Proceedings of the 8th International Conference on Civil Engineering for Sustainable Development (ICCESD 2026), 5~7 February 2026, KUET, Khulna, Bangladesh

FLOOD HAZARD MAPPING FOR FARIDPUR AND MANIKGANJ DISTRICT IN BANGLADESH USING HEC-RAS AND MULTI-CRITERIA ANALYSIS

Abrar Galib Bhuiyan*

GIS Analyst, IWM, Bangladesh, e-mail: (abrargalib100@gmail.com)

***Corresponding Author**

ABSTRACT

Bangladesh, located at the confluence of the Ganges, Brahmaputra, and Meghna rivers, forms the world's largest delta and experiences frequent and often severe flooding. Although several national-scale flood hazard assessments exist, they typically rely on coarse-resolution data and generalized assumptions, limiting their ability to capture local-scale hydrodynamic variability in complex floodplain environments. Consequently, critical spatial heterogeneities in inundation depth, flow velocity, terrain characteristics, and land-use conditions remain inadequately represented at the district level. Addressing this gap, the present study develops a high-resolution flood hazard mapping framework for the flood-prone districts of Faridpur and Manikganj by integrating two-dimensional hydrodynamic modelling with GIS-based multi-criteria decision analysis. A HEC-RAS 2D model was employed to simulate the extreme 2020 flood event using observed discharge, water level, and bathymetric data, and the model was rigorously calibrated and validated, achieving coefficients of determination (R^2) of 0.93 and 0.90, respectively. Hydrodynamic outputs—specifically inundation depth and flow velocity—were combined with six additional flood-influencing parameters, namely land use/land cover (LULC), rainfall, slope, Normalized Difference Vegetation Index (NDVI), Topographic Wetness Index (TWI), and distance to river, selected for their hydrological relevance and spatial influence on flood behaviour. The Analytical Hierarchy Process (AHP) was applied to assign relative weights to each parameter, and flood susceptibility classes were quantified through weighted linear spatial overlay. The resulting hazard map reveals pronounced spatial variability, with high and very high hazard zones concentrated along active river corridors and low-lying agricultural floodplains. Beyond the case study area, the proposed hybrid hydraulic–GIS framework offers a transferable and scalable approach for localized flood hazard assessment in other flood-prone deltaic regions of Bangladesh and South Asia, where national-scale models often fail to resolve fine-scale flood dynamics essential for effective disaster risk reduction and land-use planning.

Keywords: *GIS, Flood Hazard, Padma River, HEC-RAS, Flood Risk.*

1. INTRODUCTION

Bangladesh, located within the Ganges–Brahmaputra–Meghna (GBM) delta, is one of the most flood-prone regions in the world due to its low-lying terrain, monsoon-driven climate system, and highly dynamic river network. With over 90% of upstream flow entering from neighbouring countries, the nation experiences recurrent flooding that often escalates into large-scale disasters, as observed in 1974, 1988, 1998, 2004 and 2020. While seasonal floods contribute to ecological productivity, extreme events cause extensive damages to infrastructure, agriculture, settlements, and human livelihoods. The central districts of Faridpur and Manikganj are particularly vulnerable because of their geomorphological positioning along the active floodplains of the Padma and Jamuna rivers, where rapid urbanization, land-use changes, and bank erosion further exacerbate local flood risk. Although several national-scale assessments exist, there remains a shortage of high-resolution, district-specific flood hazard analyses that combine hydraulic behaviour with environmental and land-surface characteristics. Hydrodynamic models such as HEC-RAS can effectively simulate inundation depth and flow velocity, but physical modelling alone cannot capture the full complexity of flood susceptibility without integrating terrain factors, rainfall distribution, land use, vegetation conditions, and proximity to rivers. To address this gap, the present study adopts an integrated flood hazard mapping framework that couples a two-dimensional HEC-RAS hydrodynamic simulation of the 2020 extreme flood event with a GIS-based Multi-Criteria Decision Analysis (MCDA) using the Analytical Hierarchy Process (AHP). Inundation depth and velocity derived from the calibrated and validated HEC-RAS model are combined with six additional spatial indicators—slope, land use/land cover (LULC), rainfall, Normalized Difference Vegetation Index (NDVI), Topographic Wetness Index (TWI), and distance to river—to produce a weighted flood hazard assessment. Factor weights are determined through pairwise comparison and consistency checks, ensuring hydrological relevance and analytical robustness. The key objectives of this research are to develop a reliable 2D hydrodynamic model for the Lower Padma River system and to generate a detailed, high-resolution flood hazard map for Faridpur and Manikganj districts by integrating hydrodynamic outputs with geospatial multi-criteria analysis. This study not only enhances the understanding of spatial flood vulnerability in two of Bangladesh's most affected districts but also provides a replicable methodology for supporting disaster preparedness, land-use planning, and resilient infrastructure development in other flood-prone deltaic regions.(*M. M. Islam and M. A. Rahman, Flood Inundation Mapping... - Google Scholar*, n.d.)

