

**STUDY ON RIVERBANK EROSION, ACCRETION, AND EROSION PATTERN
PREDICTION OF THE JAMUNA RIVER USING HEC-RAS AND LANDSAT IMAGERY**

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ABSTRACT

The Jamuna River is one of the most morphologically dynamic rivers in Bangladesh. It experiences significant erosion and accretion processes that shape its landscape and influence socio-economic conditions. This study analyzes riverbank erosion and accretion patterns in a selected reach from Bahadurabad-Transit to Sirajganj over multiple years from 2005 to 2012 using GIS-based Landsat imagery. Additionally, HEC-RAS model is applied to simulate water surface elevation and velocity distribution, assessing their relationship with erosion patterns. Substantial fluctuations in erosion and accretion trends are revealed in the study, with peak erosion reaching 14,308 ha from 2008 to 2010 and maximum accretion of 18,541 ha from 2006 to 2008. High-velocity zones were strongly associated with severe erosion, whereas lower velocities favored accretion. Furthermore, predictive models, including ARIMA, XGBoost and LSTM, were utilized to forecast future erosion trends in a simplified way, XGBoost exhibited the highest accuracy R^2 of 0.82. The study will help the policymakers understand the dynamics of braided rivers and gain knowledge of sustainable riverbank management and land-use planning in Bangladesh. Future research could benefit from high-resolution satellite data and advanced hydrodynamic modeling, including more variables to improve efficiency and enhance predictive accuracy.

Keywords: *Erosion, Accretion, Jamuna, HEC-RAS, Bangladesh*

1. INTRODUCTION

Bangladesh is a riverine country and landform of Bangladesh is primarily influenced by the three major rivers that flow through its Ganges, Brahmaputra and Meghna (Nasir et al., 2024). These mighty rivers carry vast volumes of water and eventually merge into the Bay of Bengal, shaping the landscape of this small yet dynamic country. River erosion is a recurrent and highly unpredictable phenomenon that affects many regions worldwide. In Bangladesh, about 5% of the total floodplain is affected by river erosion and 94 out of 489 upazilas experience this disaster every year (Rahman, 2013). However, the erosion scale and frequency vary across different rivers due to different factors like bank material characteristics, water level fluctuations, river planform, near-bank flow velocities, water and sediment supply, and sandbar position (Islam & Rashid, 2012). The westward movement of the Jamuna River has resumed in recent years, with the highest erosion rates in the 1980s. The most severe erosion occurred during major floods in 1988 and 1998. Erosion is 40-50% higher on the left bank than on the right bank, and the annual rate increases with maximum flood discharge. Main side channels cause 75% of erosion on the right bank, while they contribute only 40% on the left bank (Khan et al., 2014). Previous studies such as R. Rahman, (2023) and Uddin, (2024) used remote sensing and GIS to assess bank erosion and channel migration for different periods, while hydraulic modeling and data driven prediction have often been applied separately in other studies. On the contrary, this study combines Landsat derived erosion accretion quantification with HEC-RAS derived hydraulic indicators and machine learning based forecasting for the Bahadurabad-Sirajganj reach during 2005 to 2012.

According to data availability, the study investigates the dynamic reach of the Jamuna River (Figure 1) for 2005, 2006, 2008, 2010, 2011, and 2012 years for studying braided river erosion and assessing relationship between water surface elevation and velocity, extending between two key hydrological stations.

