HYDROLOGICAL MODELING OF KOROTOA RIVER WATERSHED IN BOGURA DISTRICT OF BANGLADESH USING HEC-HMS MODEL

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ABSTRACT

Modeling of rainfall-runoff processes is widely recognized as one of the most difficult tasks of hydrological modeling because it involves the integration of a diverse array of watershed characteristics. The modeling of rainfall-runoff, being its ability to simulate the hydrological behavior of a watershed, plays a vital role in predicting the runoff generated at the outlet of a watershed. The current study focuses on the rainfall-runoff modeling for the Korotoa River watershed in Bogura District of Bangladesh by using the widely used HEC-HMS model developed by the U.S. Army Corps of Engineers (USACE). The primary objective was to estimate the flood forecasting and water resource management capabilities of the model in comparison to the watershed hydrological response simulation rainfall events of different intensities. This study presents the calibration and validation of a hydrological model for the Korotoa River watershed using the observed streamflow data obtained from Khanpur station (SW11) located at the watershed outlet. The model was calibrated for the period from 1 November 2021 to 31 October 2022 and validated over an extended period from 1 November 2022 to 31 October 2023. The Bogura watershed was delineated based the digital elevation model (DEM) data. Furthermore, land use land cover (LULC), soil type, and catchment slopes, were incorporated into the model to define the hydrologic parameters. The SCS Curve Number method was adopted to estimate the losses. Additionally, the SCS Unit hydrograph and the Muskingum method were employed for the transform and routing processes, respectively. The performance of the model was assessed through several standard statistical model perfromance egvaluation metrics, inculding the nash sutcliffe efficiency (NSE), root mean squared error (RMSE), percent bias (PBIAS), and the coefficient of determination (R^2). The results indicate that the model exhibits a strong model performance with NSE values of 0.944 at calibration and 0.795 at validation stages. The simulation of the hydrological model also gives R^2 values of 0.9505 and 0.8157, and PBIAS values of -6.82 and -0.6, respectively at calibration and validation stages. The aforementioned metrics demonstrate a very good performance of the developed hydrological model indicating a very good agreement between the observed and simulated streamflow records. Therefore, it can be concluded that the HEC-HMS model is capable of simulating hydrological characteristics of the Korotoa River watershed in Bogura District of Bangladesh. Thus, the hydrological model developed in the current study can be a reliable and efficient tool for the flood risk assessment and watershed management in the study area and other similar areas in Bangladesh.

Keywords: *Hydrological Modeling; Rainfall-Runoff; HEC-HMS model; Curve Number; SCS Unit Hydrograph; Korotoa River watershed.*

1. INTRODUCTION

Hydrological modeling involves the analysis of how the hydrology of a watershed responds to diverse physical characteristics of the basin. It has been employed in numerous river basins globally to enhance understanding of the availability of water resources systems (Adams et al., 2025; Yilma & Kebede, 2023). Management of water resources in a basin essentially requires understanding of dynamics of basin water and assessment of basin water availability for development use (Cosgrove & Loucks, 2015). The activities to estimate runoff volumes and flood peaks can be easily simplified by adopting a modelling concept and by understanding rainfall partitioning and the principal factors triggering runoff (Zhao et al., 2004). A wide range of hydrological models and software have been developed to simulate rainfall-runoff processes, each varying in complexity, data requirements, and application scope. The type of the modeling approach normally depends on the purpose, data availability and ease of use (Beven, 2012). Hydrological models are essential tools for analyzing, calculating and forecasting water systems, which play a key role in project planning, design, water resource management and flash flood warnings. It allows to predict the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practices (Ranjan & Singh, 2022). Currently, the use of hydrological models plays a vital role in assessing the water availability in river basins and devising effective approaches to manage environmental changes.

The Hydrologic Engineering Center’s Hydrologic Modeling System (HEC-HMS) model, developed by the U.S. Army Corps of Engineers, has been extensively applied in flood forecasting, water resources assessment, and climate change impact studies (Sahu et al., 2023). Its ability to integrate multiple loss models (e.g., SCS Curve Number, Green-Ampt), transform methods (e.g., Snyder Unit Hydrograph, SCS Unit Hydrograph), and routing methods (e.g., MuskingSum, Kinematic Wave) makes it adaptable to various hydrological conditions. HEC-HMS is designed to support both event-based and continuous hydrological modeling, each serving distinct purposes. Event-based modeling focuses on individual rainfall-runoff events, typically simulating short-term processes such as surface runoff, peak flow generation, and flood propagation (Hussain et al., 2021). This approach is widely used in flood risk assessment, storm water infrastructure design, and emergency planning due to its simplicity and efficiency. Event-based models remain vital for immediate flood forecasting and hazard mitigation, continuous models are increasingly recognized as essential for addressing broader water management challenges (Hamdan et al., 2021).