Despite the availability of national-scale flood hazard and inundation maps in Bangladesh, most existing assessments rely on course-resolution digital elevation models, simplified hydraulic assumptions, or one-dimensional representations of river flow. Such approaches are often insufficient for capturing local-scale variations in flood depth, flow velocity, and floodplain connectivity in complex deltaic environments. As a result, localized flood dynamics driven by micro-topography, land-use heterogeneity, and channel–floodplain interactions remain poorly resolved, limiting the usefulness of national-scale products for district-level land-use planning and disaster preparedness. This limitation is particularly pronounced in the central floodplains of the Padma and Jamuna rivers, where small elevation differences can produce substantial contrasts in flood hazard over short spatial distances.

The objectives of this study are to: (i) simulate the 2020 extreme flood event in the Padma River floodplain using a calibrated and validated two-dimensional HEC-RAS model to quantify spatial distributions of inundation depth and flow velocity; (ii) integrate hydrodynamic outputs with six additional flood-influencing parameters using an Analytical Hierarchy Process (AHP)-based GIS framework; and (iii) quantify flood susceptibility by classifying Faridpur and Manikganj districts into five hazard classes based on weighted multi-criteria evaluation.(Sharker et al., 2025)

2. METHODOLOGY

Flood-prone areas in Faridpur and Manikganj were identified using an integrated GIS- and remote-sensing-based framework supported by hydraulic modelling and multi-criteria analysis. The approach incorporated both natural terrain characteristics and human-induced land-use conditions to generate a spatially detailed flood hazard assessment. Key parameters influencing flood susceptibility—inundation depth, flow velocity, slope, TWI, NDVI, rainfall, LULC, and proximity to rivers—were selected based on hydrological relevance and data reliability. Terrain attributes were derived from a 30 m DEM, LULC and vegetation indices from Landsat 8 imagery, rainfall surfaces from interpolated station data, and river distance using Euclidean analysis. All datasets were standardized to a uniform resolution and reclassified into five hazard levels. Using the Analytical Hierarchy Process (AHP), each factor was weighted through pairwise comparisons with verified consistency. The weighted layers were then integrated in ArcGIS 10.8 through a weighted overlay to produce the final flood hazard map.

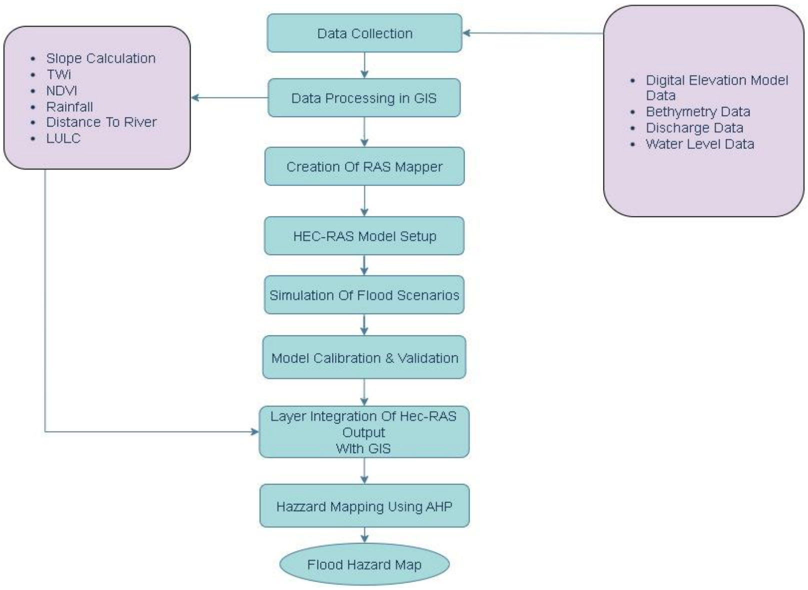

Figure 2.1. Methodological Framework for Flood Hazard Mapping

2.1 Study Area

The study focuses on the districts of Faridpur (approx. 2,052.86 km²) and Manikganj (approx. 1,383.66 km²), situated in central Bangladesh along the Padma and Jamuna rivers (Figure 2).