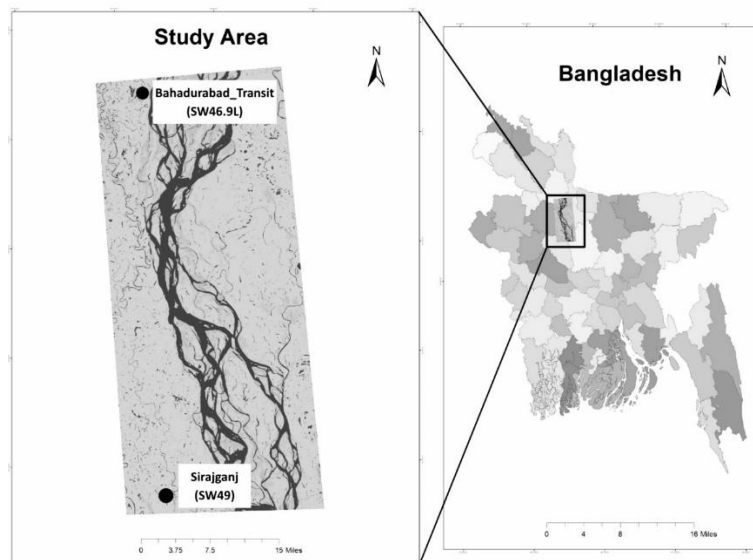


Figure 1: Study Area

Understanding erosion-accretion dynamics is important for flood risk management, riverbank protection and sustainable land-use planning (Ferdous et al., 2018). The objectives of the study are to assess river erosion and accretion of a selected reach of the Jamuna River over multiple years using GIS-based analysis of Landsat imagery and to simulate water surface elevation and velocity distribution using HEC-RAS 1D for different time periods and evaluate their relationship with erosion patterns for a particular area. Furthermore, the study aims to predict simple erosion-pattern using different machine learning, deep learning and statistical time-series forecasting model up to 2050.

2. METHODOLOGY

2.1 HEC-RAS 1D Model

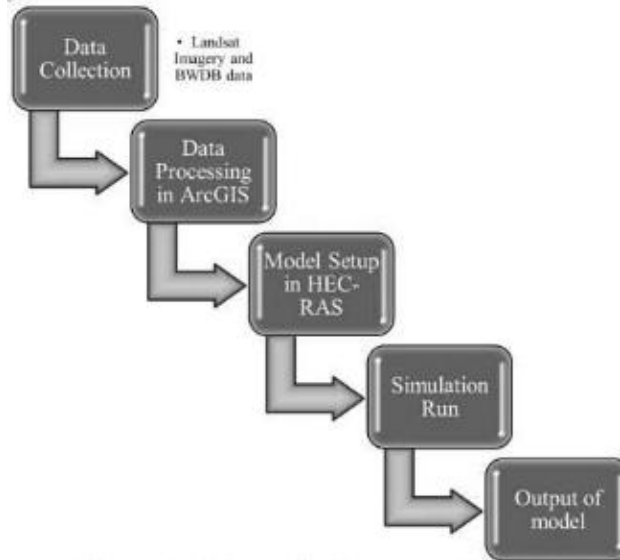


Figure 2: Schematic diagram of the Methodology

For the development of the HEC-RAS 1D model, various secondary hydraulic data such as discharge, water level and cross-sections were collected from the Bangladesh Water Development Board (BWDB) for the study area. Discharge data was collected for the Bahadurabad-Transit station (SW46.9L) as it is situated at the upstream boundary and water level data was collected for the Sirajganj Station (SW49) as it is situated at the downstream boundary.

Table 1: Types of collected data and their sources

Data Type	Source	Station ID	Time Period
Cross section	BWDB	RMJ7, RMJ7.1, RMJ8, RMJ8.1, RMJ9, RMJ9.1, RMJ10, RMJ10.1, RMJ11, RMJ11.1, RMJ12, RMJ12.1, RMJ13	2005, 2006, 2008, 2010, 2011, 2012
Discharge	BWDB	SW46.9L	2005, 2006, 2008, 2010, 2011, 2012
Water level	BWDB	SW49	2005, 2006, 2008, 2010, 2011, 2012

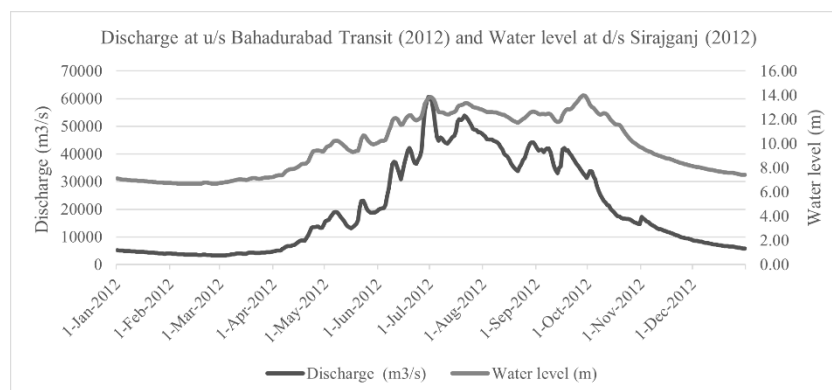


Figure 3: Discharge at u/s Bahadurabad Transit (2012) and Water level at d/s Sirajganj (2012)

