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Hydrological Modelling and Its Implication in Sustainable Water Resource Management in Gumti River Basin in Bangladesh

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Abstract—**Sustainable water resource management in Bangladesh's Gumti River Basin faces challenges from climate change, urbanization, and population growth. This study aimed to calibrate and validate the Hydrologic Engineering Center—Hydrologic Modeling System (HEC-HMS) model for the Gumti River to enhance flood prediction and water resource planning. The model was set up using precipitation, temperature, and discharge data from 2019–2021, with SRTM elevation data for catchment delineation. Manual calibration was performed for 2019–2020, followed by validation for 2021, using parameters such as Muskingum routing and SCS Curve Number. Model performance was evaluated using R^2, Nash-Sutcliffe Efficiency (NSE), root mean square error-standard deviation ratio (RSR), and Percent Bias (PBIAS) metrics. The calibration and validation R^2 values were 0.64 and 0.68, respectively, indicating satisfactory to good performance. NSE values were within the satisfactory range, while PBIAS indicated very good performance with slight underestimation. The study concludes that the calibrated HEC-HMS model provides a reliable tool for simulating the Gumti River's hydrology, though there's room for improvement. Integration with flood frequency analysis, water quality monitoring, and climate change projections is recommended for comprehensive water resource management, alongside the implementation of Sustainable Water Resource Management principles and community engagement strategies.**

Keywords—**Gumti river, HEC-HMS, hydrological modeling, calibration, parameters, management practices**

I. INTRODUCTION

Hydrology is a branch of science that examines the occurrence, distribution, and circulation of water resources on a global scale, including their physical and chemical characteristics and interactions with surrounding environments [1]. Hydrology provides vital assistance for water resource planning, management, and control by combining engineering and geographical principles [2]. In the context of climate change, accurately estimating water availability in river basins is essential, a task that can be effectively achieved through hydrological modeling [3]. Hydrological models, which can be established utilizing small-scale physical models, mathematical analogies, and computer simulations, offer a simplified yet powerful representation of complex hydrologic systems, making them indispensable for predicting water resource behavior [3–4].

The HEC-HMS (Hydrologic Engineering Center—Hydrologic Modeling System) developed by the United States Army Corps of Engineers is one of the most widely used tools for hydrological modeling [5]. Designed to model the precipitation and runoff processes in watershed systems, HEC-HMS has been applied in various geographical settings to address issues ranging from flood hydrology to urban runoff [6]. The model's versatility, open-access nature, and extensive capabilities have made it a preferred choice among researchers, particularly for applications in large river basins and complex hydrologic scenarios [7]. Calibration and validation of such models are critical to ensure their predictive accuracy and reliability, thereby enhancing user confidence in their application.

In Bangladesh, physically-based hydrological models like HEC-HMS, Soil and Water Assessment Tool (SWAT), Topography-based Hydrological Model (TOPMODEL), Variable Infiltration Capacity (VIC) and MIKE Systeme Hydrologique Europeen (MIKE-SHE) have been extensively utilized [8–12]. Among these, HEC-HMS stands out for its simplicity, user-friendly interface, and robust performance in diverse hydrologic conditions [13]. The model's ability to accurately simulate the hydrologic cycle by dividing it into manageable components makes it highly effective for watershed modeling [14]. Calibration and validation processes, involving the adjustment of model parameters to fit historical data, are essential steps in ensuring that the model can reliably predict future hydrologic events [15]. The performance of these models is typically evaluated using statistical measures such as R^2, Nash-Sutcliffe Efficiency (NSE), Root Mean Squared Error (RMSE), and Mean Absolute Error (MAE).

For the Gumti River in Bangladesh, the need for accurate hydrological modeling is particularly pressing given the region's vulnerability to climate change and the associated hydrological extremes [16]. The Gumti River basin, like many others in South Asia, faces challenges such as variable precipitation patterns, extreme weather events, and significant socio-economic impacts [17]. Effective water resource management in this basin necessitates a reliable hydrological model that can simulate current conditions and predict future scenarios. This study aims to calibrate and validate the HEC-HMS model for the Gumti River, thereby providing a robust tool for flood risk assessment and water resource planning in the region.

The calibration and validation of the HEC-HMS model for the Gumti River will involve an in-depth analysis of the river basin's hydrologic response to precipitation. This process includes the collection and analysis of historical hydrological data, the adjustment of model parameters, and the evaluation

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of model performance through statistical measures. The ultimate goal is to develop a calibrated and validated hydrological model that can accurately simulate the flow hydrograph from tributary catchments, serving as a critical input for further hydraulic modeling and flood risk assessment.