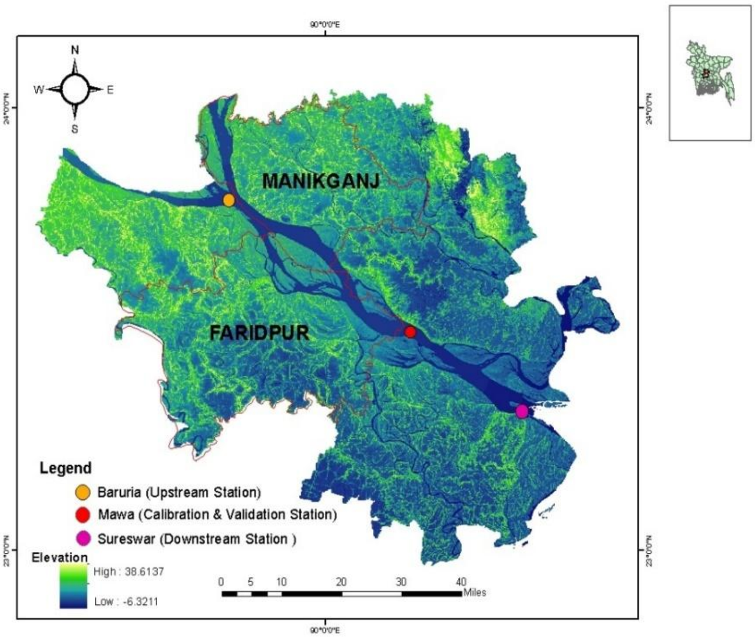

Figure 2.2 Location of the Study Area

This region is highly susceptible to seasonal riverine flooding due to its low-lying topography and proximity to major river systems, making it a critical area for flood hazard assessment.

2.2 Data Collection and Processing

Previous researchers (Bui et al., 2019) has posited that the distance of rivers from a location is a significant factor in assessing flood risk. The excessive rainfall causes the rivers to exceed their capacity.

Numerous studies have identified the distance from rivers that is most susceptible to flooding. According to (Samanta et al., 2016), regions within 100 meters of rivers are most susceptible to flooding.

Multi- data was acquired to support the hydrodynamic model and geospatial analysis.

Table 1. Data sources and specifications.

Data Type	Source	Data Location	Station Id	Period
Digital Elevation Model (DEM)	USGS	Bangladesh	———	———
Bathymetry Data at River (x, y, z)	IWM	Padma	———	———
Discharge	BWDB	Baruri Transit	SW91.9L	2015-2024
Water Level	BWDB	Mawa	SW93.5L	2020-2024
Water Level	BWDB	Sureswar	SW93.5R	2015-2024

The 30m SRTM DEM was processed in ArcGIS 10.8, including mosaicking and converting the datum from Mean Sea Level (MSL) to Public Works Department (PWD) by adding 0.46 m. The bathymetry data was integrated with the DEM to create a composite terrain model representing both land and riverbed elevations

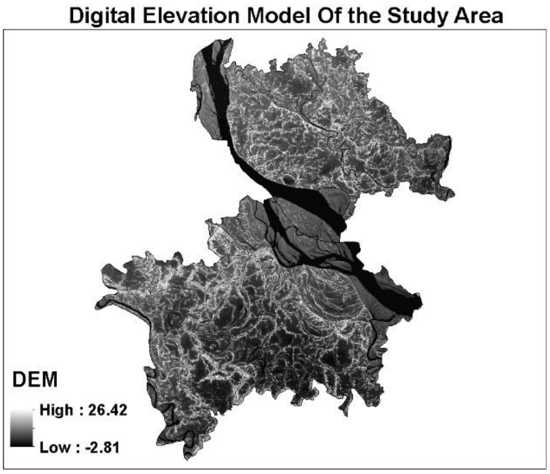

Figure 2.3. Processed DEM (extracted by mask)

2.3 Hydrodynamic Modelling with HEC-RAS 2D

The 2020 flood event was simulated using HEC-RAS (v6.3) 2D.

- Model Setup: The composite terrain was used. A 2D flow area was discretized with a 300m computational mesh.

- Boundary Conditions: An upstream flow hydrograph (Baruria Transit) and a downstream stage hydrograph (Sureswar) were applied.

- Calibration & Validation: The model was calibrated (Manning's n = 0.029) and validated against observed water levels at Mawa station for 2020 and 2021, respectively. The model

performance was robust, with high correlation coefficients ($R^2 = 0.93$ for calibration, $R^2 = 0.90$ for validation.

