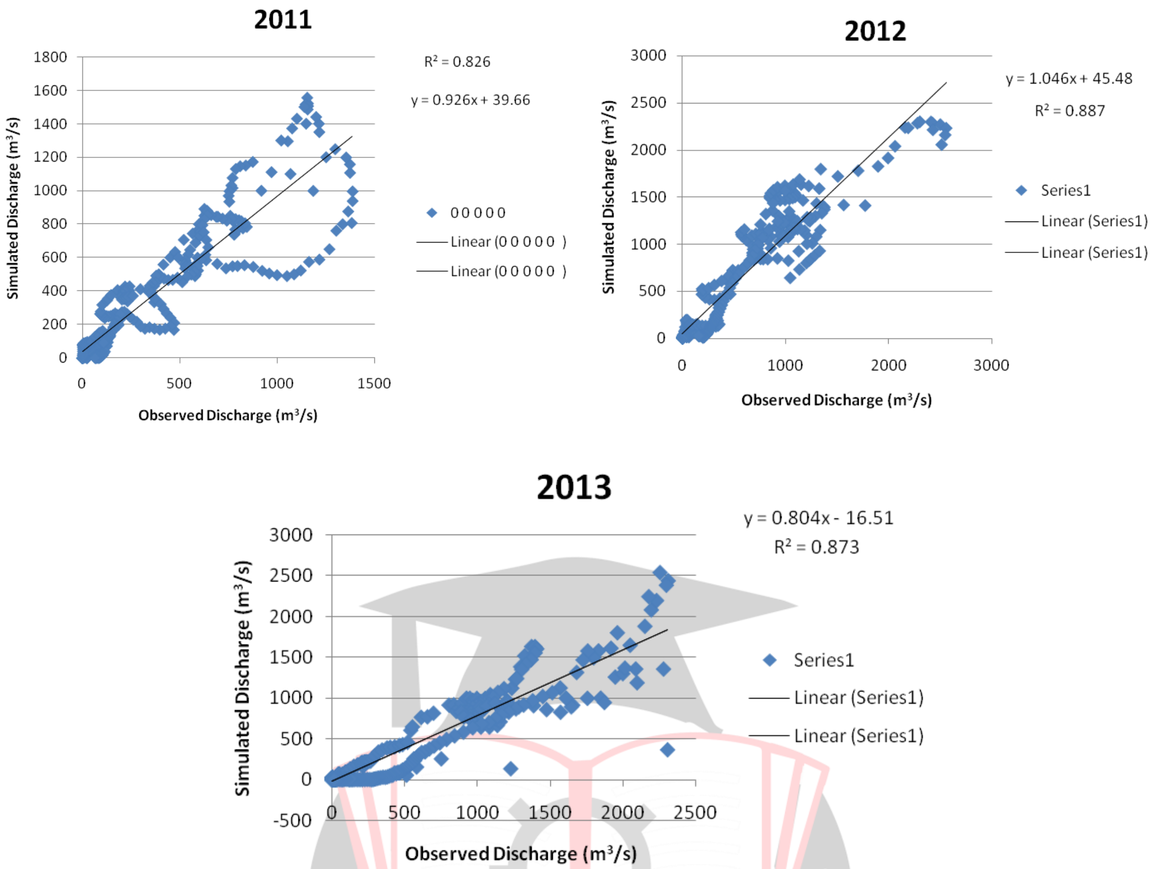

Fig. 8 Scatter plots of observed versus simulated flow during calibration

Table 5 Performance indices of the model during calibration

Year	Nash Sutcliffe Efficiency (NSE)	Percent bias(PBIAS)	Error in Peak Flow (%)	Error in Volume (%)	Coefficient of correlation (R^2)	Root mean square error-standard deviation ratio(RSR)
2011	0.864	22.19	0.193	-0.182	0.826	0.4
2012	0.818	-3.54	-0.108	-0.03	0.887	0.4
2013	0.882	-12.76	0.111	0.127	0.873	0.3