In summary, this study addresses the critical need for accurate hydrological modeling in the Gumti River basin, aiming to enhance water resource management and flood risk assessment through the calibration and validation of the HEC-HMS model. By providing a reliable tool for predicting hydrological responses to climatic and anthropogenic changes, this research contributes to the broader effort of sustainable water resource management in Bangladesh.

II. MATERIALS AND METHODS

A. *Study Area*

The Gumti River originates in the northeastern hills of Tripura, India, and enters Bangladesh near Katak Bazar in Comilla Sadar [18]. Flowing through the Comilla district in southeastern Bangladesh, it ultimately joins the Meghna River at coordinates 23°31′46.0″N 90°42′08.0″E [19]. The section from its entry point into Bangladesh to its confluence with the Meghna forms the core of this research area. The river and its tributaries are shown in Fig. 1. Within Bangladesh, the Gumti River (also known as Gumti) stretches for approximately 135 kilometers [20]. This significant portion of its total length makes it a crucial water resource for the region. The focus of this study is this 135-kilometer stretch within Bangladesh, offering a rich opportunity to explore the river's hydrological characteristics and importance to local communities.

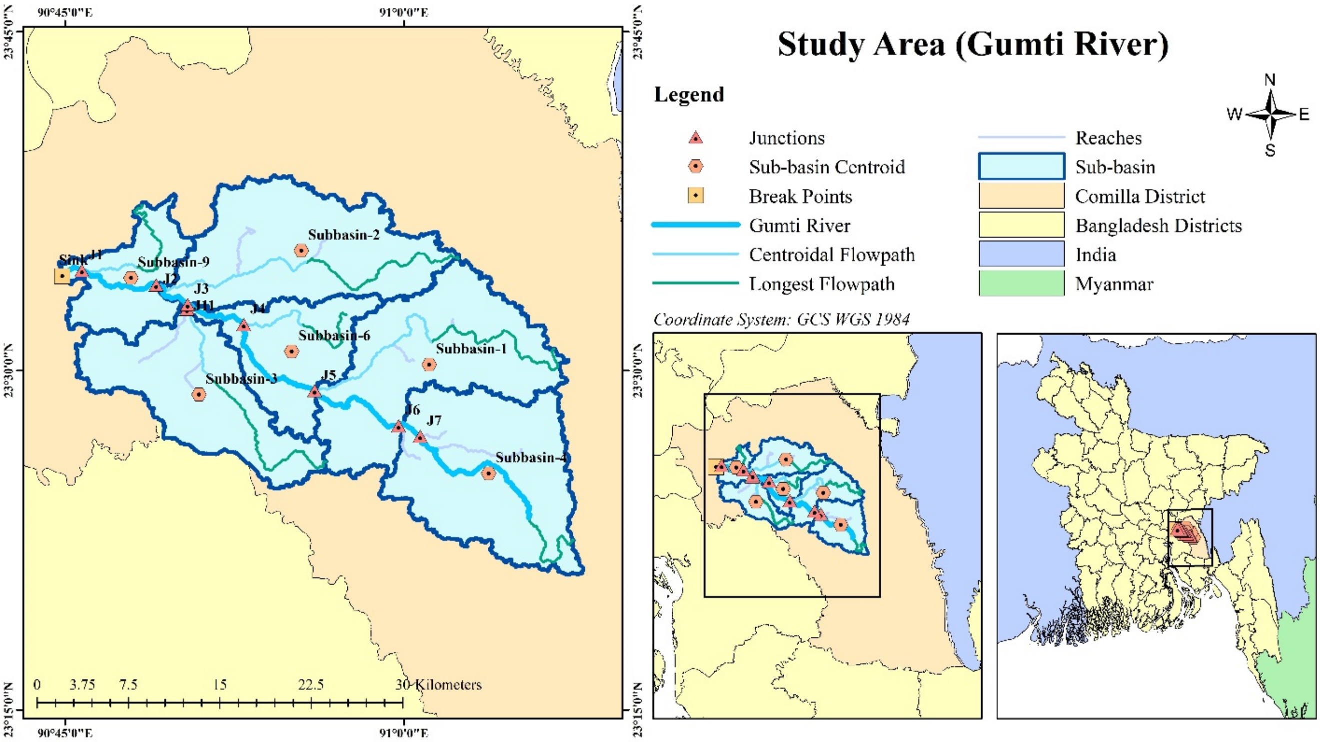


Fig. 1. The drainage system, six sub-basins, and the position of the output flow station (Sink) in the study catchment.