Numerous studies have adopted the HEC-HMS model to explore the impacts of changing precipitation patterns, rising temperatures, and altered land use on watershed hydrology (Sahu et al., 2023; Guduru et al., 2023; Ranjan & Singh, 2022; Hamdan et al., 2021). These studies have highlighted the need for robust continuous modeling approaches to capture the interplay of climatic and anthropogenic factors over time. In recent years the study carried out by Sampath et al. (2015) on runoff simulation in the Tropical Region of Deduru Oya River Basin in Sri Lanka using the HEC-HMS model, demonstrating its effectiveness in simulating runoff. Verma et al. (2022) applied HEC-HMS model for hydrological modeling of upper Sabarmati River basin in Gujarat, India. Tassew et al. (2019) performed a rainfall-runoff simulation with HEC-HMS for the Lake Tana Basin of the Gilgel Abay catchment in the upper Blue Nile basin in Ethiopia, using six extreme daily time-series events. The findings suggested the model’s suitability for hydrological simulations. Saeedrashed (2020) utilized computational hydrological and hydraulic modeling systems that integrate GIS with the modeling systems to predict floodplains for the Greater Zab River using HEC-HMS. Guduru et al. (2023) applied HEC-HMS model for hydrological modeling in the Meki River watershed and Rift Valley River basin, and concluded its efficient capabilities in rainfall-runoff simulations. Furthermore, Hamdan et al. (2021) conducted Rainfall-Runoff Modeling with the HEC-HMS Model for the Al-Adhaim River Catchment, Northern Iraq, affirming its suitability for hydrological simulation. Along with this many studies in Bangladesh have used hydrological models to estimate runoff and evaluate flood risks. Haque et al., (2023) explored the applicability of HEC-HMS model for rainfall-runoff simulation in the Halda River catchment, Bangladesh. Similarly, Nur et al. (2022) use HEC-HMS model for rainfall-runoff simulation of Khowai River basin. In another study, Peker et al. (2024) developed a flood modeling and flood hazard mapping framework by integrating HEC-RAS and HEC-HMS with GIS. They concluded that the integration of these models with GIS can generate flood simulation and assessment in an efficient way. Along with this studied done on Rainfall-runoff modeling using the HEC-HMS flow modeling framework for the Halda River catchment, Bangladesh (Haque et al., 2023). However, there has been limited research focusing on hydrological modeling in the Bogura district of Bangladesh using the HEC-HMS model. Therefore, the aim of the current study is to develop a hydrological model using the HEC-HMS model to simulate the rainfall-runoff processes for the central east part in Bogura district of Bangladesh.

2. METHODOLOGY

2.1 The Study Area

In the current study, Korotoa River watershed in the Bogura district of Bangladesh has been selected as the case study area. The location of the Korotoa River watershed is shown in Figure 1. The rainfall and streamflow gauging stations of the Bangladesh Water Development Board (BWDB) are also shown in the figure. The climate of Bogura is typically tropical monsoon, with hot, humid summers and mild, dry winters. Average annual rainfall ranges between 2,060 mm and 2,136 mm, with over 80% of the precipitation occurring from June to September. The average annual temperature varies from 15°C in January to around 30°C in April–May. Seasonal heavy rainfall, coupled with upstream inflow from major rivers, often leads to flash floods and prolonged inundation, affecting both rural settlements and agricultural lands. Bogura lies within the fertile floodplains of the Korotoa, the Bengali and the Jamuna River systems, making it an agriculturally significant region. The study area falls mostly on the Korotoa River basin and some part of the Bengali River basin. At present, the Korotoa functions mainly as a seasonal river, with noticeably lower flow during the dry months. Despite this decline, the river still plays a vital role in supporting local agriculture, managing drainage and mitigating flood risks especially in flood-prone areas like Bogura district. Due to these characteristics, the Korotoa is chosen for hydrological modeling using the widely used HEC-HMS model, which help in flood forecasting and water resource management efforts of the watershed and surrounding areas.