By comparing the percent difference between simulated and observed flow, theobjective function is utilized to compute model performance. Objective functions are the algorithms used in HEC-HMS to find the model parameters that produce the best value of an index (USACE, 2000). The Error in Peak Flow (percentage) and Error in Volume (percentage) were calculated using the results of the objective function. The lowest inaccuracy in Peak Flow (percent) was recorded in the simulation conducted in 2012, which was only -0.108 percent, and the highest error of 0.193 percent was observed in 2011. On the other hand, the lowest error in volume (-0.03 percent) occurred in 2012, while it was considerably greater (-0.182 percent) in 2011. During thecalibration period (2011-2012), the maximum volume of flow was seen in 2013, with a simulated volume of 1523.76 mm^3 and an observed volume of 1742.22 mm^3. Similarly, in the year 2012, the lowest volume of flow was 991.72 Mm^3 as simulated and 1028.63 Mm^3 as observed. The summary result illustrated model performance in terms of indices like RMSE standard deviation, NSE and percent bias by comparing the simulated and observed flow of the watershed.

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Rahul et al., (2015), used SMA method in HEC-HMS to model the stream flow in the Vamsadhara river basin in India. He reported that during calibration period the performance indices obtained were R^2-0.71, Nash-Sutcliffe Efficiency(NSE) - 0.701, percentage error in volume PEV = 2.64% and percent error in peak PEP= 0.21%. Similar results were also reported by Najim et al., (2006) and Sabzevari et al., (2009), with relative percent errors between observed and simulated values of less than 20%. Cheng et al., (2002) also proposed that if the percent error of the runoff volume is less than 20%, the runoff model is considered satisfactory. On comparison with the above results, the statistical indices obtained in the present study were within the acceptable limits for estimating runoff over the basin. According to the statistical evaluation criterion, positive percent error numbers indicated model underestimation bias, whereas negative values indicated model overestimation bias.

Validation of HEC-HMS model

Figures 8 and 9 represent the comparison of simulated and observed hydrographs over the validation period (2014-2015). For relatively longer duration storms, a similarity in the trend of simulated and observed hydrographs was displayed. Simulated values were likewise found to be close to observed values. However, for short-duration storms, there was a slight variation between the recordedand observed hydrograph. This may be fact that due to differences in rainfall occurrences in specific sub basins that were not recorded by the gauge record at the time.