B. *Data Collection*

Daily precipitation and temperature data were collected from one station, Comilla for the past three years (2019–2021) (Fig. 2). Hourly evaporation data for the same years for Gumti river was used in the study (Fig. 2). The precipitation and the temperature data were obtained from the Climate division of the Bangladesh Meteorological Department. The evaporation reanalysis data were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) [21]. Daily river discharge data for the same years at Comilla (SW110) station was obtained from the Bangladesh Water Development Board (BWDB). At the Comilla gauging station, monthly minimum flows were taken into consideration as the base flow in accordance. The SRTM 1 Arc-Second Global elevation data, with a resolution of 30 meters [22], was used for the whole catchment area which provides worldwide coverage in Georeferenced Tagged Image File Format (GeoTIFF), using WGS84 for the horizontal datum and EGM96 for the vertical datum. Table 1 shows the summary of the selected tide stations along with their sources and data availability.

C. *Data Map Preparation*

Using ArcGIS 10.7, the catchment area was drawn. SRTM 1 arc-Second Global elevation data and digitalized stream networks were used in an automated delineation process to define the watershed and subbasins (Fig. 3).

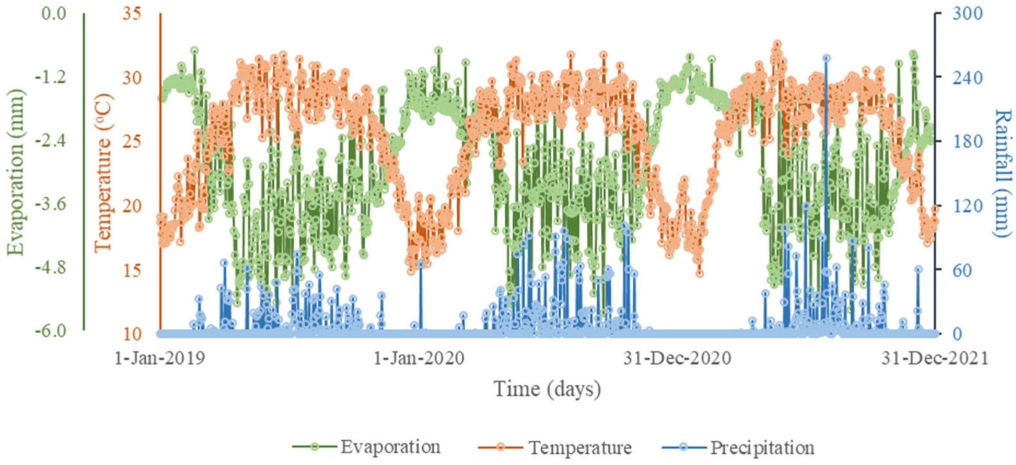
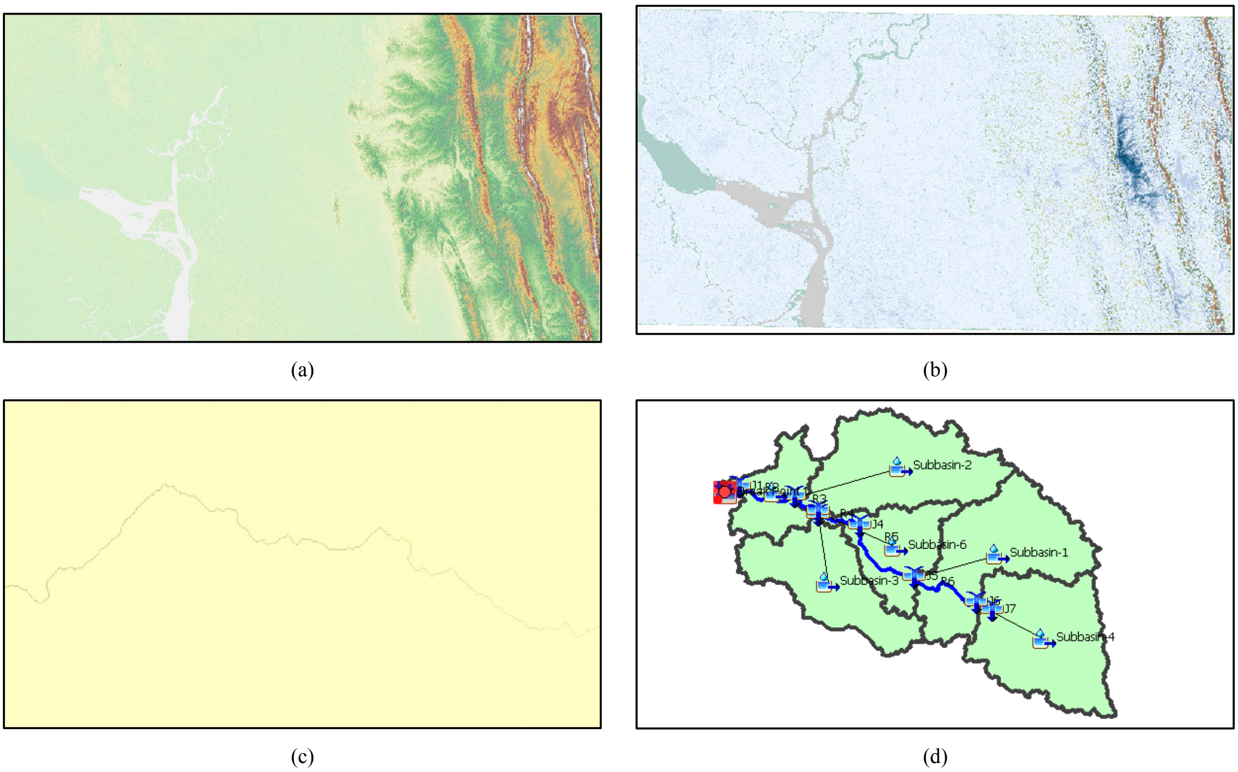