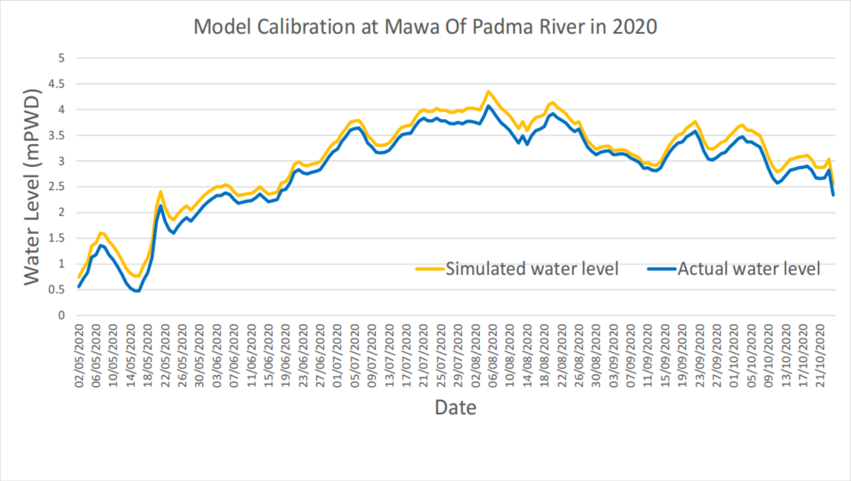

Figure 2.4. Model calibration at Mawa of Padma River in 2020

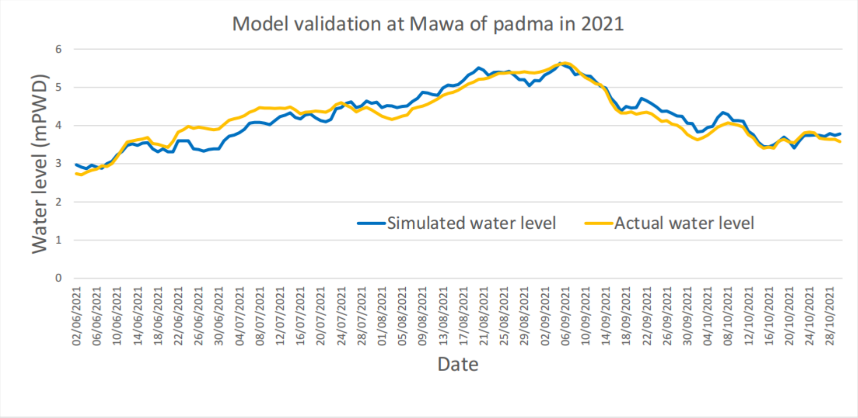

Figure 2.5 Model validation at Mawa for the year of 2021 (Padma)

2.4 Flood Hazard Factor Analysis and AHP Weighting

The relative importance of the eight flood hazard factors was determined using the Analytical Hierarchy Process (AHP), a structured multi-criteria decision-making technique. A pairwise comparison matrix was constructed based on expert judgment involving three hydrology and disaster risk management specialists with over years of field and research experience in Bangladesh's floodplain regions. Their assessments were synthesized to establish the relative scale of influence among factors, following Saaty's established scale of relative importance (psychology & 1977, 1977).

The consistency of the pairwise comparison matrix was rigorously checked using the standard AHP consistency ratio (CR) formula:

$$CR = \frac{CI}{RI}$$

where $CI = \frac{\lambda_{max} - n}{n-1}$, λ_{max} is the principal eigenvalue of the matrix, n is the number of criteria, and RI is the random index. The calculated CR was 0.04, which is well below the accepted threshold of 0.10, confirming logical consistency in expert judgments.

To assess the robustness of the AHP-derived weights, a sensitivity analysis was performed by systematically varying individual factor weights by ±10% and observing changes in the final hazard classification. Results indicated that the overall spatial pattern of flood hazard zones remained stable, with no significant reclassification of high-risk areas. This confirms that the model outcomes are not disproportionately sensitive to minor variations in weight assignments.