The cross-section data from various stations and years were converted to bathymetry data using Microsoft Excel. This processed bathymetry data was then input into QGIS and converted into a

Triangular Irregular Network (TIN) shown in Figure-4. The Geographical Coordinate System (GCS_WGS_1984_UTM_45N) was used, with a cell size of 5x5 meters. Landsat images corresponding to the study area for each year were used to clip the TIN file for improving accuracy (Figure-5). The clipped TIN files were then saved as TIFF files for use in the HEC-RAS model.



Figure 4: TIN of the study area



Figure 5: Clipped TIN of the study area



Figure 6: Terrain data of the study area

The TIFF files generated in ArcGIS were imported into the RAS Mapper of HEC-RAS as terrain data. The 1D model was developed by defining river geometry, including river centerlines, bank lines, flow paths and cross-sections. Manning's roughness coefficients were assigned 0.025 for both the left and right bank and 0.02 for the main channel.

The upstream boundary condition was defined using a flow hydrograph, while the downstream boundary condition was defined using a stage hydrograph. The model was set up for an unsteady flow simulation, and the simulation was run at 5-minute intervals for an entire year.

2.2 GIS-Based Analysis

To facilitate a comparison of erosion-accretion patterns, satellite images spanning several years were obtained from the USGS Earth Explorer website. Satellite images of many years can be obtained along with the time and date of acquisition, which helps compare the morphological changes within a certain interval period (Ahmed et al., 2014). For this study, specific periods have been taken (2005,2006,2008,2010,2011,2012) to determine the changes along the bank lines of the Jamuna river situated in Bahadurabad, Sirajganj. To download the images, data sets of Landsat 4-5 TM C2 L2, Landsat 7 ETM+ C2 L2 with a cloud cover of 15% have been used.



Figure 7: Selected Reach

Landsat images are downloaded in Geo Tiff format. The software employed for subsequent procedures is ArcGIS 10.8. The raw satellite images from Band 1 to 7 cannot be utilized for further processing without being composited into a single band. Therefore, images from Bands 1 to 7 for each interval year have been composited to facilitate the calculation of erosion and accretion.

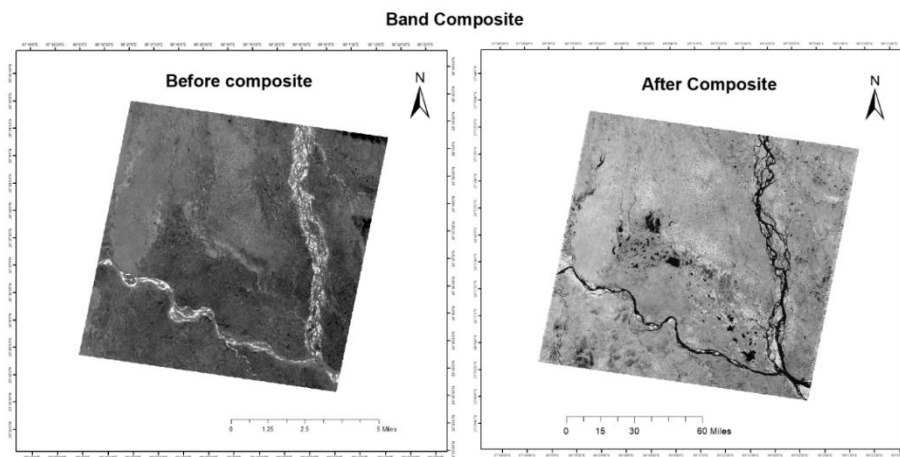


Figure 8: Band Composite

In this study, from 2005 to 2012 total 6 images were extracted. Each of these images provided insight into the gradual changes in the bank line over time. Following the extraction of the study area from the images, Iso Cluster Unsupervised Classification was done for all six images. This process improves the clarity of water bodies, land and vegetation. After that, the classified images were converted from raster to polygon shapefile from which was selected the study area and exported it. After exporting the images were ready to calculate erosion and accretion by area method.

