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Assessment of coastline change – induced human displacement using GIS and remote sensing: a case of Bhola Island of Bangladesh

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Abstract

Bangladesh is among the nation's most severely affected by the world's most pressing climate crisis. For example, extreme events such as floods, tropical cyclones, and sea level rise alter coastlines, causing displacement, property destruction, livelihood loss, and migration in the Bhola island areas. However, research on migration and coastal dynamics is limited, hindering the development of effective policymaking and adaptation strategies. Therefore, understanding these interconnections is crucial for developing long-term solutions. The present study aims to assess coastline alterations-induced human displacement using geospatial modeling. The paper utilizes Landsat and Sentinel satellite images from 2000, 2010, 2020, and 2025 to detect coastlines using the Modified Normalized Difference Water Index (MNDWI). It also measures land use and land cover to identify population movement directions and analyze migration trends using a geostatistical approach. The study reveals significant coastal erosion on Bhola Island, affecting approximately 4.22 km² of land per year and resulting in socioeconomic consequences and migration due to reduced vegetation cover, steep slope gradients, soil compaction, and human influence. The findings also indicate that from 2001 to 2025, the area of settlement patterns expanded from 195.73 km² to 414.59 km², with the majority of migration originating from coastal regions among the seven upazilas. The paper emphasizes the significance of community-based needs assessment for safe migration in climate change adaptation, proposing dynamic resettlement projects to address livelihood concerns for internally displaced individuals.

Keywords: Climate Change; Natural Disaster; Coastline Erosion; Human Displacement; Bhola Island; Bangladesh

1. Introduction

Climate change has emerged as one of the most pressing challenges of the 21st century, posing profound risks and uncertainties for societies worldwide (Kemp et al., 2022). While global environmental change is a universal phenomenon and an inevitable aspect of human existence, its intensity and consequences are not experienced uniformly across the globe. Communities whose livelihoods are directly tied to natural resources are particularly vulnerable, as environmental disruptions disproportionately threaten their well-being and survival (Adger and Brown, 2009; IPCC, 2014; Martin et al., 2014; Shamsuddoha, 2012). Climate change has become a critical global concern, already exerting profound impacts on ecosystems, human communities, and economic conditions at an alarming pace. The changing patterns of temperature, rainfall, rising sea levels, and the increasing intensity of extreme climatic events clearly reflect the manifestations and consequences of climate change (Chen and Mueller, 2018; Hossain et al., 2020). Coastal zones, which are naturally dynamic and economically vital, have been increasingly affected by extreme natural events such as severe coastline erosion, tsunamis, cyclonic storm surges, and rising sea surface temperatures—consequences that have intensified under global climate change over the past century (Islam et al., 2015). Developing nations are no exception; in fact, they face growing vulnerability as the frequency and intensity of natural hazards continue to rise (IPCC, 2014; Islam et al., 2019; Yousafzai et al., 2022). Studies indicate that communities residing along major riverbanks or coastal areas in many developing and less developed countries—such as Bangladesh, India, the Philippines, and Indonesia—are highly vulnerable to the impacts of erosion (Alam, 2016; Das et al., 2014; Hall and Bouapao, 2010). Bangladesh is recognized as a global disaster risk hotspot, ranking fifth among the 15 most vulnerable countries out of 173 assessed worldwide (Cross and Societies, 2012; Shaw et al., 2013; World Disaster Report, 2012).

Bangladesh is recognized as one of the most climate-vulnerable countries in the world, primarily due to its unique geographical setting, fragile socioeconomic conditions, rapid population growth, widespread poverty, and limited financial and technological resources (DAS et al., 2024; Hossain et al., 2024). The country is already experiencing a steady rise in average temperature, and projections indicate that by 2030 and 2050, temperatures are expected to increase by approximately 1.0°C and 1.4°C, respectively, due to climate change (Adom, 2024; IPCC, 2014; Roth et al., 2021). Bangladesh has drawn international attention due to its pronounced vulnerability to the impacts of climate change and its proactive efforts to address the needs of displaced populations. Regarding exposure to extreme weather events, Bangladesh ranks as the fifth most vulnerable country globally. Consequently, Bangladesh experiences recurrent severe climate events almost every year, including floods, riverbank erosion, cyclones, saline intrusion, landslides, storm surges, and droughts (Rakib et al., 2019). Bangladesh is highly vulnerable to the impacts of climate change, with projections suggesting that up to 30 million people could be displaced by 2100 if sea levels rise to 80 cm or more (Barua et al., 2017; Bell et al., 2021; Khan et al., 2011). Displaced populations face severe challenges, including limited access to fundamental human rights, intense competition for resources, rapid urbanization pressures, water scarcity, energy shortages, and increased exposure to frequent and severe natural disasters (Goodwin-Gill and McAdam, 2017).

