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# FLOOD MODELING OF THE SURMA-KUSHIYARA RIVER BASIN USING HEC-HMS

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## Abstract

Flood modeling and simulation helps in anticipating flood events thus can minimize flood damage. This study simulated flood occurrences at Surma-Kushiyara river basin which is situated at the north-east part of Bangladesh. Digital elevation model (DEM) of the study areas was used in ArcGIS 10.3 interface to delineate basin, sub-basin and stream networks. With the help of HEC-GeoHMS hydrologic parameters of the river basin such as basin slope, basin area, river length etc were extracted from DEM. These extracted hydrologic parameters were applied to imitate the rainfall-runoff model using HEC-HMS. In this study model has been calibrated for two years and validated for one year. Surma-Kushiyara river basin and upper Surma-Kushiyara river basin has been calibrated for the years of 2009, 2010 and validated for the year of 2011.In addition, to check the efficiency of the results, statistical evaluation was also performed. The study had generated an inclusive description of the basin with decent precision and the R-squared value of the rainfall-runoff model for the Surma-Kushiyara river basin and upper Surma-Kushiyara river basin was found to be 0.93 and 0.79 respectively. This study concludes that rainfall-runoff model using HEC-HMS gives satisfactory result of flood simulation in the Surma-Kushiyara river basin.

**Keywords:** *Digital elevation model, flood, HEC-GeoHMS, HEC-HMS, Rainfall-Runoff model, statistical evaluation.*

## Introduction

Flood indicates a high stage in river and normally the level at which the river overflows its banks and inundates adjoining area (K Subramanya, 2008). Various factors are responsible for this natural incident. Factors include urbanization, river erosion, removal of forest area, insufficient drainage network and systems; however, heavy and continuous rainfall is the main contributing factor. After a rainfall, amount of water that reaches the outlet waterways depends on catchment characteristics. River characteristics and adjacent structures also affect flooding as well as the economic, social and environmental consequences of flood (Garrett, 2011). Therefore, it is important to analyze any flood events and response of catchment to excessive rainfall. Using GIS platform together with rainfall-runoff modeling can help in this regard. GIS uses digital elevation model (DEM) to generate catchment characteristics as well as delineating catchment and determining drainage line which is used as an input parameter in rainfall-runoff model (Ramly and Tahir, 2016).

Among many rainfall-runoff model software programs, HEC-HMS is a widely used program for rainfall-runoff modeling. It gives relationship between runoff from a catchment in response to rainfall in that catchment. HEC-HMS as rainfall-runoff model has been applied to various studies for flood forecasting in various river basins (Knebl *et al.*, 2005; Oleyiblo *et al.*, 2010). Apart from flood forecasting, it can also be used in land use change analysis(Ali *et al.*, 2011) and stream flow analysis (Chu *et al.*, 2009; Zhang *et al.*, 2013).

Bangladesh is situated in low-lying deltaic flood plain of the GBM (Ganges–Brahmaputra–Meghna) river basin. Monsoon rainfall and poor drainage system causes large scale flooding in the country (Winston *et al.*,2010). From June to October heavy monsoon rainfall occurs and annual average rainfall fluctuates from 1200 mm to 5800 mm from west to northeast region of Bangladesh (Rahman *et al.*, 1996). About 20% region of Bangladesh (31,000 $km^2$) becomes flooded in typical flood year and 80% of the region is regarded flood vulnerable (Mirza, 2002). Floods in 1988, 1998, 2004 and 2007are considered as disastrous and lead to one to two million metric tons of rice loss, or 4–10 % of the yearly rice production (Islam *et al.*, 2009). The northeast hydrological region is one of the depressed part of the Bangladesh consisting principal rivers are the Barak (Surma and Kushiyara), Juri, Manu and Khowai all of which originate from Assam and Meghalaya hilly areas of India. During heavy rainfall in the upland area, water moves quickly towards the southwestern direction through a number of rivers and tributaries and causes flood in haor-featured basin. In 2004 flooding, haor areas

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situated in the northeast side (Netrokona, Sherpur, Sunamganj, Sylhet, Moulvi Bz. &Habiganj) of the country suffered from flash floods that ruined a significant amount of the boro rice crop. The monsoon flooding eventually devastated 36 million people dueling in the northwestern, northeastern and central districts (GOB, 2005).