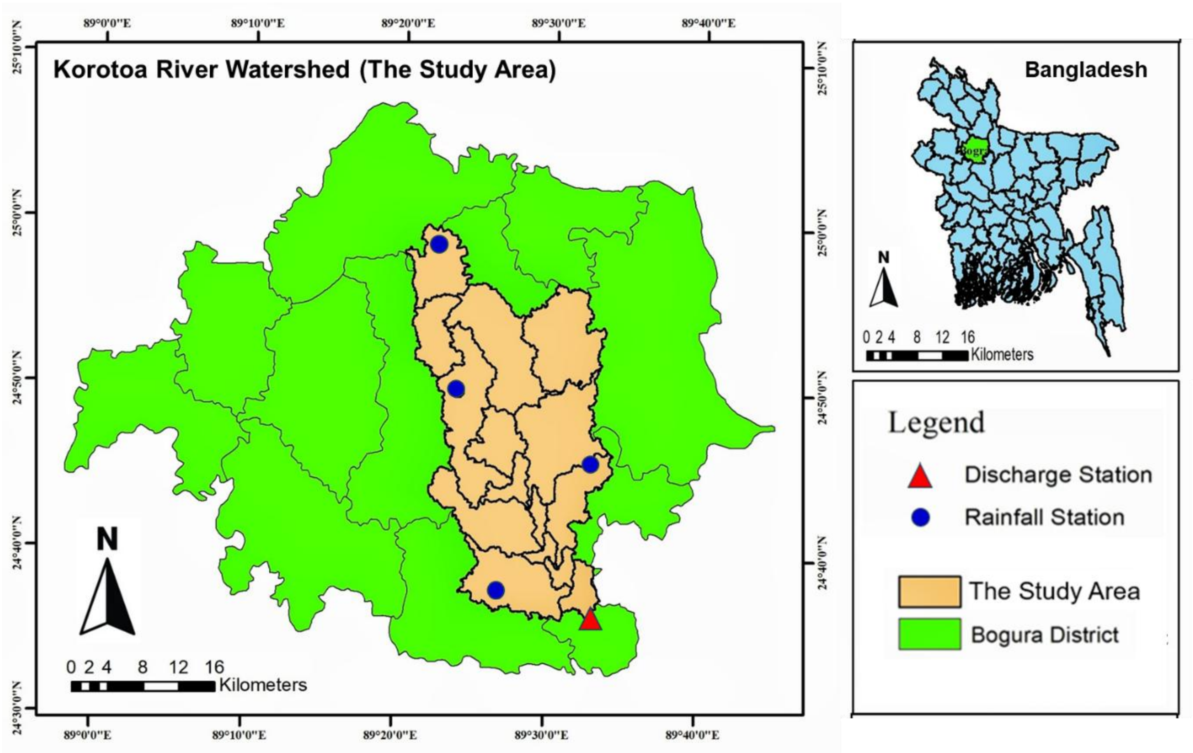

Figure 1: The Korotoa River watershed with rainfall and streamflow gauging stations of BWDB

2.2 Data Collection

Daily rainfall data from four stations within the study area were collected from the Bangladesh Water Development Board (BWDB) for two years period between 1 November 2021 to 31 October 2023. The locations of these rainfall stations are presented in Figure 1. The data were processed using the moving average method to smooth daily variations. Additionally, discharge data were obtained from BWDB for Station ID: SW11, located at the downstream end of the basin, also shown in Figure 1. A summary of the collected data is provided in Table 1. The basin area has been calculated to be about 628.69 km^2.

Table 1: Summary of the collected data for the current study

Data Type	Station ID	Source	Latitude (Degree)	Longitude (Degree)	Data Period
Rainfall	CL176	BWDB	25.000	89.270	2021-2023
	CL6	BWDB	24.871	89.368	2021-2023
	CL33	BWDB	24.678	89.416	2021-2023
	CL11	BWDB	24.689	89.565	2021-2023
Streamflow	SW11	BWDB	24.629	89.464	2021-2023

From the collected rainfall data, a rainfall hyetograph is prepared which is presented in Figure 2. It represents that in July-October of 2023 more precipitation occur at the watershed. Furthermore, soil texture and hydrologic soil group information are collected from the Soil Resources Development Institute (SRDI) of Bangladesh. Land Use Land Cover (LULC) data and Digital Elevation Model (DEM) data are collected from the google earth explorer website. The DEM is imported into the HEC-HMS platform to delineate the watershed boundary, stream networks, and sub-catchments. The soil and LULC maps are overlaid to generate a composite curve number (CN) grid based on the Soil Conservation Service (SCS) method.