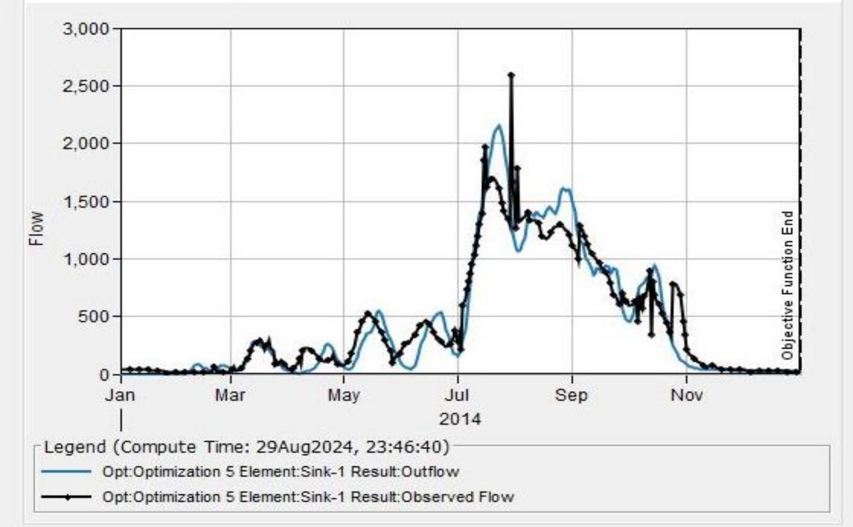

Fig. 9 Simulated and observed hydrograph for the year 2014

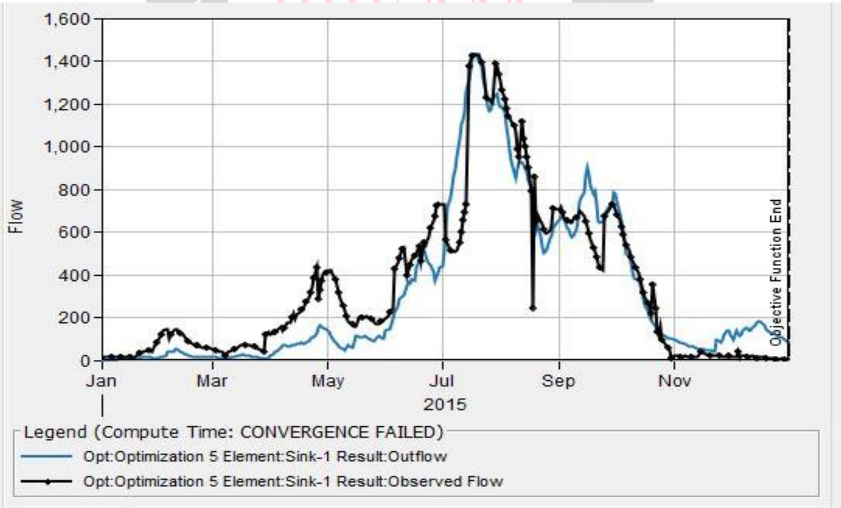

Fig. 10 Simulated and observed hydrograph for the year 2015

The value of coefficient of correlation (R^2) was found greater than 0.7 in all the validation years as shown in Fig. 10 which indicated the satisfactory performanceof the model.

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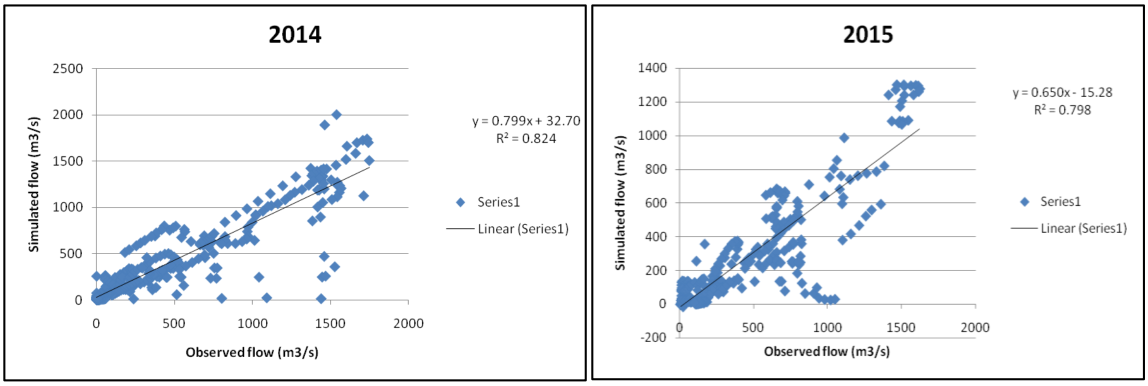

Fig. 11 Scatter plots of observed versus simulated flow during validation

Table 6 Performance indices of the model during validation

S.N.	Year	Nash Sutcliffe Efficiency (NSE)	Percent bias(PBIAS)	Error in Peak Flow (%)	Error in Volume (%)	Coefficient of correlation (R^2)	Root mean square error- standard deviation ratio (RSR)
1	2014	0.868	-1.09	0.3	-7.47	0.824	0.4
2	2015	0.861	-7.44	-16.8	-1.08	0.798	0.4

The percent error in peak flow is small and close to the observed flood peakwithin the permissible limit of 20%, as shown in the results. During the validation

period, the maximum peak discharge occurred between July and September. The Fig.