Northeast region of Bangladesh comprised of hilly areas. As the region is comprised of hilly areas, the terrain is sunken below the surrounding area. Due to lack of proper hydrological data in the northeast depressed zone of Bangladesh, creating a hydrologic model to aid flood forecasting of this region is a troublesome matter.

*Objectives of the Study*

*(a)* To model the flood flow of Surma-Kushiyara river basin and doing so a hydrologic model using HEC-HMS has developed.

*(b)* To calibrate the HEC-HMS model for flood simulation.

*(c)* To assess the performance of calibrated model in simulation of flood.

*Study Site*

Surma-Kushiyara river basin is an important river system of north-east part of Bangladesh. It is a transboundary river basin and has an area of approximately 39,009 km$^2$. It is situated between 89°58'48.908" and 93°2'46.873" east longitudes and in between 23°59'38.816"and 25°44'49.154" north latitudes. The upper Surma-kushiyara river basin which is located within the Surma-Kushiyara river basin is situated between 92°58'58.368" and 91°45'26.386" east longitudes and in between 25°8'28.593" and 24°0'9.382" north latitudes shown in Fig. 1. In this basin, there are 3 rainfall station and 3 discharge measuring gauge station. Surma, Kushiyara, Barak, Juri, Manu, Khowai are some of the major rivers in this basin.

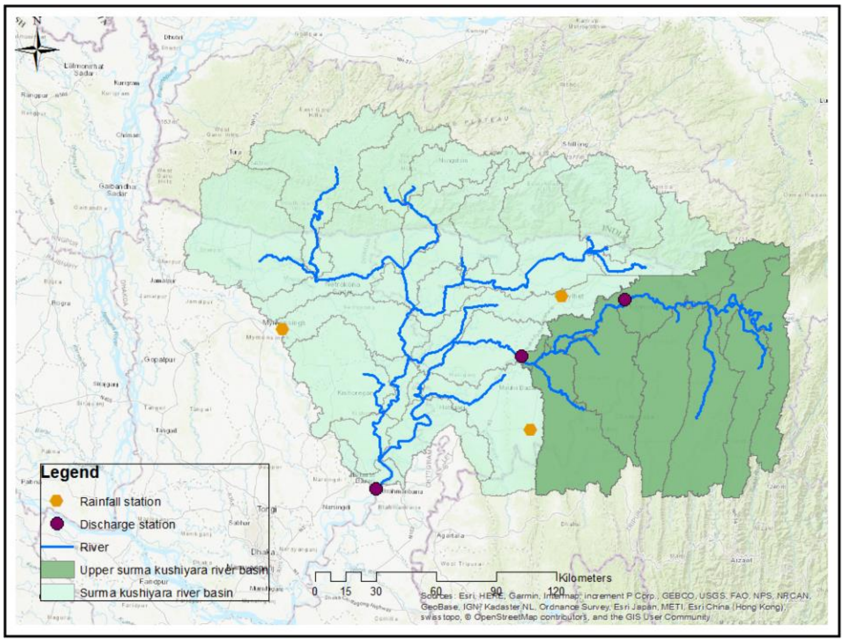


**Fig. 1.** Location map of the study area

## Methodology

Based on the important flood vulnerable areas within the study area and as well as for better simulation of the model, the total study area was divided into two basins namely upper Surma-Kushiyara river basin and Surma-Kushiyara river basin. In order to generate the hydrological model for the study area a 5-steped model was developed. The steps were followed, (i) geographic location of the studied area was obtained from satellite imagery; (ii) various kind of data such as rainfall data, discharge data, water level data were collected and compiled; (iii) using HEC-GeoHMS, useful hydrologic parameters of the basin were extracted from DEM; (iv) extracted hydrologic parameters and processed data were imported to HEC-GeoHMS; (v) incorporating observed data with model simulated data for model calibration and validation.