All of the six images from 2005 to 2012, which were exported used for the determination of erosion-accretion rates along the bank lines of the study area. For the estimation of erosion-accretion rates, the area method was used as it happened to be one of the most effective processes for determining erosion-accretion rates. This method was done by calculating the study area where erosion and accretion take place. Areas of two consecutive interval years were calculated at first and then the unchanged area is calculated by the intersect tool under Geoprocessing. The calculated intersect area depicts the unchanged area of the two consecutive intervals. Finally, erosion was calculated by subtracting from the unchanged area of the previous year and accretion is calculated by subtracting from the unchanged area of the next year.

2.3 River Erosion Prediction

Erosion data from 2005 to 2012 was collected, including values for observed erosion (hectares), velocity, and water surface elevation (WSE). Missing values were handled using interpolation and outliers were detected using the IQR (Interquartile Range) method to ensure data consistency. To analyze and predict erosion trends, four different models were implemented:

- **Random Walk Model**

The Random Walk Model assumes that future erosion values are determined by past values with a random fluctuation (Shumway & Stoffer, 2011). This model follows:

$$E_t = E_{t-1} + \epsilon_t \quad (1)$$

where E_t is erosion at time t , and ϵ_t is a random error term. This model captures short-term fluctuations but lacks long-term predictive power.

- **ARIMA (Autoregressive Integrated Moving Average) Model**

The ARIMA model (Box & Jenkins, 1976) is a time-series forecasting technique that accounts for past values and errors to make future predictions. The model follows:

$$Y_t = \alpha + \sum \phi_i Y_{t-i} + \sum \theta_j \epsilon_{t-j} + \epsilon_t \quad (2)$$

Where, Y_t is the erosion at time t ; ϕ_i represents past observations (autoregressive component); θ_j represents past forecast errors (moving average component); ϵ_t is white noise. Model parameters were selected based on AIC (Akaike Information Criterion) and optimized using the Box-Jenkins method.

- **XGBoost (Extreme Gradient Boosting) Model**

The XGBoost model (Chen & Guestrin, 2016) is a machine learning algorithm that uses gradient boosting on decision trees to improve predictive accuracy. The model optimizes the objective function:

$$\mathcal{L}(\theta) = \sum_{i=1}^n l(y_i, \hat{y}_i) + \sum_{k=1}^K \Omega f_k \quad (3)$$

Where, $l^*(y_i, \hat{y}_i)$ is the loss function (Mean Squared Error); $\Omega(f_k)$ is the regularization term to prevent overfitting; the learning rate, max depth, and n estimators were tuned using grid search cross-validation for better performance.

- **LSTM (Long Short-Term Memory) Neural Network**

LSTM, a type of recurrent neural network (RNN) (Hochreiter & Schmidhuber, 1997), is used for sequential data prediction. The architecture consists of:

- Input layer (previous erosion values).
- LSTM hidden layers with memory cells to capture long-term dependencies.
- Dense output layer for final prediction.

The training was performed using the Adam optimizer and Mean Squared Error (MSE) loss function. However, due to limited data, LSTM exhibited overfitting, producing unrealistic constant values (approximately 2000 hectares).

Model performance was evaluated using R² score (coefficient of determination) (X. Yan, 2009):

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2} \quad (4)$$

where y_i are actual values, \hat{y}_i are predicted values, and \bar{y} is the mean of the values.

3. RESULTS AND DISCUSSION

3.1 River Erosion and Accretion Analysis Using Arc-GIS

The results of this study were divided into two parts. The first part focuses on analyzing river erosion and accretion using ArcGIS based on historical Landsat imagery.

Table 2: Eroded and accreted area over the years

Year	Erosion (hectares)	Accretion (hectares)
2005-2006	6757.205	7936.507
2006-2008	9568.721	18541.78
2008-2010	14308.02	10703.49
2010-2011	6995.188	8146.321
2011-2012	6448.543	17327.59

Table 2 demonstrated the dynamic nature of erosion and accretion in the study area over five time periods. From 2005 to 2006, erosion measured 6757.205 hectares while accretion reached 7936.507 hectares, resulting in a net gain of land. The period from 2006 to 2008 saw the highest activity, with erosion at 9568.721 hectares and a substantial accretion of 18541.78 hectares, which led to a significant net increase in land. However, from 2008 to 2010, erosion surpassed accretion, measuring 14308.02 hectares compared to 10703.49 hectares, indicating a net loss of land. The following year, 2010 to 2011, showed a return to net accretion, with 6995.188 hectares of erosion and 8146.321 hectares of accretion. Finally, from 2011 to 2012, erosion was recorded at 6448.543 hectares and accretion at a substantial 17327.59 hectares, again resulting in a considerable net gain. Overall, the data highlights the considerable fluctuations in both erosion and accretion over time, with a trend towards net accretion despite a period of net loss between 2008 and 2010.