Disaster-induced displacement occurs when natural hazards, such as riverbank erosion, storms, or floods, force people to abandon their homes, which become unlivable, even if only temporarily (Heslin et al., 2018; IPCC, 2014). The impacts of climate-related displacement are particularly acute in least developed countries, where weak infrastructure, widespread poverty, and social inequalities—such as gender-based discrimination—limit people's ability to cope and recover (Alston, 2015). Over the past decade, coastal communities have become increasingly vulnerable to environmental pressures, including sea level rise, tropical cyclones, flash floods, soil salinity, and riverbank erosion—factors that have compelled many to migrate. According to Aid (2007), climate change could permanently displace around 250 million people by 2050, a projection echoed by Morrissey and House (2009), who estimated this would amount to roughly one in every forty-five people worldwide. Notably, approximately 13% of the global population currently resides in low-lying coastal areas that are less than 10 meters above sea level (Hebbert, 2012). A wide range of projections has been made regarding the scale of displacement and migration associated with climate change. In countries with rapidly growing populations, securing livelihoods has become increasingly challenging as communities struggle with the effects of recurring and severe natural disasters.

In Bangladesh, char lands—riverine islands—are among the most vulnerable areas to climate change due to their location along erosion-prone rivers (Alam, 2016; Hossain et al., 2022). Bhola Island, Bangladesh's largest riverine Island, is highly vulnerable to coastal erosion. It is situated at the mouth of the Meghna River and experienced a substantial reduction in land area over the decades—its current elevation is just about 6 feet at its highest point, making it susceptible to flooding and erosion. These lands typically form over a period of 2–3 years through ongoing riverbank erosion and sediment deposition in major rivers and along coastal shorelines. Char lands are often isolated from the mainland, making them particularly exposed to environmental hazards and limiting access to resources and infrastructure (Karim and Thiel, 2017; Saha, 2017). Over the past four decades, sea surface temperatures (SST) have been rising across the northern Indian Ocean, including the Bay of Bengal (Kumar et al., 2016). Elevated SSTs contribute to rough sea conditions, creating significant challenges for coastal fishing communities in Bangladesh (Ahmed et al., 2021; Chowdhury et al., 2012). Estimates suggest that annually, between 50,000 and 200,000 people are displaced due to riverbank erosion, around 600,000 by extreme climatic events, and potentially 25 million by sea level rise over the next 40 years (Malak et al., 2021). These increasing climate extremes disproportionately affect poorer populations who depend on natural resources, compelling them to migrate from their ancestral homes. While climate change does not directly cause displacement, it intensifies environmental pressures and existing vulnerabilities, undermining the capacity of communities to sustain their livelihoods in affected areas. Research has shown that displaced individuals face significant challenges to both their livelihoods and daily lives after relocating from their ancestral homes (Elshater, 2021). Households residing on riverine islands, commonly known as chars, are among the most vulnerable to the impacts of climate change (Ahmed et al., 2021; Shah et al., 2013). Climate-induced disasters often devastate their crops, farmland, and homes, leaving these communities highly exposed. Due to their fragile living conditions, char dwellers frequently face extreme poverty and food insecurity. Their vulnerability is further intensified by limited access to necessities, including food, agricultural support, education, healthcare, and financial services, making them disproportionately susceptible to more profound impoverishment.

Bhola Island experienced catastrophic flooding in 2005, which displaced nearly half a million people from their permanent settlements (Islam, 2016; Saifuzzaman and Alam, 2006). This large-scale displacement highlights the district's crucial role in understanding migration dynamics driven by coastal erosion, making it a focal point for examining the human impacts of environmental change. Bhola, the largest Island in Bangladesh, lies at the southern edge of the country, opening into the Bay of Bengal. Geographically, it is bordered by the Meghna River to the north and east, the Tentulia River to the west, and the Bay of Bengal to the south, making it a uniquely vulnerable yet significant coastal landscape (Salam et al., 2003). Coastal erosion can be effectively assessed through satellite imagery by applying the Modified Normalized Difference Water Index (MNDWI) algorithm. For instance, Ghosh et al. (2015) employed an integrated approach using remote sensing and geographic information systems (GIS) to analyze shoreline dynamics of Hatiya Island, Bangladesh, between 1989 and 2010. Their findings revealed that both erosion and accretion significantly contributed to the Island's coastline shifts. Similarly, Biswas and Islam (2017) examined coastal changes on Bhola Island and highlighted their profound impacts on the lives and livelihoods of its inhabitants. Xu (2006) proposed the Modified Normalized Difference Water Index (MNDWI) as an improved method for delineating water features. Unlike the traditional NDWI, which often introduces errors by mixing water signals with noise from built-up areas, vegetation, and soil, the MNDWI effectively minimizes or even removes such interference. As a result, it provides more accurate water extraction, particularly in regions where urban land cover dominates the landscape, making it more reliable for water-related studies in complex environments.