*Data Collection and Processing*

SRTM 1 Arc-second global DEM data was used for the study. The data was collected from USGS Earth explorer website. In order to fully cover the catchment area six DEM raster files were collected and merged. Daily rainfall data were collected from Bangladesh Meteorological Department for the three rainfall stations located in Sylhet, Sreemangal and Mymensingh. Daily stage data and weekly discharge data were collected from three discharge stations of Bangladesh Water Development Board which are located in Bhairab bazar, Sherpur and Sheola. Using rating curve daily discharge data were obtained from corresponding daily stage data.

In order to obtain input parameters for hydrologic model setup, at first terrain preprocessing was carried out using HEC-GeoHMS terrain preprocessing platform. Steps for terrain preprocessing were DEM reconditioning, filling sinks, obtaining flow direction, flow accumulation, defining stream, segmentation of stream, delineating catchment grid, converting catchment grid to catchment polygon, processing drainage line and adjoin catchment. After completing terrain preprocessing, physical characteristics such as river length, river slope, basin slope, basin centroid, and longest flow path were calculated using HEC-GeoHMS.

*Rainfall-Runoff Model Set Up: HEC-HMS*

Rainfall-runoff model set up is done using Hydrologic Engineering center's Hydrologic modeling System (HEC-HMS) which was developed by U.S Army Corps of Engineers. The model simulates hydrologic response in dendritic watershed. In order to, simulate a rainfall-runoff model via HEC-HMS, the HEC-HMS project must have the following components: a basin model, a meteorological model and control specifications. Physical properties of the basin is represented by the basin model. Using HEC-GeoHMS, the physical characteristics of the watershed was developed and it was then imported in HEC-HMS. The meteorological model uses precipitation data, evapotranspiration data and snow melt data for model set up. Both point and gridded data can be used in the meteorological model. In this study, point data was used. Using the three rain gauges data in the study area, Inverse Distance Weighted (IDW) interpolation was used to get the precipitation data for the entire catchment. The control specifications component contains simulation time and time interval for the simulation.

The SCS (soil conservation service) curve number method was used for infiltration loss and the SCS unit hydrograph was used to transform precipitation excess to direct run-off. Constant monthly base flow was used to model the base flow component for the catchment. Finally the Muskingum routing method was adopted to route the reach. In order to best fit observed and simulated hydrograph, HEC-HMS built-in optimization procedure was followed to adjust the parameters so that observed and simulated hydrographs fits precisely. Fig. 2 and Fig. 3 respectively present the HEC-HMS model for upper Surma-Kushiyara river basin and Surma-Kushiyara river basin. The model was calibrated for year 2009 and 2010 and validated for year 2011.