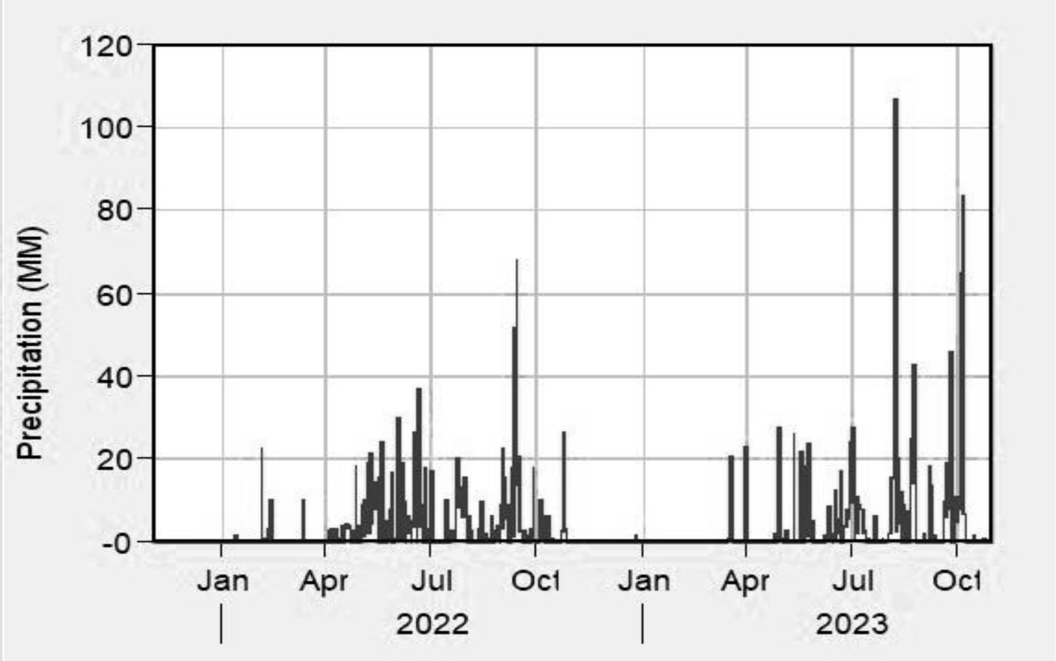

Figure 2: Rainfall hyetograph generated based on the collected BWDB rainfall data

2.3 Data Processing

Using the GIS technology and the HEC-HMS model, the Bogura district watershed is generated systematically by employing DEM. In the current study, the HEC-HMS (version 4.12) model is used to delineate sub-basins in a series of steps: (i) creating a new project in the HEC-HMS model, (ii) generating a new basin model from the component option and downloading DEM data, and (iii) utilizing GIS (ArcGIS; version 10.7.1) to define the coordinate system, fill sinks, preprocess drainage, identify streams, manage break points, and delineate elements (sub-basins) as well as creating the study area map. The CN is calculated to estimate water leakages in soil and is generated automatically based on the land use land cover (LULC) characteristics and hydrological soil groups. Its value varies from 30 (maximum infiltration) to 100 (low infiltration) (NRCS, 1986). The LULC is then re-classified into four fundamental training together with woodland, open water region, agricultural land, and built-up regions. The calculation done for the CN from the CN lookup table used in the model (Guduru et al., 2023). The weighted CN for the Bogura district watershed is then estimated using the Soil Conservation Service Curve Number (SCS-CN) method, which is shown in Figure 3a. The processed data are then formatted into time series input suitable for the HEC-HMS model, which is shown in Figure 3b.

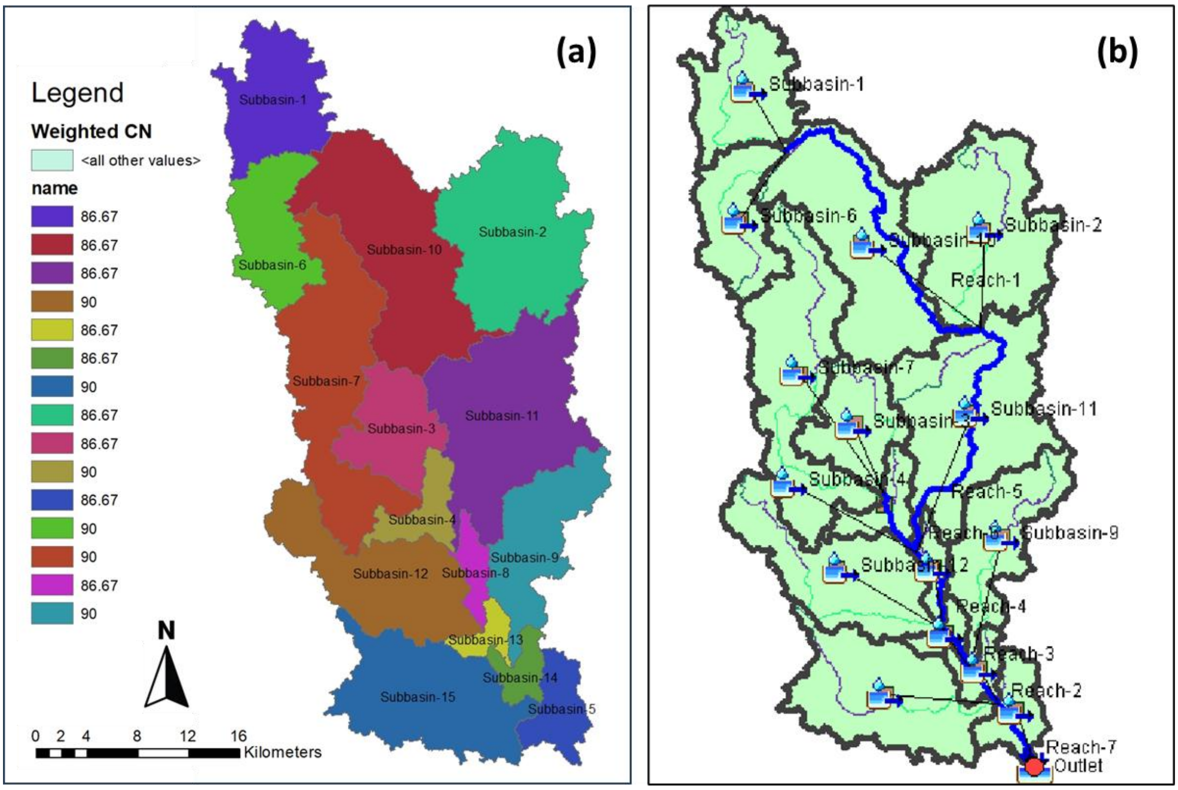

Figure 3: (a) Weighted curve number map of the model watershed, (b) HEC-HMS model domain