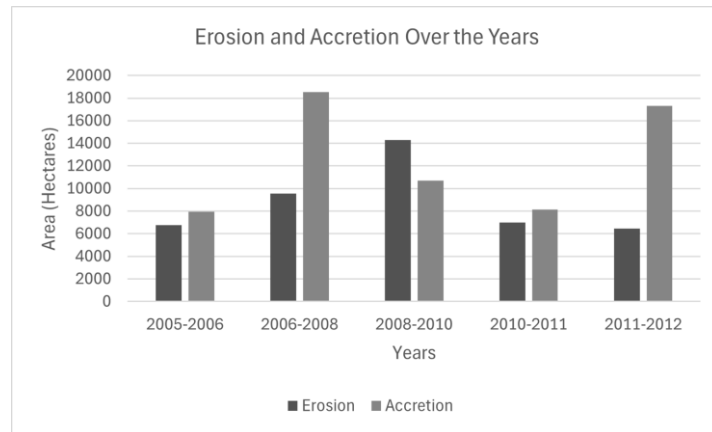


Figure 9: Erosion and accretion amounts

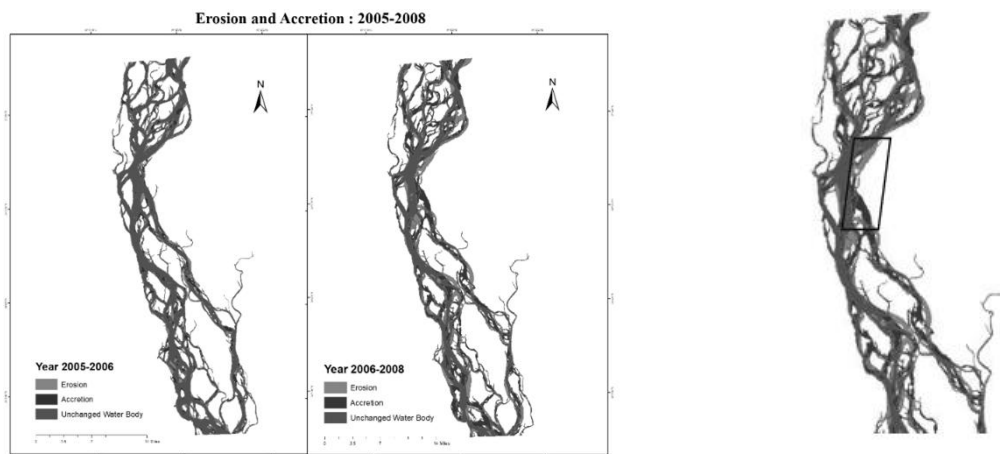


Figure 10: Erosion and Accretion for the year 2005-2008

Figure 10 compared erosion and accretion along a river reach between 2005-2006 and 2006-2008. Using a consistent color-coded legend, green represented erosion, red represented accretion and blue denoted unchanged water bodies. The side-by-side maps visually demonstrated a rise in accretion between the two periods, suggesting significant land gain, while also showing shifts and changes in the patterns of erosion and channels of the river.