8 clearly indicates that maximum peak discharge was 1205.66 m^3/s which occurred in the year 2014. The total volume of discharge from the basin after settlement of all losses was computed to evaluate the volumetric error and it was found that the calibrated discharge volume was close to the observed discharge volume within the acceptable limit of 20% of total volume. It was also in the acceptable range because the RSR value was less than 0.5. Moreover, the Nash Sutcliffe Efficiency (NSE) value for the validation period was in the range of 0.861-0.868, which was acceptable. According to Roy et al., (2013), the Nash-Sutcliffe efficiency, error percentage in volume, peak error percentage and net difference of observed and simulated time to peak were utilized for model efficiency analysis. The values were found to vary from (0.861-0.868), (-1.09 to -7.44%), (0.3 to -16.8%) and (0 to 1 day) respectively. The results on comparison indicates good performance of the model for simulation of stream flow and thereby quantification of available water.

Comparison of observed and simulated measures of flow for the basin

During the simulation period (2011-2015), the maximum volume of flow was observed in 2013, with a simulated value of 1523 mm^3 and an observed value of 1747.22 Mm^3. Similarly, the lowest volume of flow was seen in 2015, with a simulated value of 879.84 Mm^3 and an observed value of 950.9 Mm^3.

The highest peak flow of the river was obtained in 2013, with a predicted value of 2555.8 m^3/s and a measured value of 2300 m^3/s. The lowest peak flow was obtained in 2012, with a predicted value of 1385.8 m^3/s and a measured value of 1555m^3/s. Overall, it was found that all of the observed and simulated values in the table showed a strong positive correlation.

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Table 7 Comparison of observed and simulated flows

Measure	Simulated	Observed	Year	Time of peak
Peak flow rate(m^3/s)	2312	2865	2011	22 Sep 2011
Volume(Mm^3)	1443.79	1180.76		
Peak flow rate(m^3/s)	1385.8	1555	2012	19 Aug 2012
Volume (Mm^3)	991.72	1028.63		
Peak flow rate(m^3/s)	2555.8	2300	2013	20 Oct 2013
Volume(Mm^3)	1523.76	1747.22		
Peak flow rate(m^3/sec)	2153.6	2589	2014	23 Jul 2014
Volume(Mm^3)	1205.66	1218.78		
Peak flow rate(m^3/s)	1431.7	1385	2015	19 Jul 2015
Volume(Mm^3)	879.84	950.9		

V. CONCLUSION

The HEC-HMS model which is a widely usedhydrological model was chosen for river basin management, simulation of watershed responsesand generation of flood hydrographs in this study. The simulated runoff will be useful for well-planned programmes in water conservation and resource management projects and futureprediction of runoff for flood mitigation strategies in the catchment.

During the calibration period (2011-2013), the highest flow volume was seen in the year 2013 with 1523.76 Mm^3/year as the simulated flow and 1747.22 Mm^3/year as the observed flow. Similarly, lowest volume of flow was seen in the year 2012 with 991.72 Mm^3/year as simulated and 1028.63 Mm^3/year as observed. During the validation period (2014-2015), the highest volume of flow was seen in the year 2014with a flow of 1205.66 Mm^3/year as simulated and 1218.78 Mm^3/year as observed. Likewise, lowest volume of flow was seen in the year 2015 with a flow of 879.84 Mm^3/year as simulated and 950.9 Mm^3/year as observed. The highest peak flow of river was observed during the year 2013 and it was predicted as

2555.8 m^3/s whereas as the observed value was 2300 m^3/s. Since the error in peak flow was in the range of ±20% the predicted value may be accepted. Statistical Performance indices of the model, Nash-Sutcliffe efficiency (NSE) and Coefficient of correlation (R^2) values were obtained above 0.7, Error inPeak Flow (%) and Error in Volume (%) were figured below 20 and Root mean square error- standard deviation ratio (RSR) was acquired as 0.5 and below. All these values indicated satisfactory performance of model simulation both in calibration and validation. The better performance of model in rainfall-runoff transformation proved applicability of HEC-HMS model in the study area in spite of the limited data availability.

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