Fig. 2. Graphical representation of the meteorological data collected from various sources.

Table 1. Summary of the selected tide stations along with their sources and data availability

Data Sources and References	Parameters	Station name with availability
Bangladesh Water Development Board (Daily)	Discharge (m^3/s)	Comilla (SW110) (January 01, 2019–December 12, 2021)
Bangladesh Meteorological Department (Daily)	Precipitation (mm), Temperature (°C)	Comilla (January 01, 2019–December 12, 2021)
ECMWF (Hourly) [21]	Evaporation (m of water equivalent)	23°39′00″N, 90°41′24″E; 23°31′12″N, 90°15′00″E (January 01, 2019–December 12, 2021)
USGS [22]	SRTM-DEM 1 arc-second for global coverage (~30 meters)	Whole Catchment Area (2018)



(a) (b)

(c) (d)

Fig. 3. Hydrologic model setup: (a) terrain generation, (b) preprocessing sinks, (c) preprocessing drainage, (d) stream identification and delineation.

D. HEC-HMS Model Set-up

The hydrological analysis model setup was performed using the HEC-HMS 4.11 software, which consists of four primary components: the basin model, meteorological model, control parameters, and input data. The basin model represents the drainage system's water movement through hydrologic elements and their connectivity, The meteorological component distributes precipitation input spatially and temporally across the river basin. For this study, only the Comilla station was utilized, as shown in Table 1, which presents the adopted precipitation, temperature, and discharge stations. Table 2 outlines the model elements and parameters applied in the HEC-HMS setup. The sub-basin methods included Simple Canopy for canopy, Simple Surface for surface, Soil Conservation Service (SCS) Curve Number for loss, SCS

Unit Hydrograph for transform, and Recession for baseflow (Table 2). Additionally, the Muskingum method was applied for reach routing. This comprehensive setup allows for a detailed analysis of the Gumti River's hydrological characteristics within the study area.

Table 2. Element and parameter set up in the HEC-HMS model with references

Model Element	Model Parameter	References
Canopy Method	Simple Canopy	Casulli [23], Minshall [24], Welle and Woodward [25]
Surface Method	Simple Surface	
Loss Method	SCS Curve Number	
Transform Method	SCS Unit Hydrograph	
Baseflow Method	Recession	
Routing Method	Muskingum	Ponce [26]

E. Model Calibration and Validation

To ensure the reliability of the hydrological model's outputs, calibration and validation using observed stream flow data were conducted. All parameters were changed from their original values until a good fit between the simulated and observed stream flows was obtained (Tables 3–5). The model underwent calibration from January 1, 2019, to December 31, 2020, By modifying selected parameters to establish a satisfactory match between simulated and observed data. The validation phase, spanning from January 1, 2021, to December 31, 2021, served as a critical test of the model's performance. This process of comparing simulated stream flow to observed data allows for the evaluation of the model's goodness of fit and its ability to predict and present credible results. As emphasized by Vaze *et al.* [27], validation is a key criterion in assessing a hydrological model's performance, ensuring its applicability and reliability for the Gumti River study area.

Table 3. Tested model parameters of canopy, surface and loss method for calibration and validation processes

Subbasin	Canopy Method (Simple Canopy)					Surface Method (Simple Surface)		Loss Method (SCS Curve Number)		
	Initial Storage (%)	**Max Storage (MM)**	**Crop Coefficient**	**Evapotranspiration**	**Uptake Method**	**Initial Storage (%)**	**Max Storage (MM)**	**Initial Abstraction (MM)**	**Curve Number**	**Impervious (%)**
Subbasin-4	10	60	1.00	Wet and Dry Periods	Simple	10	92	100.37	27.66	60
Subbasin-1	10	60	1.00	Wet and Dry Periods	Simple	10	89	100.00	22.00	58
Subbasin-3	10	60	1.00	Wet and Dry Periods	Simple	10	88	100.00	24.00	56
Subbasin-6	10	60	1.00	Wet and Dry Periods	Simple	10	85	63.64	32.17	60
Subbasin-2	10	60	1.00	Wet and Dry Periods	Simple	10	87	70.35	17.70	55
Subbasin-9	10	60	1.00	Wet and Dry Periods	Simple	10	88	83.16	38.66	60