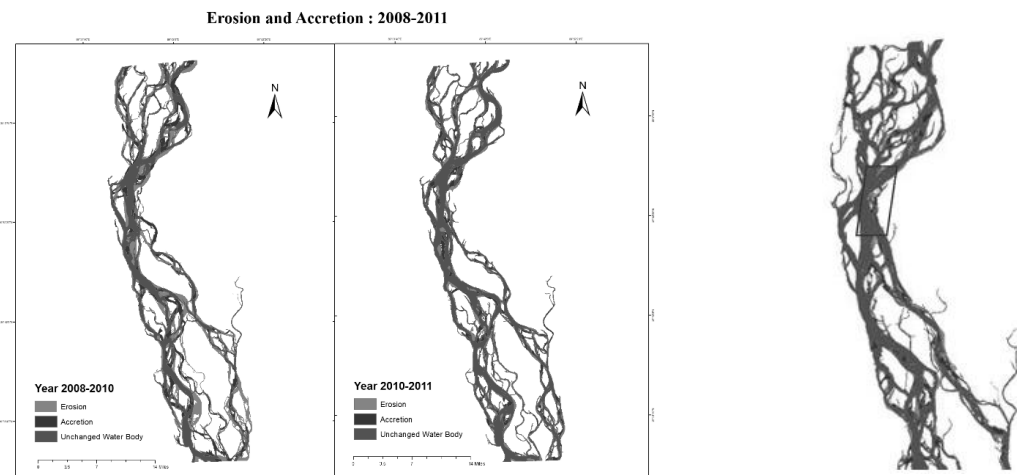


Figure 11: Erosion and Accretion for the year 2008-2011

Similarly, Figure 11 and Figure 12 compares erosion and accretion patterns along a river reach between 2008-2010 and 2010-2011 and 2011-2012 respectively.

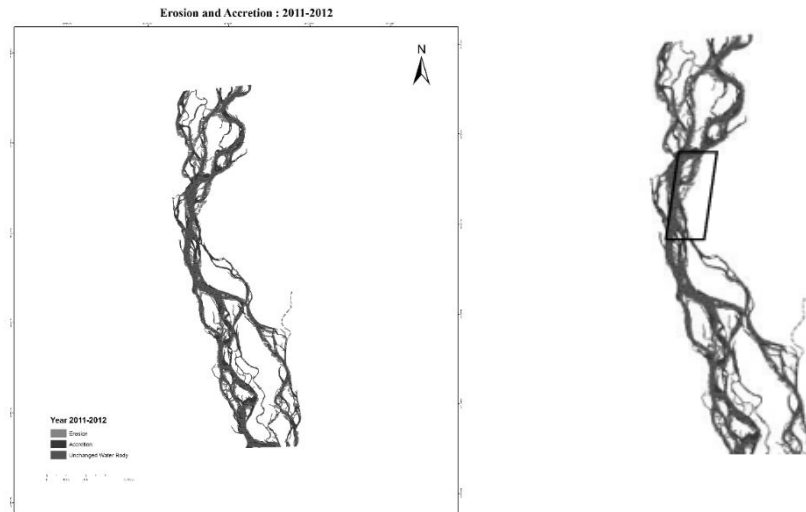


Figure 12: Erosion and Accretion for the year 2011-2012

3.2 Water Surface Elevation and Velocity Analysis Using HEC-RAS

The second part involved analyzing Water Surface Elevation (WSE) and velocity using the HEC-RAS 1D model for a selected area of the reach of the river. The simulation results highlighted a correlation between WSE, velocity and erosion for a particular area of the selected reach. Erosion increased over the years with the rise in velocity and WSE (Figure 13 and Figure 14). This indicated that higher velocity and WSE contribute to greater erosion in the particular area of the selected river reach. These results showed valuable insights into the temporal dynamics of erosion and accretion and their relationship with hydraulic parameters.

Table 3: Velocity and water surface elevation along the years

Year	Average Velocity (m/s)	Average WSE (m)
2005	0.174701754	12.80510765
2006	0.492823316	15.99475286
2008	0.688238426	16.34403333
2010	0.717836509	16.45206939
2011	0.77955287	16.46892589
2012	1.12976399	16.68201599