Remote sensing offers a valuable tool for detecting, mapping, and analyzing coastal features, as well as assessing spatiotemporal changes and their ecological impacts (Petropoulos et al., 2015). When integrated with GIS, satellite-based remote sensing has become widely recognized as a robust and reliable approach for monitoring LULC dynamics (Barua and Eslamian, 2024). Its ability to deliver cost-effective multispectral and multitemporal data makes it particularly valuable for constructing LULC datasets and for understanding and tracking land development patterns and processes over time. This study utilized satellite imagery from Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI/TIRS, spanning the period from 2000 to 2025. Several studies have explored climate change–related issues, including health, livelihoods, displacement, resettlement, and adaptation strategies (Alam, 2017; Fang et al., 2018; Hossain et al., 2021; Liu et al., 2020). However, limited attention has been given to the livelihoods of communities on Bhola Island, particularly in relation to the consequences of coastline erosion. In fact, research specifically addressing how coastline dynamics shape the lives and livelihoods of Bhola's inhabitants remains largely absent. The present study aims to assess coastline alterations that promote forced migration using geospatial modeling. The study also aims to measure land use and land cover to identify population movement directions and analyze migration trends on Bhola Island.

1. Methodology

This study relies solely on secondary data sources. Secondary data were obtained from the United States Geological Survey (USGS), the Internal Displacement Monitoring Center (IDMC), the 2022 Population and Housing Census, and the Bangladesh Bureau of Statistics (BBS, 2023). Additionally, population databases from Bhola Island, as published by the 2022 census of the Ministry of Planning, Government of Bangladesh, were used as a reference. The collected data was processed and analyzed using Microsoft Excel and ArcGIS 10.8.

2.1 Selection of the Study Area

Bhola Island, referred to as the "Queen Island of Bangladesh," is an administrative district in southwestern Bangladesh, located between latitudes 21°54' and 22°52' North and longitudes 90°34' and 91°01' East (Rana et al., 2024). It is the largest Island in Bangladesh's coastal area, comprising approximately 3,737.21 km², and is surrounded by a water body (Shaibur et al., 2023). Moreover, this district is part of the Barisal Division, bordered by the cardinal directions, including north (Lakshmipur and Barisal Districts), south (the Bay of Bengal), east (the lower Meghna and Shahbazpur Channels), and west (Patuakhali District and the Tentulia River) (Toa, 2022). Additionally, the lower part of the Meghna River, which flows across various islands in the Bhola district, includes Char Anandaprashad, Char Bhuta, Sona Char, Tazumuddin, and Manpura (Siddeqa et al., 2023). Administratively, the district comprises five municipalities, nine thanas, 66 unions, 473 villages, and seven upazilas **(**as shown in **Fig.-1)**, with a population of 2,037,201, a high agricultural production rate (63.64%), and a high literacy rate (47%) (BBS, 2023). Despite being a coastal region, the area boasts high agricultural productivity and uses deep tubewell groundwater as fresh water for irrigation and drinking (Ahmmed et al., 2020). The majority of people are involved in agriculture, fish cultivation, and livestock farming, with a notable focus on buffalo farming (Jahan et al., 2024). Geomorphologically, the Island is a coastal plain of flat land below 5 feet from sea level, classified as estuarine floodplains, with uniformly silty deposits, a lack of meander scars, abandoned channels, and a close network of tidal creeks, distinct from meanders and tidal floodplains (Galib and Moniruzzaman, 2017). According to the Bangladesh Meteorological Department (BMD), over a thirty-year period (1975-2005), the daily observed climate data included precipitation (2,408 mm) and temperature (T_{min}: 21.52°C and T_{max}: 30.3°C), respectively (Rana et al., 2023). Throughout decades, river and coastal processes have changed the Island's topography, resulting in harmful consequences for the population and property, with regular monsoon-season floods compounded by excessive rainfall and tidal surges (Islam et al., 2020). Furthermore, the region is significantly impacted by changes in human displacement patterns due to riverbank erosion (Malak et al., 2021). This unique phenomenon prompted the selection of Bhola Island as the research site for evaluating migratory patterns in terms of coastal erosion. This interesting phenomenon led us to choose Bhola as the study area for analyzing migration pattern in terms of coastline erosion.