Table 4. Tested model parameters transform and baseflow method for calibration and validation processes

Subbasin	Transform Method (SCS Unit Hydrograph)		Baseflow Method (Recession)				
	Graph Type	***Lag Time (MIN)***	***Initial Type***	***Initial Discharge (M3/S)***	***Recession Constant***	***Threshold Type***	***Ratio to Peak***
Subbasin-4	Standard (PRF 484)	408.88	Discharge	8	0.20	Ratio to Peak	0.3
Subbasin-1	Standard (PRF 484)	765.96	Discharge	7	0.25	Ratio to Peak	0.3
Subbasin-3	Standard (PRF 484)	596.19	Discharge	6	0.30	Ratio to Peak	0.3
Subbasin-6	Standard (PRF 484)	524.94	Discharge	7	0.25	Ratio to Peak	0.3
Subbasin-2	Standard (PRF 484)	748.33	Discharge	6	0.31	Ratio to Peak	0.3
Subbasin-9	Standard (PRF 484)	408.49	Discharge	8	0.23	Ratio to Peak	0.3

Table 5. Tested model parameters routing method for calibration and validation processes

Reach	Routing Method (Muskingum)			
	Initial Type	**Muskingum K (HR)**	**Muskingum X**	**Number of Subreaches**
R7	Discharge = Inflow	133.15	0.07573	2
R6	Discharge = Inflow	149.00	0.01100	2
R5	Discharge = Inflow	149.00	0.00120	2
R4	Discharge = Inflow	149.00	0.00125	1
R11	Discharge = Inflow	149.00	0.02000	1
R3	Discharge = Inflow	149.00	0.02000	1
R2	Discharge = Inflow	149.00	0.01000	1
R1	Discharge = Inflow	115.26	0.01802	1

The model was manually calibrated to optimize and obtain the best possible fit. Parameters optimized for good calibration included Muskingum-K, Muskingum-x, SCS Curve Number—Initial Abstraction, and SCS Curve Number—Curve Number. The calibration and validation performance of HEC-HMS 4.11 was assessed by comparing daily simulated runoff with observed stream flow at the catchment outlet (Sink in the Fig. 1). To evaluate the model's predictability in representing the basin's hydrological reality, four basic statistical performance metrics were employed: coefficient of determination (R^2), Nash-Sutcliffe efficiency [28], root mean square error-standard deviation ratio (RSR), and Percent Bias (PBIAS). These metrics provide a detailed assessment of the model's capacity to effectively reproduce the hydrological properties of the Gumti River.

1) Soil Conservation Service (SCS) curve number method

During calibration and validation, the Soil Conservation Service (SCS) Curve Number (CN) loss method was refined. This method uses the curve number methodology to quantify incremental losses [29]. The Initial Abstraction parameter specifies the precipitation threshold that must be surpassed before surface excess arises. The Curve Number itself represents a composite value that encapsulates the various soil group and land use combinations within the sub-basin [30].

2) Muskingum routing method

In the calibration and validation process, the Muskingum Routing method was optimized to simulate flow through the stream reach. This method employs a simple conservation of mass approach, with two key parameters: Muskingum K and Muskingum X. Muskingum K reflects the trip time through the reach and may be estimated using cross-sectional and flow parameters; however, it may also be used as a calibration parameter. Muskingum X, which ranges from 0.0 to 0.5, compares the influence of inflow and outflow. A value of 0.0 results in maximum attenuation, whereas 0.5 produces no attenuation. Most stream reaches require an intermediate value, established by calibration [31].

By fine-tuning these parameters, the model can more accurately represent the flow dynamics and attenuation characteristics of the Gumti River, enhancing the overall reliability of the hydrological simulations.

F. Model Performance Evaluation

Finally, the model performance was tested for calibration and validation in many ways, including R^2, Nash-Sutcliffe efficiency [28], RSR, and PBIAS.

1. By visually verifying and comparing the calculated and observed hydrographs.
2. The coefficient of determination (R^2).

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i-\bar{O})\times(S_i-\bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2\times\sum_{i=1}^{n}(S_i-\bar{S})^2}}\right]^2 \tag{1}$$

where O_i, S_i are the observed and simulated flows at time i, respectively; and O^{-}, S^{-} are the average observed and simulated flows during the calibration period, respectively.