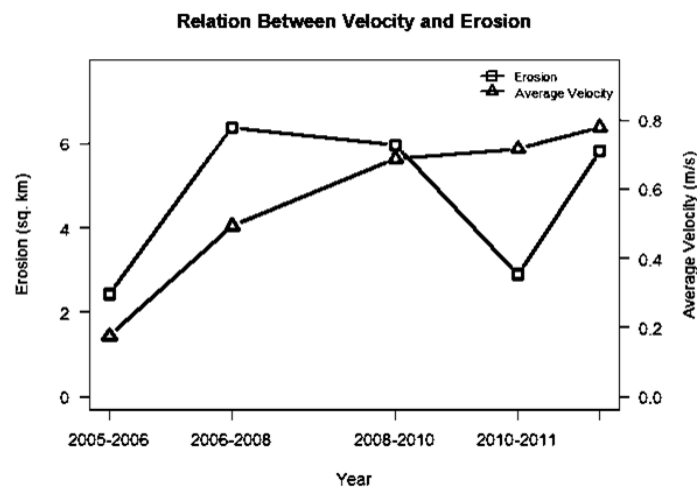


Figure 13: Relation Between Erosion and Average Velocity

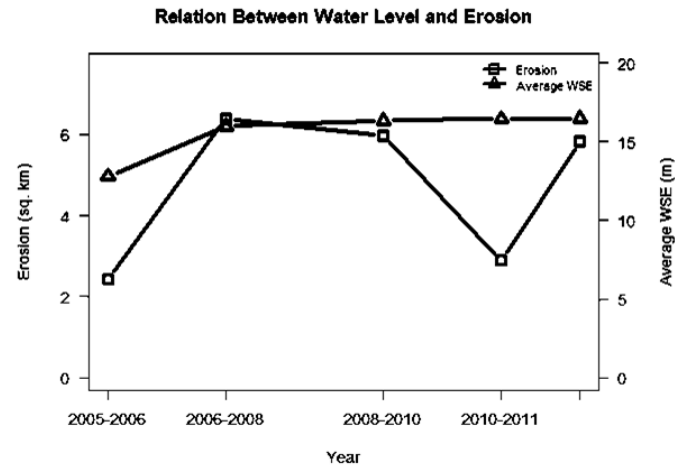


Figure 14: Relation Between Erosion and Water Surface Elevation

3.3 Erosion Prediction

Although river erosion is a complex phenomenon that is influenced by a multitude of factors, including climate change, erratic rainfall, monsoon floods, human interventions and river training structures, predicting its extent remains quite challenging. In this study, HEC-RAS derived data for the study area, supplemented with available information from the BWDB was used to develop a simple erosion prediction model.

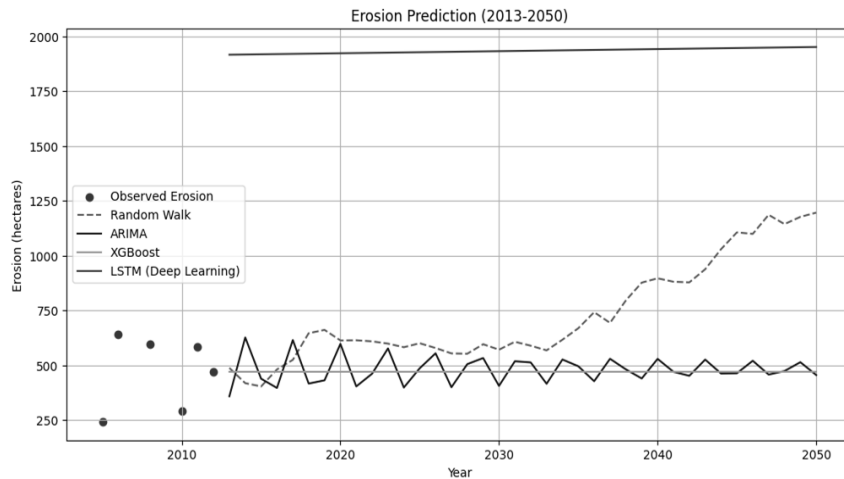


Figure 15: Erosion Prediction

Figure 15 visualized the model predictions against the observed erosion values. Observed erosion from 2005 to 2012, represented by red dots, fluctuated between approximately 200 and 600 hectares, showing no clear upward or downward trend and the interannual variability of erosion. The Random Walk model predicted highly erratic fluctuations, with a dramatic increase exceeding 1000 hectares by 2050, indicating substantial uncertainty in its long-term forecast. In contrast, the ARIMA model forecasted a more stable, oscillating trend within the 300 to 600 hectares range, suggesting a relatively consistent level of erosion in the future. The XGBoost model, which exhibited the highest R^2 score (0.82), followed a similar pattern to ARIMA but demonstrated slightly greater responsiveness to past trends, predicting erosion consistently within the 300 to 600 hectares range and thus representing the most reliable prediction among the models. Finally, the LSTM model predicted an unrealistically high constant value of nearly 2000 hectares, indicating severe overfitting and rendering its predictions unreliable. In summary, while the Random Walk and LSTM models provided unreliable long-term projections, ARIMA and, most notably, XGBoost suggested a stable future erosion pattern within the 300 to 600 hectares range, although substantial uncertainty remains due to the dependency on several influential factors.