The final weights derived from the AHP process are summarized in Table 3, with inundation depth (24.8%), distance to river (22.4%), and flow velocity (19.5%) emerging as the most influential factors, aligning with the hydrodynamic character of the Padma River floodplain.(Kaur et al., 2017)

Table 2. Matrix for pairwise comparisons in the AHP process

Factor	Inundation Depth	Distance to River	Velocity	TWI	Rainfall	Slope	LULC	NDVI
Inundation Depth	1	1	2	3	5	4	7	7
Distance to River	1	1	2	3	3	4	5	6
Velocity	0.5	0.5	1	3	5	5	6	7
TWI	0.33	0.333	0.33	1	3	5	6	6
Rainfall	0.2	0.33	0.2	0.333	1	3	4	5

Slope	0.250	0.25	0.2	0.2	0.333	1	5	7
LULC	0.140	0.200	0.167	0.167	0.25	0.2	1	3
NDVI	0.140	0.167	0.140	0.167	0.2	0.14	0.333	1

Table 2.4. Flood factors, average weights, classes, rating values, and percentage area

Factor	Average Weights	Class	Flood Susceptibility	Rating	Area %
Inundation Depth	24.8%	0 0-2.11 2.11-3.1 3.1-4.6 4.6-29.89	Very low hazard Low hazard Moderate hazard High hazard Very high hazard	1 2 3 4 5	23% 18% 19% 19% 21%
Distance to the rivers (DR) (km)	22.4%	0-378.84 378.84-823.55 823.55-1301.2 1301.2-1877.7 1877.7-4200.1	Very high hazard High hazard Moderate hazard Low hazard Very low hazard	5 4 3 2 1	9% 20% 30% 29% 12%
Rainfall	7.9%	319.68-349.93 349.93-374.15 374.15-398.35 398.35-421.95 421.95-473.99	Very low hazard Low hazard Moderate hazard High hazard Very high hazard	1 2 3 4 5	27% 22% 16% 11% 24%
Topographic Wetness Index (TWI)	13%	0-27.88 27.88-55.78 55.78-97.60 97.60-683.19 683.19-3555.4	Very low hazard Low hazard Moderate hazard High hazard Very high hazard	1 2 3 4 5	84% 10% 1.3% 1.8% 2.9%
Land use/Land cover (LULC)	3.2%	Water Body Bare Land Built up Cropland Vegetation	Very high hazard High hazard Moderate hazard Low hazard Very low hazard	5 4 3 2 1	11.6% 4.4% 14% 55% 15%
Velocity	19.5%	0.-0.13 0.13-0.4 0.4-0.77 0.77-1.38 1.38-5.02	Very low hazard Low hazard Moderate hazard High hazard Very high hazard	1 2 3 4 5	39% 27% 20% 10% 4%

Slope	7%	0-0.01	Very high hazard	5	31.05%
		0.01-0.02	High hazard	4	48.18%
		0.02-0.03	Moderate hazard	3	16.68%
		0.03-0.05	Low hazard	2	3.79%
		0.05-0.08	Very low hazard	1	0.3%
NDVI	2.2%	-0.11-0.01	Very high hazard	5	9%
		0.01-0.130	High hazard	4	40%
		0.13-0.21	Moderate hazard	3	30%
		0.21-0.26	Low hazard	2	20%
		0.26-0.42	Very low hazard	1	1%

3. RESULT AND DISCUSSIONS

3.1 Model Performance

The hydrodynamic model reproduced the 2020 and 2021 flood events with high accuracy. The calibration at Mawa for 2020 showed a strong match between simulated and observed water levels, with R^2 equal to 0.93. The validation for 2021 maintained this performance with R^2 equal to 0.90. The model captured peak stages and recession patterns without major timing errors. These results confirmed that the composite terrain and hydraulic parameters were suitable for representing the floodplain dynamics of the Padma River.

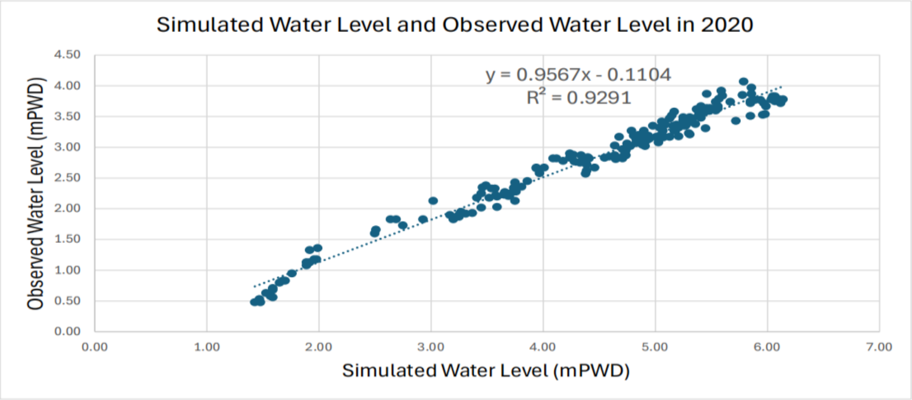

Figure 6. Model generated water level vs observed water level at Mawa of Padma River in 2020