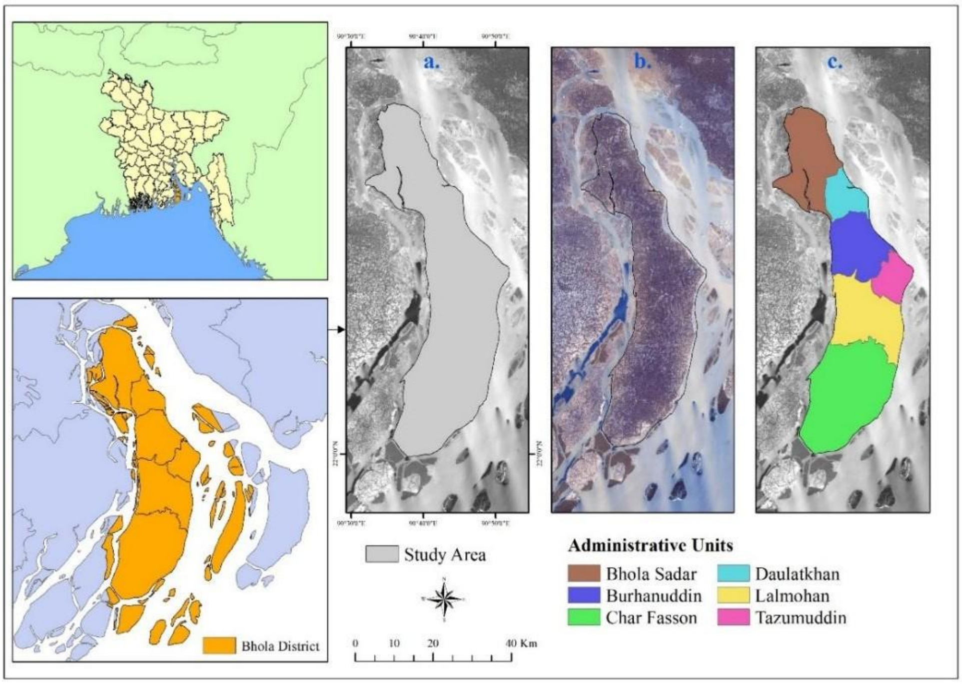


Fig.-1: Location of the Study Area

2.2 Satellite Data Collection

This study acquired four Landsat satellite images to identify coastlines **(Table-1)**. To minimize cloud interference and improve coastline visibility, image acquisition was focused on the late winter months—primarily January, February, and November—when atmospheric conditions are generally clearer (Eteh et al., 2024; Hossen and Sultana, 2023). For the analysis, Landsat datasets with a spatial resolution of 30 meters were utilized, including Landsat ETM+ (2000), Landsat TM (2010), and Landsat OLI (2020 and 2025). Each seasonal dataset consists of two overlapping frames, corresponding to paths/rows 137/44 and 137/45, across all three sensors. Therefore, the present study utilized four Landsat satellite images to identify coastlines.

Table-1: Details of the Landsat Dataset

Space craft ID	Sensor ID	Spatial Resolution (m)	Path	Row	Format	Cloud over	UTM Zone	Band used	Acquired Date	Source
Landsat 7	ETM+	30*30	137	44	TIFF	0	46	2,5	2000-02-28	https://earthexplorer.usgs.gov/
	ETM+	30*30	137	45	TIFF	0	46	2,5	2000-02-28	
Landsat 5	TM	30*30	137	44	TIFF	0	46	2,5	2010-01-30	
	TM	30*30	137	45	TIFF	0	46	2,5	2010-01-30	
Landsat 8	OLI	30*30	137	44	TIFF	0	46	3,6	2020-01-26	
	OLI	30*30	137	45	TIFF	0	46	3,6	2020-01-26	
Landsat 8	OLI	30*30	137	44	TIFF	0.46	46	3,6	2025-03-28	
	OLI	30*30	137	45	TIFF	.07	46	3,6	2025-03-12	

2.3 Coastline Delineation

Delineating coastlines is often challenging due to the presence of water-saturated zones along the land-water interface (Maiti and Bhattacharya, 2009). To address this, water indices such as the Normalized Difference

Water Index (NDWI) and its modified version (MNDWI) are widely applied for detecting water features (Tha et al., 2022; Wang et al., 2022). In the present study, coastlines were derived from water bodies identified using the MNDWI, with a particular emphasis on this technique. The MNDWI is particularly effective in enhancing open water features while suppressing noise from soil, vegetation, and built-up areas (Hasan et al., 2024; Xu, 2006). The NDWI was calculated using **Eq.1** (McFeeters, 1996)

$$\text{NDWI} = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}} \quad (1)$$

The MNDWI was calculated using the green band in combination with the MIR band for Landsat 7, and the SWIR band for Landsat 5 and 8 (**Eq. 2 and Eq. 3**) (Hasanuzzaman et al., 2021).

$$\text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}} \quad (2)$$

$$MNDWI = \frac{\text{Green} - \text{SWIR}}{\text{Green} + \text{SWIR}} \quad (3)$$

Delineating coastlines for the purpose of calculating erosion and accretion presented a significant challenge. Although the NDWI was first used for the extraction of water bodies, the MNDWI was then employed to reduce the noise effect of the built-up land and vegetation, thus improving the contrast between water and non-water features. Between 2000 and 2020, satellite images were collected at ten-year intervals. From 2020 to 2025, they were acquired at a five-year interval to capture more recent changes with higher temporal detail. High water imagery related to change detection was collected to prevent misinterpretation of the land-water boundary. To execute this specific assignment, a selection of images was randomly chosen, predominantly from the winter season, exhibiting a significant temporal gap from the latest image, which was taken in 2025. All pre-selected imagery was cross-referenced with high tide data obtained from the Bangladesh Inland Water Development Board (BIWTA). Ultimately, a previous image was chosen with a satisfactory synchronization of high tide and satellite passing time. For distinct land-water boundaries, the modified normalized difference water index (MNDWI) was developed using the band-ratio technique (Xu, 2006). The MNDWI map was then transformed into a binary raster and a polygon shapefile. In the final step, the erosion and accretion were computed after the two polygons were superimposed using the union tool. Conversely, 30-year tide gauge data were used to calculate the mean tide range values and the rate of relative sea level change. The 2011 population census provided the union-level population data (BBS, 2023).