R^2 is a typical regression criterion that is limited because it only considers linear connections between observed and simulated variables. Legates and McCabe Jr. [32] and Moriasi *et al.* [33] proposed that a good model efficiency criterion include at least three important components that improve on the coefficient R2: one dimensionless statistic, one absolute error index statistic, and one graphical approach. That is, none of the statistics should be employed alone; when combined, they provide a set of model selection criteria that balance each other's constraints [34–35]. According to the categorization of the most commonly used statistics, we added the following criteria:

3. The dimensionless statistic: Nash-Sutcliffe model Efficiency [28] given by:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i-S_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \tag{2}$$

Nash-Sutcliffe efficiencies range from -∞ to one. An efficiency of NSE = 1 indicates a perfect match between the predicted discharge and the observed data. An efficiency of NSE = 0 shows that the model predictions are as accurate as the observed data mean, while an efficiency less than zero ($-\infty < NSE < 0$) happens when the observed mean outperforms the model. The model's accuracy improves as its efficiency approaches one [28].

4. The absolute error index represented by the RMSE—standard deviation ratio (RSR) of observations given by:

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(O_i-S_i)^2}}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}} \tag{3}$$

RSR ratings range from 0 (ideal value) to 0.5 (very good performance) for both the calibration and validation phases. reduced RSR values indicate a reduced root mean square error standardized by the standard deviation of the observations, indicating that the model simulation is appropriate [33, 36].

5. The dimensionless statistic: Percentage of Bias (PBIAS) given by:

$$PBIAS = \frac{\sum_{i=1}^{n}(O_i-S_i)}{\sum_{i=1}^{n}O_i} \times 100 \tag{4}$$

PBIAS = 0 occurs when a hydrological model performs optimally. Positive or negative values imply that the model either overestimates or underestimates the simulated flows [37].

To interpret the results, Table 6 from HEC (Hydrologic Engineering Center) [38] and Moriasi *et al.* [33] was used.

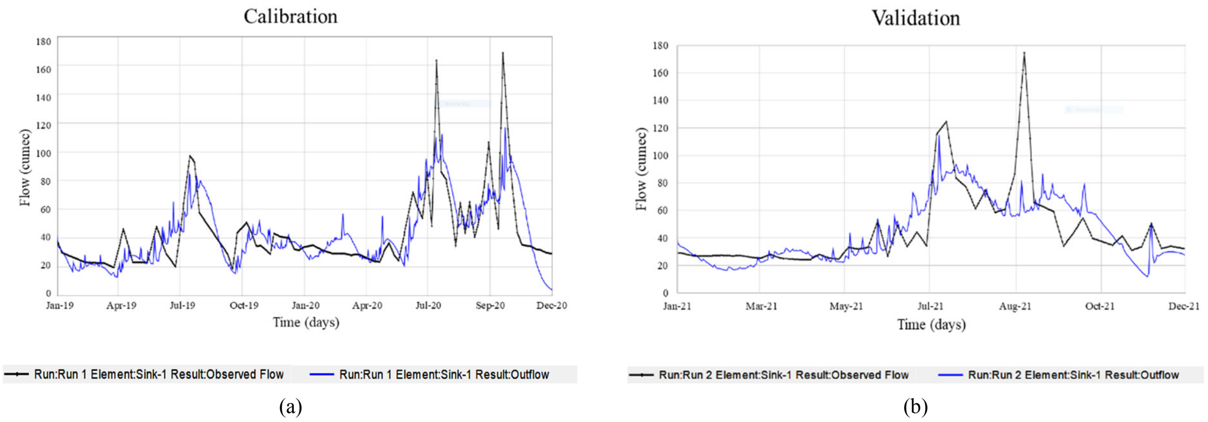
Table 6. General performance ratings for recommended statistics

Performance	**HEC [38]**				**Moriasi *et al.* [33]**		
Rating	**R^2**	**RSR**	**NSE**	**PBIAS**	**R^2**	**NSE**	**PBIAS**
Very good	0.65 to 1.00	0.00 to 0.60	0.65 to 1.00	>−15 and <15	0.75 to 1.00	0.75 to 1.00	>−10 and <10
Good	0.55 to 0.65	0.60 to 0.70	0.55 to 0.65	−20 to −15 and 15 to 20	0.65 to 0.75	0.65 to 0.75	−15 to −10 and 10 to 15
Satisfactory	0.40 to 0.55	0.70 to 0.80	0.40 to 0.55	−30 to −20 and 20 to 30	0.50 to 0.65	0.50 to 0.65	−25 to −15 and 15 to 25
Unsatisfactory	<0.40	>0.80	<0.40	<−30 and >30	<0.50	<0.50	<−25 and >25

II. Results

A. Calibration and Validation

The HEC-HMS model underwent manual calibration using observed stream flow data from the Comilla gauging station for the period of Jan. 1, 2019, to Dec. 31, 2020. Fig. 4 illustrates the close agreement between simulated and observed stream flows during the calibration period, particularly in terms of peak values and flow distribution. The optimized parameter values for the study area are presented in Table 7. For validation, the model was run with these optimized parameters for the period of January 1, 2021, to December 31, 2021, to assess its predictive capability at the Comilla gaging station.