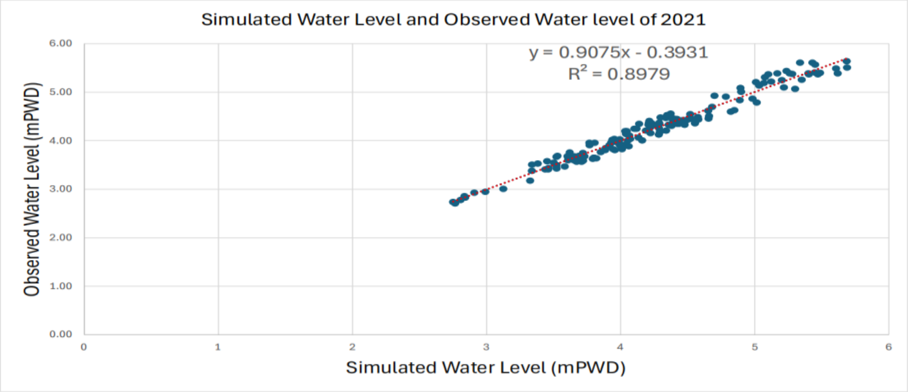

Figure 7. Model generated water level vs observed water level at Mawa in the Padma River in 2021.

3.2 Spatial Behaviour of Flood-Influencing Factors

All eight factors were processed and mapped to identify their spatial contributions to flood hazard. Inundation depth showed deep flooding along the active Padma channel and internal depressions. Distance to river displayed a strong gradient, where areas within a short buffer of the river had the highest susceptibility. Velocity values were highest within the main channel and narrow flow paths. TWI highlighted saturated and poorly drained zones that coincide with historically inundated regions.

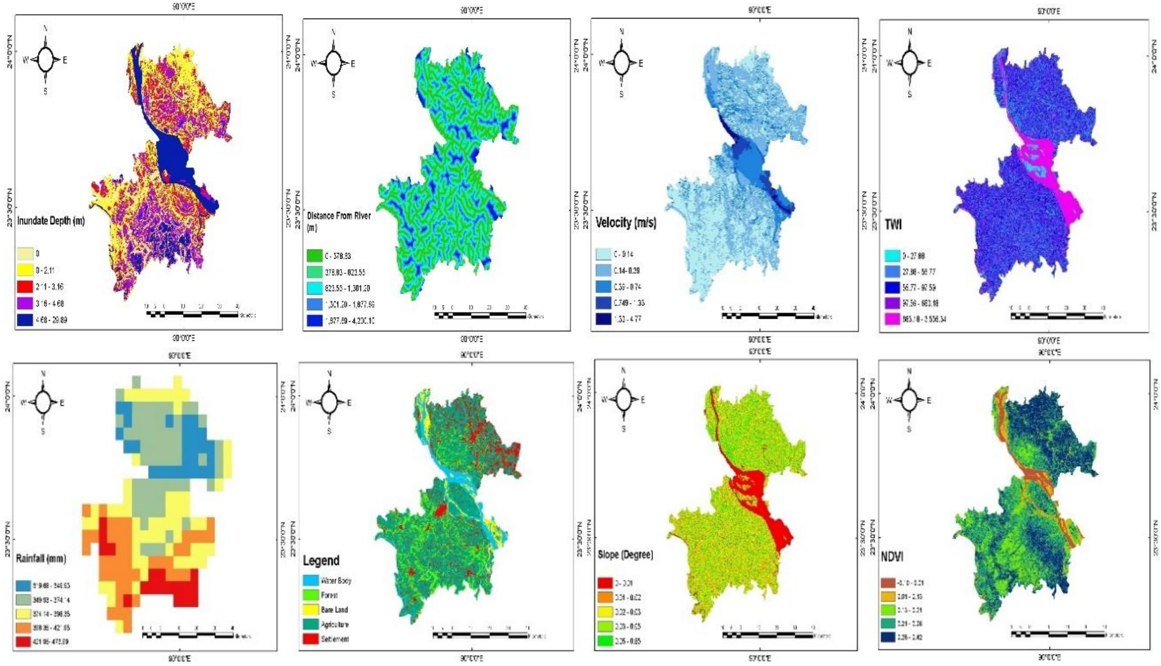

Figure 8. Spatial distribution of the eight flood hazard factors: inundation depth, distance to river, flow velocity, TWI, rainfall, LULC, slope, and NDVI.