2.4 Land use and land cover (LULC) Classification

In this study, supervised learning techniques were applied to develop a classification model, where predictor variables were used to generate and assign class labels (Kotsiantis et al., 2007). Landsat images obtained from the United States Geological Survey (USGS) Earth Explorer platform (https://earthexplorer.usgs.gov/), were employed to classify land use and land cover (LULC) using the asset of machine-learning algorithms.

Drawing on an extensive literature review and local expert insights, Landsat imagery from 2000, 2010, 2020, and 2025 was classified into five major land use/land cover (LULC) categories: agricultural land, built-up areas, barren land, vegetation, and waterbody (**Table-2**). For each class, representative training patterns were delineated through visual interpretation, and classification results were validated using ground truth data. Signature files containing multivariate statistics of each LULC category were generated from the training samples within ArcGIS to determine the most effective classification. The accuracy and Resolution of the

LULC classification can be further enhanced by increasing the number of training samples.

2.5 Change detection

Land use and land cover (LULC) change can be extracted from different remote sensing datasets using a range of techniques (Asokan and Anitha, 2019). However, the process is often complex and not always straightforward. A relatively simple yet effective approach involves comparing satellite datasets acquired at different times to detect changes in LULC (Afaq and Manocha, 2021). In this study, LULC maps generated from the most accurate classifier were compared across successive time periods (2000-2025) to assess both qualitative and quantitative changes. For the best-performing classifier, variations in the four primary land cover classes are summarized in **Table-2**. These classified maps were further used to analyze settlement expansion, dynamic resettlement patterns, and fluctuations in surface water within the depression area over the past two decades.

Table-2: Description of the Identified LULC Classes

Class Name	Class Description
Agricultural land	Area covered by crops, paddy fields, seasonal crop fields, and homestead gardens.
Built-up area	Area covered by settlements, housing clusters, schools, markets, and road networks.
Barren land	Land on the riverbed, riverine sandbars, exposed riverbeds, and newly accreted chars.
Vegetation	Area covered by forest, sparse trees, dense mangrove vegetation, homestead tree cover, social forestry plantations, and patches of mangrove vegetation in coastal zones.
Waterbody	Area covered by water, rivers, canals, ponds, wetlands, and seasonal floodplains

3. Results

3.1 Socioeconomic Conditions of Displaced People: Causes and Consequences

This study aims to examine the socioeconomic characteristics and background of the displaced people within this study area. It is structured around key indicators of socioeconomic status—such as age, gender, primary occupation, family size, and household income—particularly in relation to how these factors are influenced by coastline erosion. The objective is to gain a deeper understanding of the background and circumstances of the participants. Across the Bhola island, there are seven administrative units, namely Bhola Sadar, Borhanuddin, Charfasson, Daulatkhan, Lalmohan, Monpura, and Tazumuddin. The total population and number of households on this Island are 1,932,518 and 449,018, respectively. The detailed socio-demographic background of the study area is shown in **Table-3**.

There are several significant reasons why people migrate to nearby cities. Findings indicate that livelihood-related factors largely drove migration. More than half of the respondents cited the loss of homesteads and cultivated land as the primary causes. The reason behind this trend is a lack of employment opportunities, damage to houses and household assets, food and water shortages, sanitation problems, and concerns over the safety of women and adolescents (Islam and Hasan, 2016).

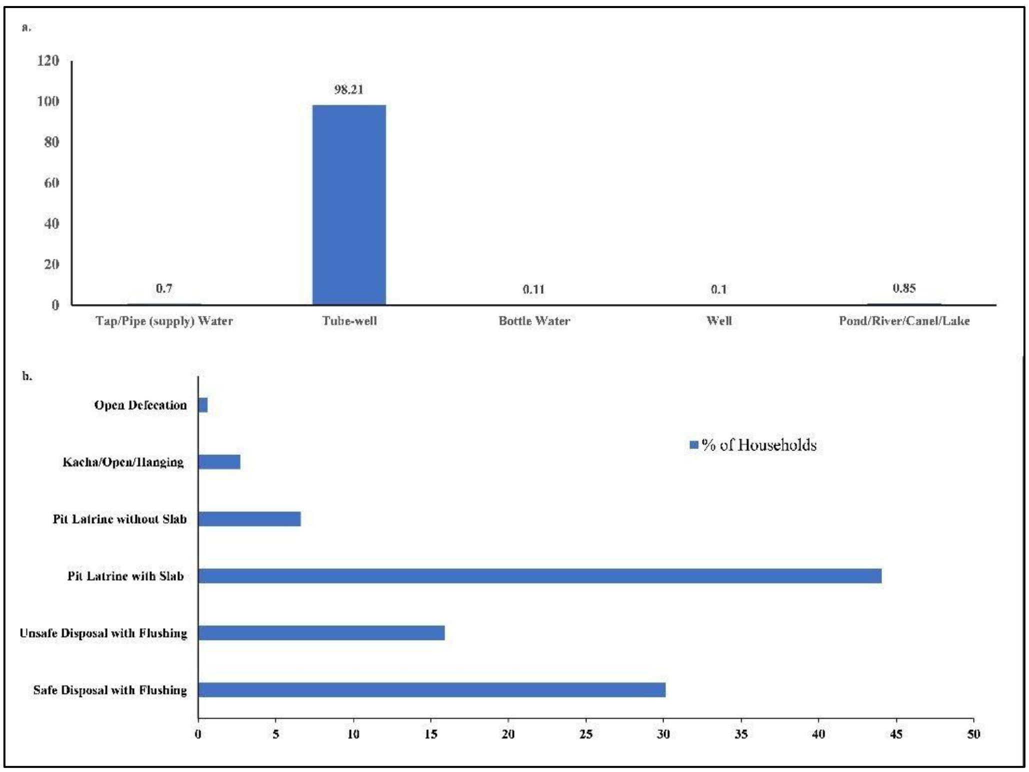
The study revealed severe inadequacies in water supply and sanitation facilities for the population of Bhola Island **(Fig.-2a).** The local government had few supplementary provisions, and only 0.7% of the population reported access to safe water from Bhola WASA. Nearly the whole (98%) relied on tube wells, while 0.11% collected water from shared roadside tube wells or taps. Only 0.85% depended on distant ponds, rivers, canals, or lakes.