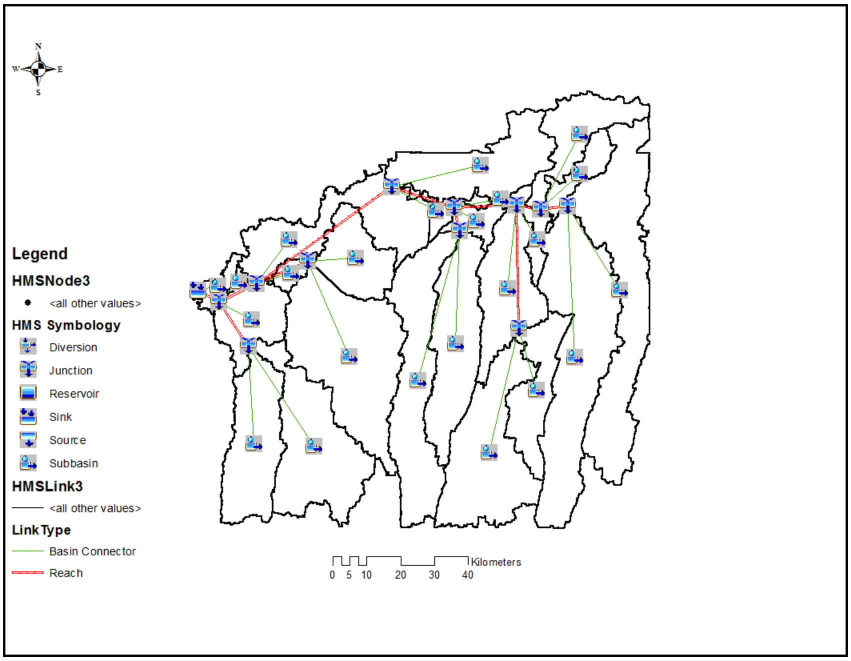


**Fig. 2.** HEC-HMS model set up for upper Surma-Kushiyara River basin

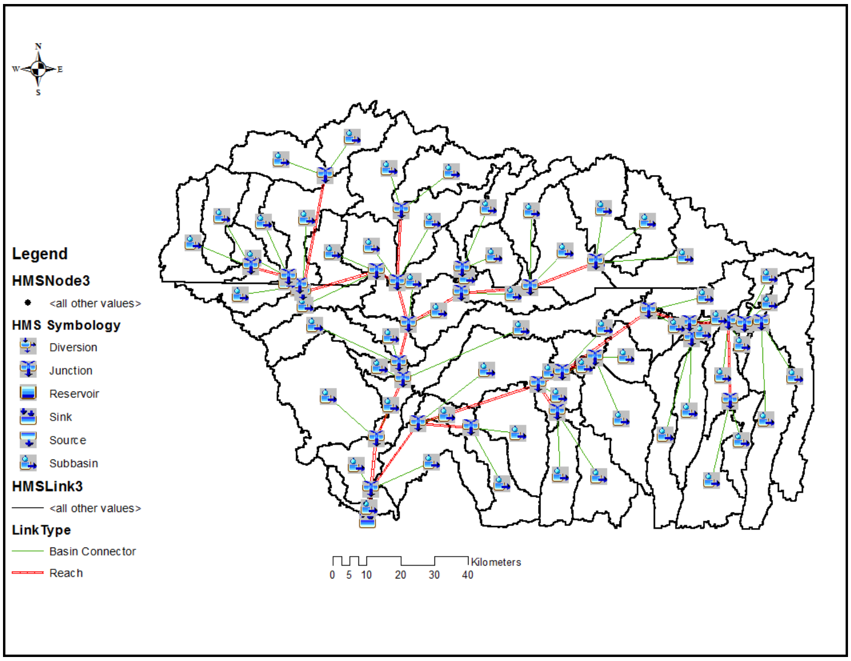


**Fig. 3.** HEC-HMS model set up for Surma-Kushiyara River basin

## Results and Discussion

*Calibration of HEC-HMS Model for Flood Simulation*

As mentioned in the model set up, the model was calibrated using the data for two years and validated with one year data. Both Surma-Kushiyara river basin and upper Surma-Kushiyara river basin were calibrated for years 2009 and 2010. But due to lack of observed discharge data, simulation of HEC-HMS model for Surma-Kushiyara river basin was done for the months of July to October of 2009 and 2010.The observed and simulated discharge is presented in Fig. 4 and Fig. 5 respectively for the year 2009 and 2010. Similarly, simulation for upper Surma-Kushiyara river basin was done for the months of April to October of 2009 and 2010and similarly presented in Fig. 6 and Fig. 7 respectively. It can be observed from figure 4 that a distinctive simulated and a distinctive observed peak discharge both occurred around the same day. In contrast, multiple peak discharges can be perceived in observed discharge data in Fig. 5, Fig. 6 and in Fig. 7. Model simulated discharge also have multiple peaks and approximately identical to observed discharge data referred in Fig. 5, Fig. 6 and in Fig.7.