LULC maps revealed that cropland and built-up areas dominate the moderate hazard class. Rainfall showed spatial variation but did not create sharp contrasts at the floodplain scale. Slope values remained low across most of the region, creating favourable conditions for prolonged inundation. NDVI identified sparse vegetation and exposed surfaces in the more hazard-prone zones. These spatial patterns aligned with the AHP weights, where inundation depth, distance to river, and velocity emerged as the three strongest contributors. zones.

3.3 Flood Hazard Zonation

The weighted overlay of all factors produced the final hazard map for Faridpur and Manikganj. The region was divided into five classes. Moderate hazard covered the largest share, driven by low terrain and extensive cropland.

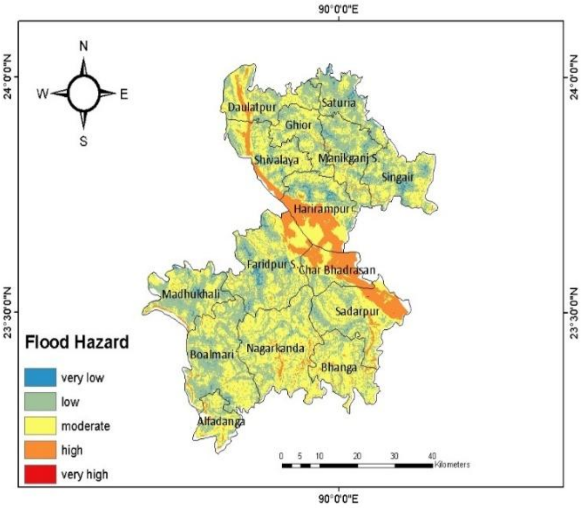

Figure 9. Flood Hazard Map

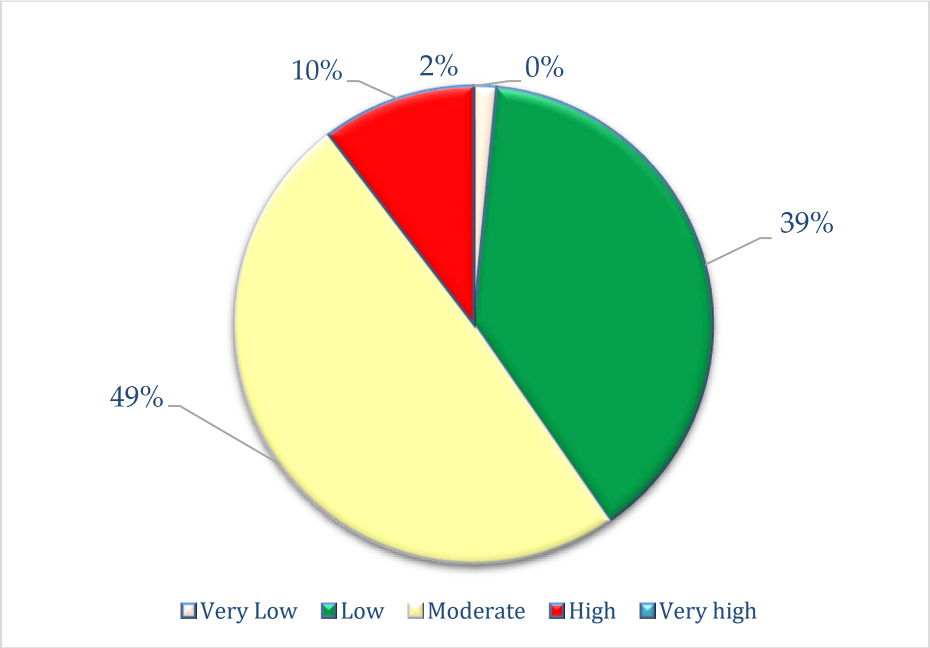

Figure 10. Percentage of Flood Zones

Upazila-level analysis identified Charbhadrasan as the most exposed, with 53.52 percent of land in the high-risk category. Harirampur and Sadarpur also showed significant hazard levels. These areas share three characteristics: close proximity to the Padma, low elevation, and limited protective landscape features. Table 4 presents the quantified exposure for the top five high-risk Upazilas.