Sanitation conditions were equally concerning in the study area. Among households on Bhola Island, only 0.6% of people practice open defecation **(Fig.-2b)**. In the existing facilities, 44.04% were deemed pit latrines with slab and hygiene, and 30.13% use safe disposal with flushing. In some cases, latrines were directly connected to nearby drainage systems, where damaged security covers allowed human waste to float in stagnant water, further exacerbating health risks.

Table-3: Socio-demographic Characteristics of the People in Bhola Island, Bangladesh

Administrative Unit	Population	Total Households	Sex Ratio (Male to Female)	Literacy Rate (%)	Religion				NO of Employed Persons	Field of Employment		
					Muslim	Hindu	Christian	Buddhist		Agriculture	Industry	Service
Bhola Sadar	444,838	102157	959	69.75	431,059	13,704	31	25	221,000	62.5	10.2	25.5
Borhanuddin	265,437	62027	908	68.61	255,020	10,384	15	10	128,000	65.1	8.7	24.9
Charfasson	518,817	120176	1,072	66.66	403,043	10,505	15	9	246,000	58.8	12.4	27.5
Daulatkhan	181,813	42302	927	65.89	177,851	3,937	6	7	88,000	63.5	8.5	27
Lalmohan	297,692	69850	926	63.81	288,983	8,657	14	14	88,000	66	9	24
Monpura	89,745	20065	1,006	60	71,985	4,594	3	0	142,000	72	5.5	21
Tazumuddin	134,176	32441	994	61.43	127,583	6,575	8	7	41,000	70.2	6.5	22.3

***Source**: BBS (2022); District report: Bhola*



***Source**: BBS (2022)*

Fig.-2: Available Basic services in the Bhola Island: a. Sources of Drinking Water, and b. Sanitation Facilities

In a developing country like Bangladesh, educational statistics play a vital role in shaping future socioeconomic development strategies and policies. **Table-3** presents literacy rates across three specific age groups, disaggregated by sex and upazila. The findings indicate that the overall literacy rate for individuals aged seven years and above in the district stands at 67.3%, compared to the higher national average of 74.8%. Within the district, literacy levels show a slight gender disparity, with rates of 67.24% among males and 67.35% among females.

3.3 Coastline Erosion: Occurrence and Displacement

A GIS-based analysis of erosion on the coastline of Bhola Island over 25 years (2000-2025) is presented in **Fig.-3.** The Island experienced erosion across all three intervals—2000-2010, 2010-2020, and 2020-2025, as shown in both **Fig.- 4**. The most severe erosion occurred between 2000 and 2010, particularly along the northern and eastern margins of the Island. In contrast, the southwestern, southern, and southeastern regions remained largely stable throughout the period. **Fig.-4** presents the statistical summary of erosion on Bhola Island, illustrating the continuous decline in the Island's area across the study intervals (2000-2010, 2010-2020, and 2020-2025). This declining trend can be attributed to the intensified erosional processes, likely driven by high- velocity currents from the Ganges-Meghna-Brahmaputra (GBM) system during the monsoon season. Overall, the analysis indicates that approximately 105.69 square kilometers of land have been lost to the sea over the past 25 years (2000-2025).