The erosion and accretion patterns quantified in this study (peak erosion of 14,308 ha during 2008 to 2010 and maximum accretion of 18,541 ha during 2006 to 2008) for the Bahadurabad Transit to Sirajganj reach are broadly consistent with erosion accretion dynamics reported in previous GIS-based studies of the Jamuna River. Khan et al., (2014) identified pronounced erosion during major flood years and strong spatial variability along river reaches, supporting the episodic erosion peaks observed in the present study. Long-term analyses by R. Rahman, (2023) indicated that during 1973 to 2019 the Jamuna River experienced substantially higher cumulative erosion than accretion (about 1038 km² versus 154 km²), along with sustained channel widening (average about 88 m/yr), which is consistent with the highly dynamic planform behavior observed in this study. Similarly, Uddin, (2024) reported large lateral bank migration (mean left-bank erosion shift about 3116 m), aligning with the high-velocity erosion phases identified from the HEC-RAS simulations in this research. While direct numerical comparison is constrained by differences in spatial extent and temporal scale, the overall trends of flood-driven erosion, asymmetric bank instability, and localized downstream accretion near engineered sections such as the Sirajganj hard point remain in strong agreement with earlier findings. Furthermore, the XGBoost-based erosion forecasts, with highest R² value (0.82), provide a forward-looking extension beyond historical analyses, highlighting the value of combine analyses of hydraulic modeling and machine-learning approaches for riverbank management in highly dynamic braided rivers.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

This study investigated the dynamic river morphology of a selected reach of the Jamuna River, focusing on erosion and accretion patterns over multiple years. Utilizing a combined approach of GIS-based analysis of Landsat imagery and 1D hydraulic modeling with HEC-RAS, the research assessed river changes and their relationship to hydraulic conditions. During the study period (2005-2012), the Jamuna River experienced significant changes in its channel, according to an analysis of multitemporal Landsat imagery. There was notable accretion (land gain) on the right bank downstream near Sirajganj Hard Point, with land gain ranging from approximately 7,936 to 18,541 hectares. Conversely, the left bank upstream near Bahadurabad experienced significant erosion (land loss), with land loss ranging from about 6,757 to 14,308 hectares. Again, HEC-RAS 1D modeling successfully simulated water surface elevation and velocity distribution for the selected reach, corresponding to different periods. The model results indicated a strong correlation between high flow velocity and discharge and areas facing severe erosion condition. Conversely, areas of accretion were associated with comparatively low flow velocity. This analysis highlighted the influence of hydraulic factors on the morphological evolution of the river. Various prediction models are applied to forecast future erosion patterns. The XGBoost model provided the most reliable estimates with R² value 0.82.

4.2 Recommendations

Some actions for the improvement of the study can be recommended based on the results and experiences. Due to data limitations, the model could not be calibrated and validated in this study. Future research should incorporate calibration and validation to improve model accuracy and reliability. This study utilized HEC-RAS 1D simulation. Using more advanced models such as HEC-RAS 2D, SRH-2D, or Delft3D could provide more detailed and accurate results. Again, instead of a TIN file, using a high-resolution DEM as terrain data could enhance model accuracy and improve simulation results. It may increase accuracy of the results. This would enhance the reliability of the findings and facilitate more precise monitoring of erosion and accretion dynamics. However, future studies can include more parameters to predict erosion more effectively. The findings are very important for riverbank protection planning, sustainable land-use management and flood risk mitigation in Bangladesh.

Declaration of Use of AI

The authors of this manuscript declare that in the writing process of this work, no generative artificial intelligence (AI) were used to generate ideas, or theories. AI tools were used solely for the purpose of

enhancing readability and refining language. All such use was conducted under strict human supervision and control. The authors fully acknowledged that authorship comes with responsibilities and tasks that can only be attributed to and performed by humans, and authors have adhered to these guidelines in the preparation of this manuscript.

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