Table 4. Top 5 High-Risk Upazilas Based on Flood Vulnerability

Upazila	High Risk Area (km²)	High Risk Area (%)	Total Area (km²)
Charbhadrasan	69.14	53.52	129.19
Harirampur	83.65	32.33	258.83
Sadarpur	57.14	20.57	277.74
Faridpur Sadar	32.47	8.89	365.41
Shibalaya	26.02	12.84	202.68

3.4 Discussion

The integration of HEC-RAS 2D modeling with AHP-based GIS analysis successfully produced a high-resolution flood hazard map for Faridpur and Manikganj. Results indicate that 12% of the area is high to very high risk—concentrated along the Padma River—driven predominantly by inundation depth, proximity to river, and flow velocity. These factors accounted for over 66% of the total weight in the AHP model, highlighting the dominance of hydrodynamic processes in flood hazard generation.
The high-risk zones, particularly in Charbhadrasan, Harirampur, and Sadarpur, correlate strongly with low elevation, high TWI, and limited vegetative cover. Sensitivity analysis confirmed model robustness, with minimal spatial redistribution (<5%) underweight variations.

This study provides actionable insights for targeted flood management, including embankment reinforcement, drainage improvement, and land-use regulation in identified hotspots. The methodology is transferable to other flood-prone deltas, supporting evidence-based disaster planning and climate adaptation strategies

4. CONCLUSIONS

This study demonstrates that combining two-dimensional hydrodynamic modelling in HEC-RAS with a GIS-based Multi-Criteria Analysis (MCA) framework provides a robust and spatially explicit representation of flood hazard distribution across the districts of Faridpur and Manikganj. The resulting flood hazard map successfully classified the region into five susceptibility categories, revealing that nearly half of the study area falls under moderate hazard, while high and very high hazard zones are concentrated along riverbanks and low-lying floodplains. The integration of AHP weighting within the MCA framework ensured that key factors—such as inundation depth, proximity to rivers, land use, slope, and soil characteristics—were objectively assessed, enhancing the reliability of hazard delineation. Upazila-level analysis identified Charbhadrasan, Harirampur, and Sadarpur as the most vulnerable areas, with Charbhadrasan exhibiting the highest proportion of high-risk land. These findings highlight the urgent need for both structural measures, including embankment reinforcement and improved drainage systems, and non-structural strategies such as enhanced early warning systems, community awareness, and risk-informed land-use planning. Overall, the integrated HEC-RAS and MCA approach proved effective for identifying flood-prone zones and provides a valuable decision-support tool for policymakers, planners, and disaster management authorities. As climate change continues to intensify the frequency and severity of flooding, incorporating such hazard assessments into long-term regional development will be essential for strengthening resilience and reducing future losses.

ACKNOWLEDGEMENTS

The authors extend their sincere gratitude to the Bangladesh Water Development Board (BWDB) and the Institute of Water Modelling (IWM) for providing the essential hydrological and bathymetric data crucial for this research. We also acknowledge the technical support from the Department of Water Resources Engineering at the Chittagong University of Engineering and Technology (CUET).

AI USE DECLARATION

The authors declare that generative artificial intelligence tools were used only for language refinement, grammar checking, and improvement of academic clarity in the manuscript. All scientific concepts, data processing, modeling, analyses, interpretations, figures, and conclusions were entirely conceived, executed, and validated by the authors. The use of AI tools did not influence the study design, methodology, data analysis, or research outcomes. The authors take full responsibility for the content of this paper.

REFERENCES

M. M. Islam and M. A. Rahman, Flood Inundation Mapping Of Major Rivers Of Bangladesh Using Hec-Ras 2d. 2020.

R. Sharker et al., “GIS-based AHP approach to flood susceptibility assessment in Tangail district, Bangladesh,” 2040, doi: 10.1007/s12040-024-02480-3.

T. L. Saaty, “A scaling method for priorities in hierarchical structures,” J Math Psychol, vol. 15, no. 3, pp. 234–281, Jun. 1977, doi: 10.1016/0022-2496(77)90033-5.

D. T. Bui et al., “Flood Spatial Modeling in Northern Iran Using Remote Sensing and GIS: A Comparison between Evidential Belief Functions and Its Ensemble with a Multivariate Logistic Regression Model,” Remote Sensing 2019, Vol. 11, Page 1589, vol. 11, no. 13, p. 1589, Jul. 2019, doi: 10.3390/RS11131589.

S. Samanta, C. Koloa, D. K. Pal, and B. Palsamanta, “Flood Risk Analysis in Lower Part of Markham River Based on Multi-Criteria Decision Approach (MCDA),” Hydrology 2016, Vol. 3, Page 29, vol. 3, no. 3, p. 29, Aug. 2016, doi: 10.3390/HYDROLOGY3030029.

H. Kaur, S. Gupta, S. Parkash, R. Thapa, and R. Mandal, “Geospatial modelling of flood susceptibility pattern in a subtropical area of West Bengal, India,” Environ Earth Sci, vol. 76, no. 9, pp. 1–22, May 2017, doi: 10.1007/S12665-017-6667-9/METRICS.