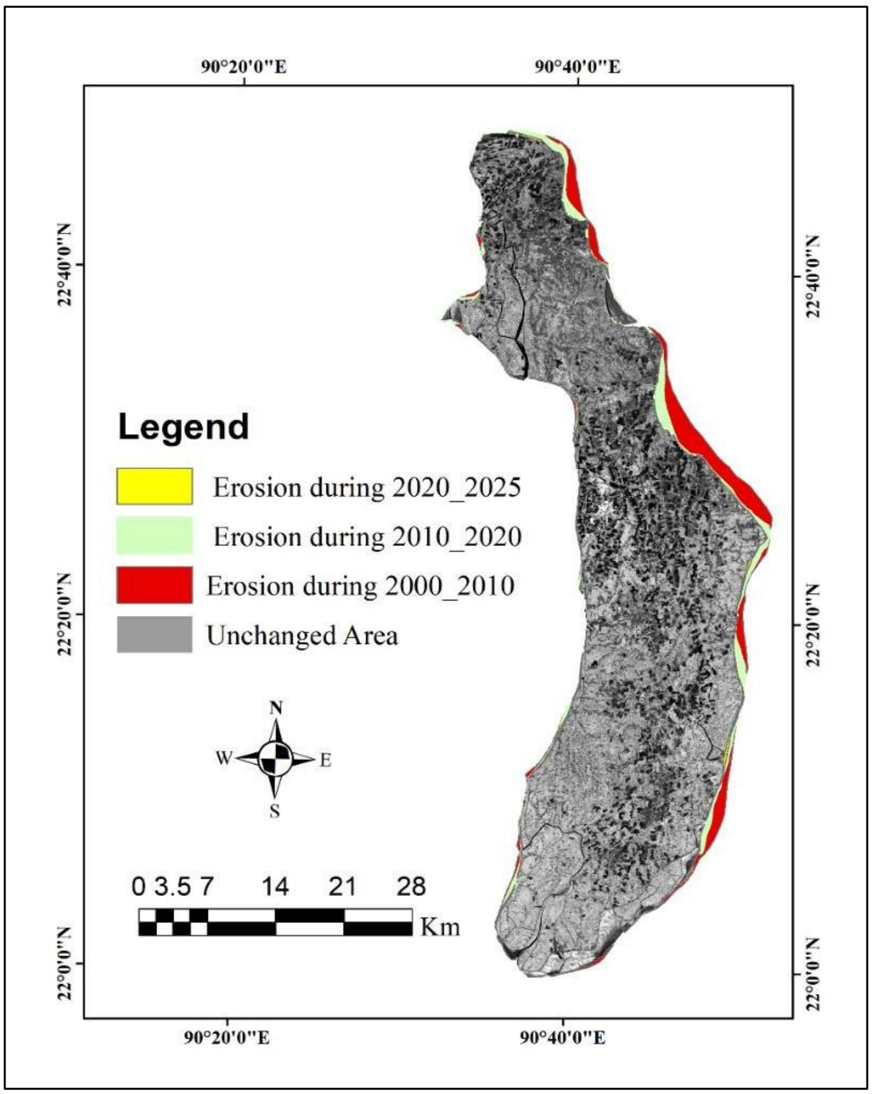


Fig.-3: Erosional change detection map of Bhola Island during 2000-2025

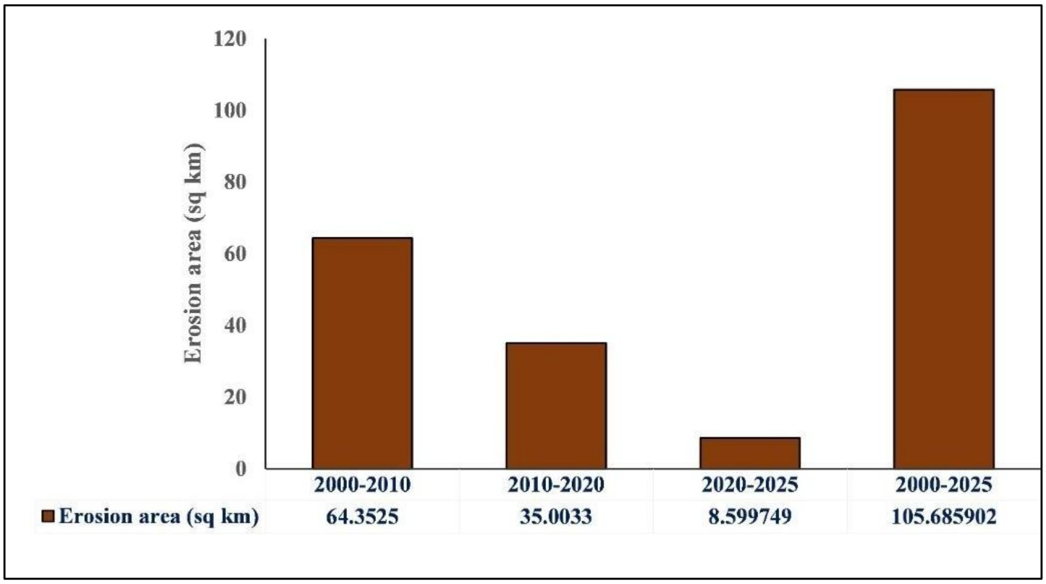


Fig.-4: Total Coastline Erosion of Bhola Island, 2000-2025

3.4 Monitoring Change Detection

In **Table-4,** a significant change was observed in waterbody and vegetation classes between 2000 and 2010. However, the substantial change from 2010 to 2020 was primarily in vegetation and barren land classes. Waterbody class decreased from 206.63 km² in 2000 to 98.24 km² in 2010 due to land reclamation; from 2010 to 2020, it increased from 98.24 to 118.22 km² due to erosion on agricultural land; and finally, from 2020 to 2025, it also increased again from 118.22 to 118.6 km² due to land erosion in barren land classes.