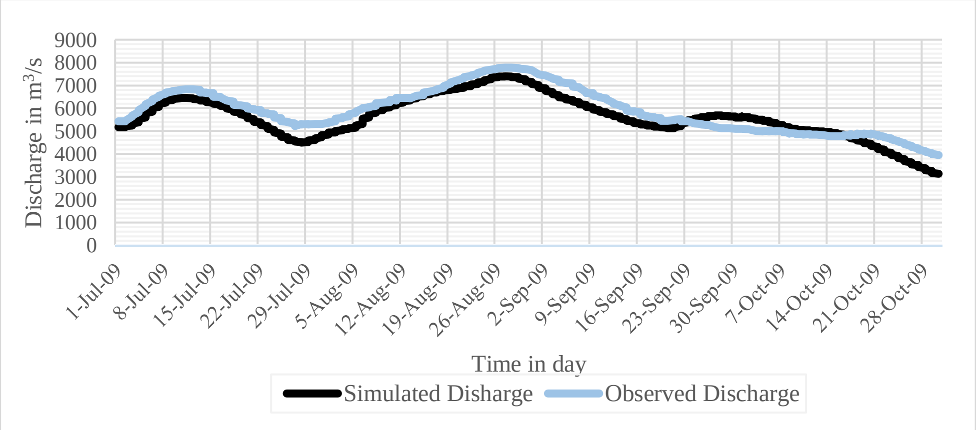


**Fig. 4.** Model Calibration for Surma-Kushiyara River basin for the year of 2009

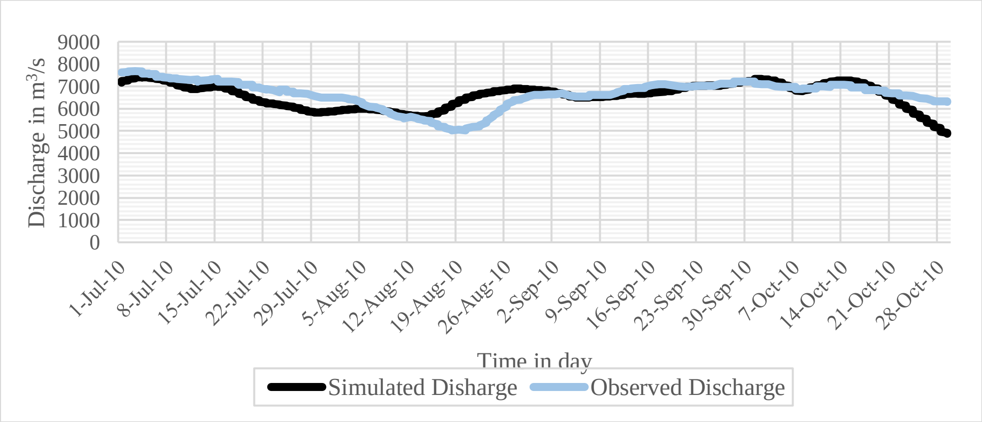


**Fig. 5.** Model Calibration for Surma-Kushiyara River basin for the year of 2010

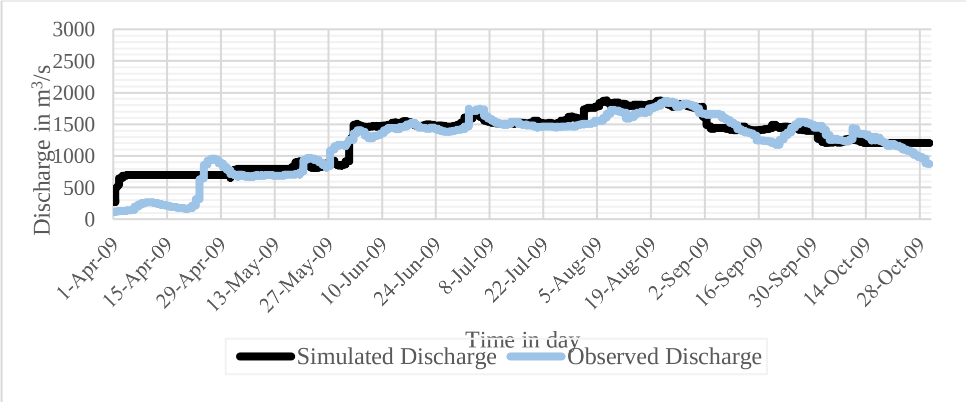


**Fig. 6.** Model calibration for upper Surma-Kushiyara River basin for the year of 2009

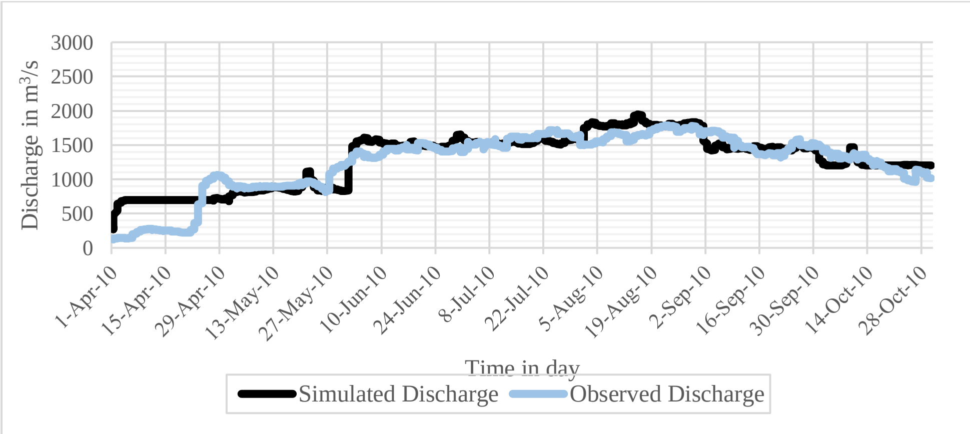


**Fig. 7.** Model calibration for upper Surma-Kushiyara River basin for the year of 2010

Root mean square error, Nash-Sutcliffe model efficiency coefficient and mean absolute percentage error were calculated (Table 1) using model calibrated results and observed data to showcase the efficiency of the model.

**Table 1.** Statistical evaluation of the calibrated results

| Simulation duration | Basin | Gauge station used for calibration | Root Mean Square Error (RMSE) | Nash-Sutcliffe model efficiency coefficient (NSE) | Mean absolute percentage error (MAPE) |
|---|---|---|---|---|---|
| 1st July 2009 to 31st October 2009 | Surma-Kushiyara river basin | Bhairab Bazar | 166.3 | 0.764 | 7.44 |
| 1st July 2010 to 31st October 2010 | Surma-Kushiyara river basin | Bhairab Bazar | 205.26 | 0.527 | 5.81 |
| 1st April 2009 to 31st October 2009 | upper Surma-Kushiyara river basin | Sherpur | 197.90 | 0.814 | 34.48 |
| 1st April 2010 to 31st October 2010 | upper Surma-Kushiyara river basin | Sherpur | 200.2 | 0.79 | 30.42 |

*Performance of Calibrated Model in Simulation of Flood for Year 2011*

Model validation, which is an essential test for any simulation case, is achieved by applying the model to the second set of data for the period of July to October of 2011 for Surma-Kushiyara river basin and April to October of 2011 for the upper Surma-Kushiyara river basin. The verification process of the model has been achieved by making a comparison between the observed and computed discharge of the basin. Results of the verification process show that the observed and simulated discharge are very much identical to each other as shown in Fig. 8 and Fig. 9.