2.4 Model Description

The hydrology of any catchment is strongly influenced by climatic conditions, particularly rainfall. Hydrological modelling aids in understanding how rainfall is transformed into runoff through various physical processes. The Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS), developed by the US Army Corps of Engineers (USACE) in 1998, is designed for both continuous and event-based hydrologic modelling. It provides multiple options for simulating different components of the hydrologic cycle. For watershed modelling, the HEC-HMS model contains four components: (i) basin component, (ii) meteorological component, (iii) control specification component, and (iv) input data component (time series, paired data and gridded data).

HEC-HMS integrates various methods for runoff calculation. In this study, The SCS-CN method is used to estimate losses, the SCS Unit Hydrograph method was employed to convert excess rainfall into runoff and the Muskingum method was used to model the flow routing process. Descriptions of the methods, their applicability and definitions are provided in Table 2.

Table 2: Description of methods adopted in calibration of the Korotoa River watershed model

Method Type	**Method Details**	**Parameters**
Loss Method	SCS Curve Number Method	Curve Number (CN), Initial Abstraction (I_a), Potential Maximum Retention (S)
Transfrom Method	SCS Unit Hydrograph Method	Time of Concentration (T_c), Lag time
Routing Method	Muskingum Method	K, X

3. RESULTS AND DISCUSSION

3.1 Hydrologic Parameters

At first, the crucial watershed attributes such as CN, basin lag time, watershed area, potential maximum retention (S), and the initial abstraction from the watershed are established. These values are necessary for the loss and transform methods. The detailed watershed characteristics of the study area are presented in Table 3 and shown in Figure 3. As can be seen from the Figure 3, the study area are divided into 15 subbasin with a minimum area of 6.6483 km^2 in subbasin 13 and maximum area of 81.744 km^2 in subbasin 11. The minimum and maximum weighted curve number values were identified as 86.67 and 90, respectively. Similarly, the minimum and maximum initial abstractions were recorded as 5.64 mm in and 7.81 mm respectively. This discrepancy signifies the variance in runoff values among subbasins. The basin lag time ranged between 76.806 min in subbasin 13 and 285.4009224 min in subbasin 11 for the study area. A lower basin lag time implies quicker surface runoff reaching the outlet point.

Table 3: Calibration parameters for the Korotoa River watershed model

Sub-basin ID	**Parameters**				
	Area (km^2)	**Maximum Retention Potential (mm)**	**Curve Number**	**Initial Abstraction (mm)**	**Lag Time (min)**
Subbasin-1	40.426	39.07	86.67	7.81	201.585
Subbasin-10	79.413	39.07	86.67	7.81	250.001
Subbasin-11	81.744	39.07	90	5.64	285.401
Subbasin-12	56.199	28.22	90	5.64	245.338
Subbasin-13	6.6483	39.07	90	5.64	76.806
Subbasin-14	9.030	39.07	90	5.64	87.257
Subbasin-15	61.763	28.22	86.67	7.81	216.740
Subbasin-2	73.995	39.07	86.67	7.81	187.890
Subbasin-3	30.683	39.07	86.67	7.81	140.899
Subbasin-4	14.128	28.22	86.67	7.81	113.524
Subbasin-5	16.452	39.07	86.67	7.81	105.342
Subbasin-6	33.497	28.22	90	5.64	158.758
Subbasin-7	76.306	28.22	86.67	7.81	262.251
Subbasin-8	8.128	39.07	86.67	7.81	122.301
Subbasin-9	40.275	28.22	90	5.64	218.957

3.2 Model Simulation, Calibration and Validation

The hydrological model has been calibrated using observed data from Khanpur station (SW11) for the period from 1 November 2021 to 31 October 2022 and validate at the same station for an extended period from 1 November 2022 to 31 October 2023. For routing process, the Muskingum method is incorporated. The weighted discharge coefficient (X equals to 0 to 0.5) and the calibrated and validated flood wave travel length (K equals to 0 to 150) are adopted. The final calibrated parameters for the simulation represented that the Muskingum parameter K ranges its values from 55 to 65 for different reaches and parameter X ranges its values from 0.2 to 0.3, which are presented in Table 4.