(a) (b)

Fig. 4. Daily hydrograph comparison between simulated and observed flow for the Gumti river. (a) Calibration period (2019–2020), (b) Validation period (2021).

Table 7. Optimized model parameters

Optimized Parameter Results				
Element	**Parameter**	**Units**	**Initial Value**	**Optimized Value**
R7	Muskingum-K	HR	149.00	126.63
R7	Muskingum-x	-	0.01	0.03
Subbasin-4	SCS Curve Number-Initial Abstraction	MM	100.00	100.37
Subbasin-4	SCS Curve Number-Curve Number	-	40.00	27.66
Subbasin-9	SCS Curve Number-Initial Abstraction	MM	100.00	83.16
Subbasin-9	SCS Curve Number-Curve Number	-	40.00	38.66
Subbasin-6	SCS Curve Number-Curve Number	-	40.00	32.17
Subbasin-6	SCS Curve Number-Initial Abstraction	MM	100.00	63.64
Subbasin-2	SCS Curve Number-Curve Number	-	40.00	17.70
Subbasin-2	SCS Curve Number-Initial Abstraction	MM	100.00	70.35
R1	Muskingum-K	HR	149.00	115.26
R1	Muskingum-x	-	0.01	0.02

B. Model Performance Evaluation

Model performance was evaluated during the calibration and validation phases. The time series of simulated and observed flows from the simulation run in the HEC-HMS model were examined in Microsoft Excel to calculate the statistics needed to assess performance. The statistics utilized are described in Section II.F, as previously presented. The performance ratings for these criteria are shown in Table 8. During calibration for the Comilla gauging station, the values of R^2, RSR, NSE, and PBIAS were 0.64, 0.60, 0.585, and −2.59%, respectively. Similarly, during the validation, the model assessment criteria for R^2, RSR, NSE, and PBIAS were determined to be 0.68, 0.70, 0.513, and −3.78%, respectively. Fig. 4 shows the performance evaluation of the HEC-HMS model during the calibration and validation periods. According to Table 6, the model's performance ranges from satisfactory to excellent.

Table 8. Model Performance presented as Goodness-of-Fit Statistics for Calibration (01/01/19–12/31/20) and Validation period (01/01/21–12/31/21) of Gumti-Burinadi River. Data are presented with Default color codes for Statistics Reports [38]

	Peak Discharge (m^3/s)	**Volume (MM)**	**[1] R^2**	**[2] RSR**	**[3] NSE**	**[4] PBIAS**
Calibration	168.70	3,674.89	0.64	0.60	0.585	−2.59%
Validation	174.80	1,928.12	0.68	0.70	0.513	−3.78%

Legend

Very Good

Good

Satisfactory

Unsatisfactory

[1] R^2 = coefficient of determination; [2] RSR = root mean square error-standard deviation ratio; [3] NSE = Nash-Sutcliffe efficiency; [4] PBIAS = mean relative bias.

IV. DISCUSSION

The HEC-HMS model required proper calibration of loss and routing parameters to accurately predict runoff in the Gumti river. These parameters are typically linked to soil characteristics and demand meticulous observation and field studies for precision. However, the Gumti river lacked such records, and no specific investigations were performed for this study. Instead, the researchers relied on literature and secondary sources to estimate the necessary parameters. Despite this indirect approach to data acquisition, the resulting outcomes were remarkably satisfactory.

The present study of the Gumti-Burinadi River demonstrates satisfactory model performance across both calibration (2019–2020) and validation (2021) periods. The R^2 values of 0.64 for calibration and 0.68 for validation indicate a moderate to good fit, while NSE values fall within the satisfactory range. The PBIAS shows very good performance with slight underestimation, and the RSR is satisfactory for calibration and good for validation. These results suggest that the model provides an acceptable simulation of the river's hydrology, although there is room for improvement in certain aspects.

Comparing the findings with those of Ali *et al.* [39] for the Upper Meghna River Basin reveals some differences in model performance. Their study achieved higher R^2 values of 0.876 and 0.829 for calibration and validation, respectively, indicating better overall fit. The NSE values were also higher, particularly for calibration (0.83), suggesting improved model efficiency. However, the present study demonstrates better PBIAS results, indicating more accurate volume prediction. These differences could be attributed to variations in basin characteristics, data quality, or modeling approaches. Munna *et al.*'s [40] study in the Surma basin using the Curve Number (CN) method yielded a notably high R^2 of 0.981, surpassing both your results and those of Ali *et al.* [39]. However, the negative NSE value (–6.27) in this study indicates poor model performance in this aspect, contrasting with the satisfactory NSE values in the present study. This discrepancy highlights the importance of considering multiple performance metrics when evaluating model effectiveness, as a high R^2 alone may not guarantee overall model reliability.