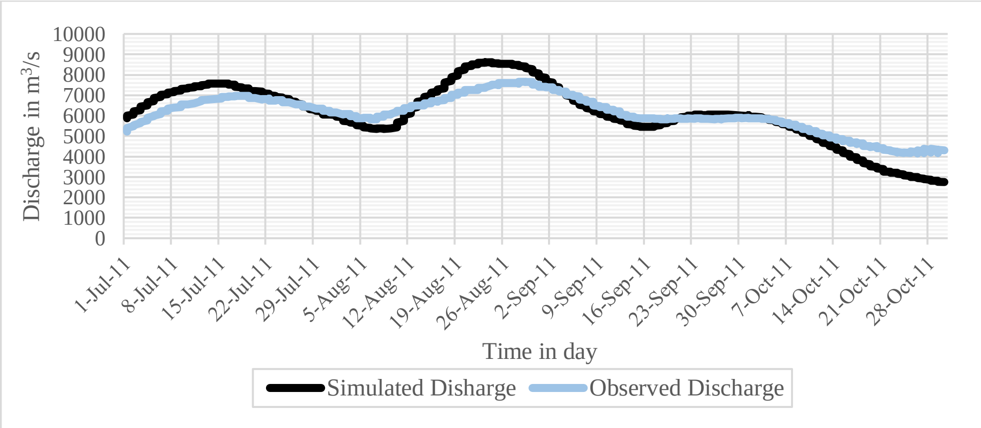


**Fig. 8.** Model validation for the Surma-Kushiyara River basin for the year of 2011

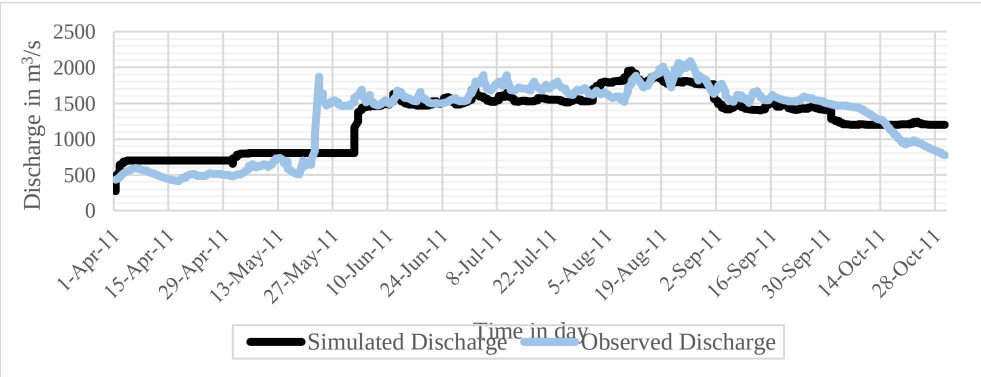


**Fig. 9.** Model validation for the upper Surma-Kushiyara River basin for the year of 2011

**Table 2.** Statistical evaluation of the validated results

| Simulation duration | Basin | Gauge station used for validation | Root Mean Square Error (RMSE) | Nash-Sutcliffe model efficiency coefficient (NSE) | Mean absolute percentage error (MAPE) |
|---|---|---|---|---|---|
| 1st July 2011 to 31st October 2011 | Surma-Kushiyara river basin | Bhairab Bazar | 223.5 | 0.52 | 8.69 |
| 1st April 2011 to 31st October 2011 | upper Surma-Kushiyara river basin | Sherpur | 233.04 | 0.772 | 18.09 |

A Nash-Sutcliffe model efficiency coefficient generally ranges from minus infinity to 1. Simulation models which give NSE values ranging from 0 to 1 can be acceptable whereas NSE values closer to 1 represents a more accurate result. In this study, NSE values generated from model predicted discharge and observed discharge both in calibration and validation are above 0.5 (Table 1 and Table 2). Other statistical evaluation such as RMSE and MAPE shows that the results can be acceptable. Another coefficient of determination, the R-squared value of the rainfall-runoff model for the Surma-Kushiyara river basin and upper Surma-Kushiyara river basin was found to be 0.93 and 0.79 which is shown in Fig. 10 and Fig. 11 respectively. The result shows that the rainfall-runoff model gives a well fit simulation and the results can be acceptable.