Table 4: Calibration parameters for river routing simulation

River Reach ID	**Muskingum Parameters**	
	K	**X**
Reach-1	60	0.2
Reach-2	60	0.3
Reach-3	65	0.2
Reach-4	55	0.2
Reach-5	65	0.2
Reach-6	65	0.2
Reach-7	55	0.3

The observed and simulated hydrographs for the calibration and validation periods are shown in Figures 4 and 5, respectively. Additionally, statistical performance metrics such as nash-sutcliffe efficiency (NSE), root-mean-squared-error (RMSE), and percent bias (PBIAS) have been calculated for both calibration and validation and are shown in the corresponding figures. The performance metrics indicate a satisfactory model performance with NSE values of 0.944 for calibration and 0.795 for validation, which fall into the "very good" category (NSE > 0.75) as suggested by Moriasi et al. (2007). The RMSE and PBIAS values are also within acceptable limits. All statistical indices are within the recommended limits described in Moriasi et al. (2007). Furthermore, the comparison between the observed and simulated flows for both calibration and validation periods is shown in Figures 6 and 7, respectively. The coefficient of determination (R^2) calculated for both periods is 0.9505 for calibration and 0.8157 for validation, indicating strong agreement and confirming the reliability of the model.

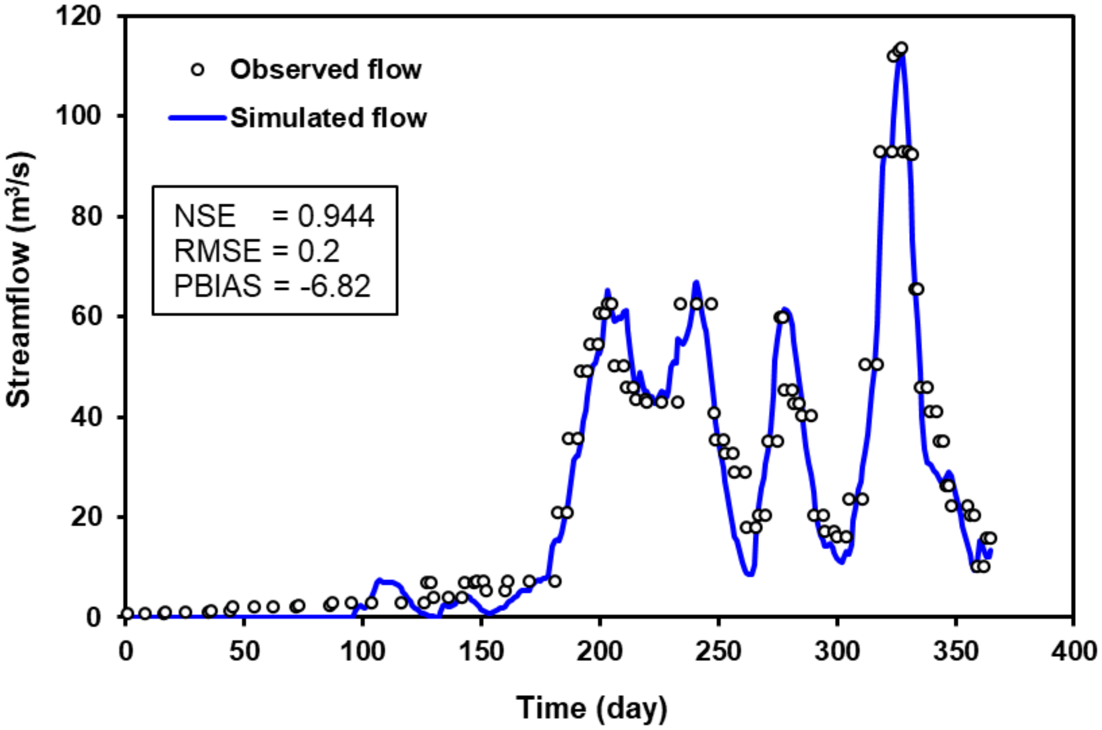

Figure 4: The observed and simulated flow hydrographs at the outlet of the Korotoa River watershed during the calibration stage