The HEC-HMS model, when properly calibrated and validated, has diverse hydrological applications. Gichamo *et al.* [41] combined it with HEC-RAS to simulate flooding on Hungary's Tisza River, demonstrating its effectiveness in areas lacking detailed topographic data. Similarly, Castronova and Goodall [42] used HEC-HMS to evaluate the OpenMI Software Development Kit, breaking down hydrological processes into separate model components. These studies highlight the versatility and adaptability of HEC-HMS in various hydrological modeling scenarios. Islam *et al.*'s [43] study on the Dhaka River basin using HEC-HMS demonstrates superior performance compared to the present study and Ali *et al.* [39], with higher R^2 and NSE values for both calibration and validation periods. These results suggest that the physically based, semi-distributed approach employed by Islam *et al.* [43] may offer improved predictability for streamflow in the region.

The effective implementation of the HEC-HMS model in the Gumti River Basin lays the groundwork for long-term water resource management in Bangladesh's Comilla district, tackling concerns such as population increase, urbanization, and climate change. Sustainable management requires a multifaceted approach combining hydrological modeling, policy interventions, and community engagement. Badhan *et al.* [44] highlighted challenges in urban water supply, while Roy *et al.* [45] found significant arsenic contamination in Comilla's water samples, emphasizing the need for comprehensive water quality monitoring. The HEC-HMS model can be enhanced to address these water quality concerns alongside quantity management.

Climate change impacts, particularly more frequent extreme weather occurrences [43], require adaptive strategies. The HEC-HMS model can simulate various climate scenarios, aiding in developing resilient water infrastructure. Qureshi *et al.* [46] stressed the importance of integrating surface and groundwater management, which is crucial for the Gumti Basin's long-term sustainability.

Integrated Water Resource Management principles, as suggested by Gain *et al.* [47], are essential for balancing competing water demands while maintaining environmental flows. Akter *et al.* [48] proposed approaches including desalination, upstream water harvesting, quality monitoring, community engagement, and public awareness, which can be adapted for the Gumti Basin. Transboundary cooperation with India is crucial, given the Gumti's connection to the larger Meghna basin.

The HEC-HMS model for the Gumti River Basin, supplemented by insights from various studies, offers a comprehensive tool for sustainable water resource management. The variations in model performance across these studies highlight the complexity of hydrological modeling in different river basins and the influence of factors such as data quality, basin characteristics, and modeling techniques on simulation outcomes. Future research should focus on refining model parameters, incorporating groundwater dynamics, water quality parameters, additional data sources, and climate change scenarios. This holistic approach will address water management challenges in the Comilla district and similar regions in Bangladesh, enhancing the accuracy and reliability of hydrological predictions.

V. CONCLUSIONS

The study demonstrates the effectiveness of the HEC-HMS model in simulating the hydrology of the Gumti-Burinadi River, despite the challenges posed by limited data availability. The model's performance, as measured by several statistical indicators, varied from satisfactory to very good for both the calibration and validation periods. The model's satisfactory performance demonstrates its potential as a valuable tool for hydrological prediction and flood risk assessment. While there is room for improvement compared to some regional studies, the model's ability to simulate the Gumti River's hydrology offers significant advantages for local water management strategies. The integration of this hydrological model with flood frequency analysis, water quality monitoring, and climate change projections addresses the multifaceted challenges faced by the region, including urbanization, population growth, and environmental changes. Future refinements should focus on incorporating groundwater dynamics, enhancing data quality, and adapting to evolving climate scenarios. By combining the HEC-HMS model with Sustainable Water Resource Management principles and community engagement, as suggested by various studies, a more comprehensive and sustainable approach to water resource management in the Gumti River Basin can be achieved. This holistic strategy will not only improve flood prediction and water allocation but also contribute to the overall resilience and sustainability of water resources in Bangladesh.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AUTHOR CONTRIBUTIONS

Conceptualization, M.N. and M.R.; methodology, M.N.; software, M.R.; validation, M.R.; formal analysis, M.N. and M.R.; investigation, M.R.; resources, M.R.; data curation, M.K.A.; writing—original draft preparation, M.N., M.R. and M.K.A.; writing—review and editing, M.K.A.; visualization, M.N.; supervision, M.K.A.; project administration, M.K.A. All authors had approved the final version.

DATA AVAILABILITY STATEMENT

The data presented in this study are available upon request from the corresponding author.

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