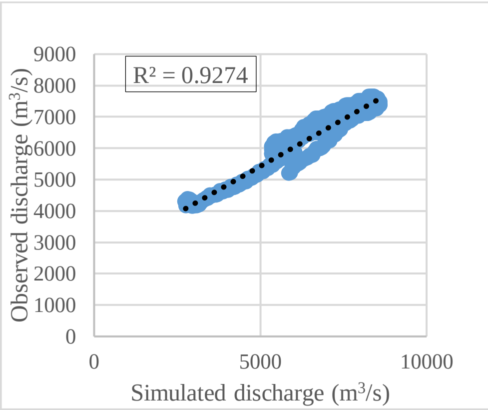


**Fig. 10.** Correlation between observed and simulated discharge for the Surma-Kushiyara River basin for validation period (year of 2011)

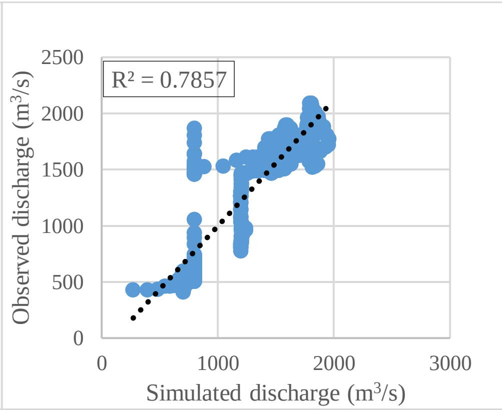


**Fig. 11.** Correlation between observed and simulated discharge for the upper Surma-Kushiyara River basin for validation period (year of 2011)

## Conclusion

From the above results, it is evident that the model simulated peak discharge matches well with the peak discharge of the observed data. Volume of the flood and timing were moderately accurate. Statistical evaluations such as RMSE, NSE, MAPE and $R^2$ has been done for both the calibration and validation period. Based on the statistical evaluations following conclusions can be summarized:

*(a)* For the validation period of the year 2011, RMSE value was 223.5 and 233.04 for Surma-Kushiyara river basin at Bhairab Bazar station and upper Surma-Kushiyara river basin at Sherpur station respectively.

*(b)* Nash-Sutcliffe model efficiency coefficient (NSE) value generated from model predicted discharge and observed discharge in validation period was 0.52 and 0.772 for Surma-Kushiyara river basin and upper Surma-Kushiyara river basin respectively. Both values are less than 1 which shows good efficiency of the model.

*(c)* MAPE value for the model validation period was found 8.69 and 18.09 for Surma-Kushiyara river basin and upper Surma-Kushiyara river basin respectively.

*(d)* R-squared value for the model validation period was 0.93 and 0.79 for Surma-Kushiyara river basin and upper Surma-Kushiyara river basin respectively which is very close to 1, shows that the rainfall-runoff model gives a well fit simulation.

Statistical evaluations RMSE, NSE, MAPE and $R^2$ show that the model predicted the result with good precision. Although there is a scarcity of hydrological data in the Northeast region, the flood simulation model to aid flood forecasting in studied region was developed which can be used to model flood flows of Surma-Kushiyara river basin with good accuracy. Furthermore, it can be said that, with the improvement of data availability in the studied area, the accuracy of the model can be improved and a more accurate simulation can be possible.

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