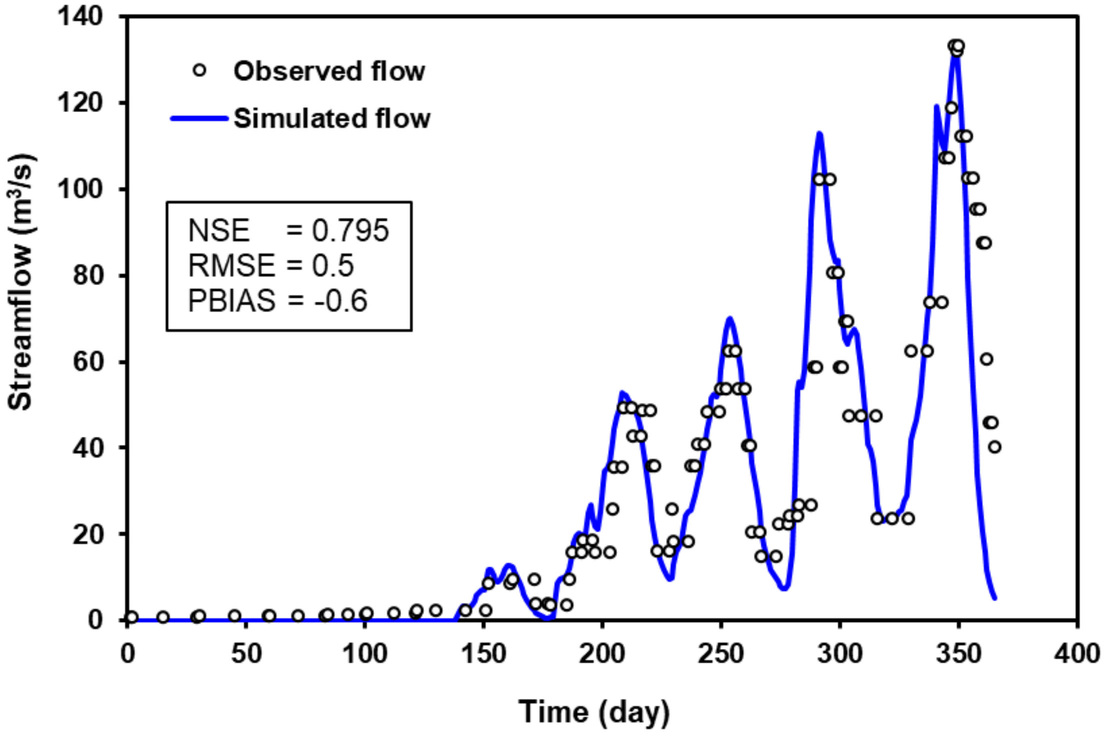

Figure 5: The observed and simulated flow hydrographs at the outlet of the Korotoa River watershed during the validation stage

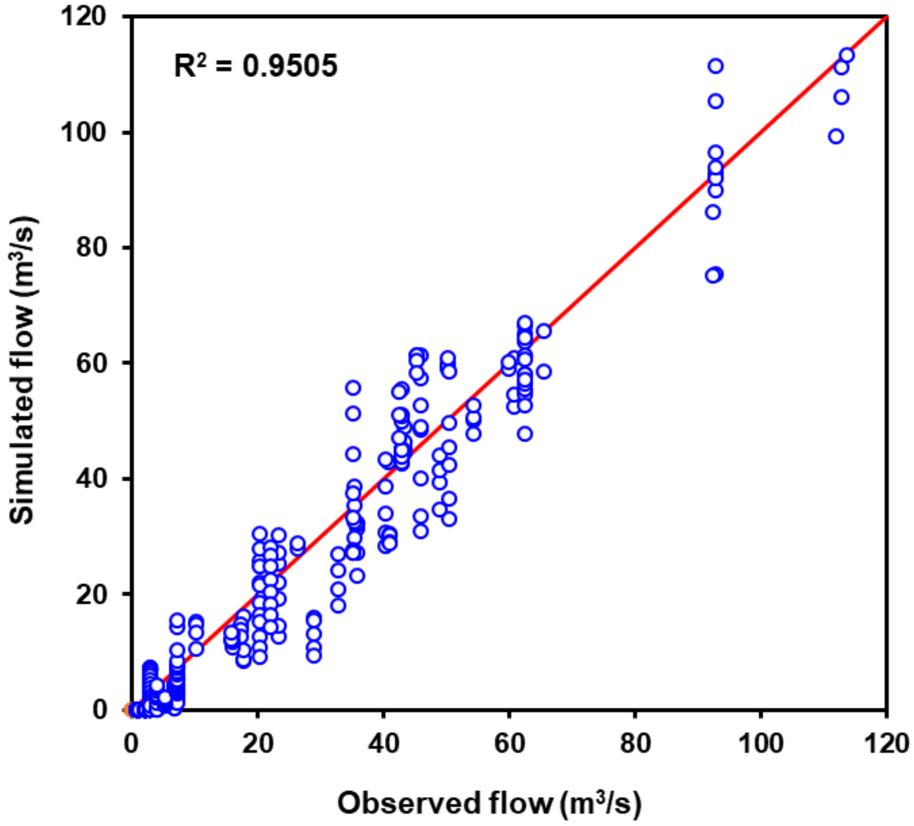

Figure 6: Scatter plot for the observed and simulated flows at the outlet of the Korotoa River watershed during the calibration stage

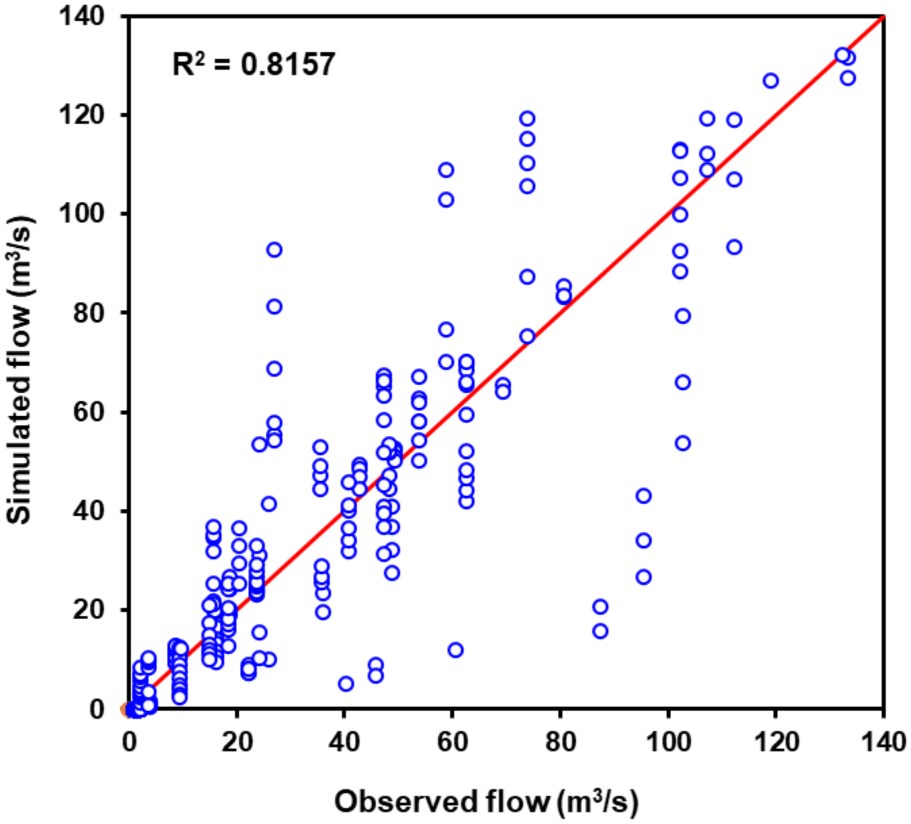

Figure 7: Scatter plot for the observed and simulated flows at the outlet of the Korotoa River watershed during the validation stage

The following Table 5 shows the summary results of the hydrological simulation of the basin. During the calibration period, the simulated and observed peak discharges were 113.3 m^3/s and 113.7 m^3/s respectively while for the validation period, they were 132 m3/s and 133.4 m3/s respectively.

Table 5: Summary of the simulation results of the Korotoa River watershed model

Description	**Calibration stage**	**Validation stage**
Time Period	1 Nov 21 to 31 Oct 22	1 Nov 22 to 31 Oct 23
Peak Discharge (m^3/s)	113.3	132
Volume (m^3)	1074.59	1206.14
Date of Peak Discharge	23 Sep 2022	15 Oct 2023
Observed Peak Discharge (m^3/s)	113.7	133.4
Observed Volume (m^3)	1153.15	1210.98
Observed Date of Peak Discharge	23 Sep 2022	14 Oct 2023

4. CONCLUSIONS

The current study focuses on the development of a hydrological modeling of the Korotoa River watershed in Bogura District of Bangladesh using the HEC-HMS model. The developed hydrological model is referred to as the of the Korotoa River watershed model that demonstrate a strong and reliable performance in simulating streamflow of the Khanpur station (SW11) at the watershed outlet. The calibration and validation results of the Korotoa River watershed model indicate that the model is calibrated satisfactorily and capable of reproducing observed flow patterns with a high degree of accuracy. The efficacy of the model has been assessed using the nash-sutcliffe efficiency (NSE), and coefficient of determination (R^2), achieving values of 0.944, and 0.951, respectively during calibration period. In the validation period, the model performance has slightly decreased as it is expected in most modeling efforts. Accordingly, the model has still maintained an NSE of 0.795, and R^2 of 0.8157, respectively. Other model performance evaluation metrics including RMSE and PBIAS also fall within the recommended acceptable ranges, reinforcing the model's predictive reliability and accuracy. These findings demonstrate the robust performance of the model, indicating that the HEC–HMS model is well-suited for simulating streamflow data based on rainfall data within the study area. Visual comparisons of the observed and simulated hydrographs further support the conclusion that the model effectively captures the flow dynamics during both periods. Overall, the model can be effectively used for future hydrological simulations, water resources planning and management decision making for the Korotoa River watershed in Bagura District or other areas of Bangladesh having similar hydrological settings.

DECLARATION OF USE OF AI

We declare that AI tools were used for grammar correction, language polishing, and improving clarity in the paper where necessary. However, no AI tools were used for developing the research design, methodological development, analysis and interpretation of results, and/or writing of discussion in this paper. We also declare that all research ideas, problem formulations, table and figure preparations, interpretation of results, and writing different secctions of the paper are solely the authors' own work.

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