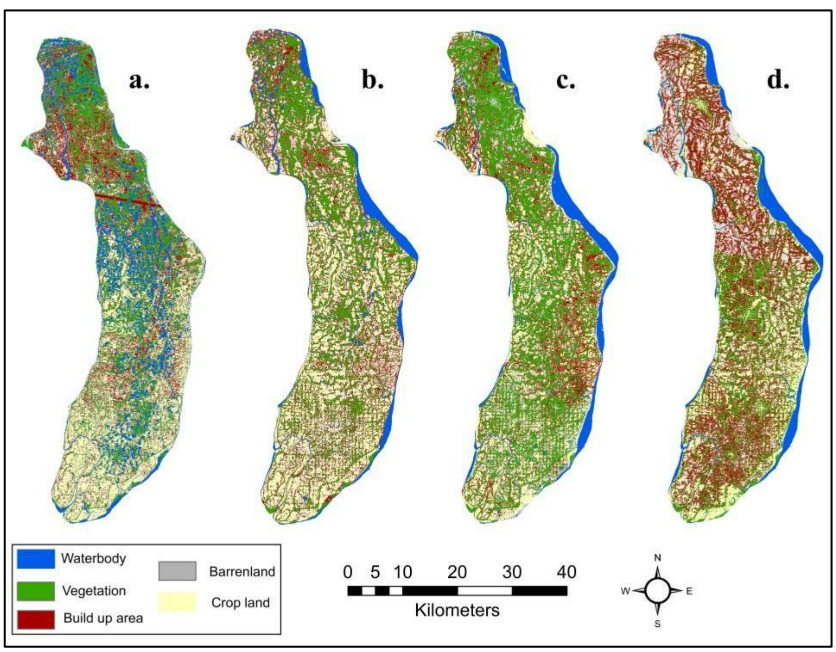


Fig.-5: LULC Maps for Four Different Years: (a) 2000, (b) 2010, (c) 2020, and (d) 2025

Table -4: Area and percentage of each class in Bhola Island (km²) and % of LULC Classes

Classes	2000		2010		2020		2025	
	Area (Km^2)	Percentage (%)	Area (Km^2)	Percentage (%)	Area (Km^2)	Percentage (%)	Area (Km^2)	Percentage (%)
Waterbody	206.63	14.73	98.24	7.00	118.22	8.43	118.6	8.45
Vegetation	376.21	26.81	407.24	29.02	546.31	38.93	325.36	23.19
Build up area	195.73	13.95	272.5	19.42	229.99	16.39	414.59	29.55
Barren land	318.07	22.67	317.77	22.65	229.08	16.33	271.33	19.34
Crop land	306.5	21.84	307.42	21.91	279.62	19.93	273.38	19.48
Total	1403.14	100	1403.14	100	1403.14	100	1403.14	100

4. Discussion

Riverbank erosion is a natural and recurring process that can occur at any time of the year, although it is most prevalent during the rainy season. In the Meghna estuary region, erosion is a common phenomenon and occurs without a predictable warning period (Sarwar and Borthwick, 2023)—sometimes unfolding within moments, while in other cases developing over several days or even weeks. Shoreline analysis of Bhola Island using Landsat imagery from 1989 to 2018 reveals that the northeastern face experienced extremely high erosion rates—up to –139 m/year near the confluence of the GBM rivers—while the southeastern zones witnessed lower erosion, around –40 m/year, due to natural shielding by the Island's upper sections. The most acute erosion occurred during 1989–2005, when monsoonal flooding and upstream barrage operations amplified shoreline retreat, with annual rates reaching as much as –249 m/year in some periods (Galib and Moniruzzaman, 2017).

The findings of this study highlight the complex interlinkages between coastline dynamics and forced migration in Bhola Island, Bangladesh. The geospatial analysis revealed significant shoreline alterations driven by erosion and accretion processes, which directly affect settlement patterns and livelihoods (Samanta and Paul, 2016). As coastlines retreat, agricultural lands, homesteads, and critical infrastructure are increasingly lost, compelling local populations to migrate in search of safety and alternative livelihood options. This pattern resonates with earlier studies that have identified riverbank erosion as one of the most severe drivers of displacement in coastal Bangladesh (Islam and Rashid, 2011; Penning-Rowsell et al., 2013). The use of geospatial modeling in this study provided a reliable means of tracking shoreline change and quantifying its impacts over time, underscoring the importance of integrating earth observation data into climate adaptation and migration research. However, the human dimension of such environmental changes is equally critical. Displacement is not only a response to land loss but also reflects the limited coping capacity of vulnerable communities, inadequate infrastructure, and insufficient institutional support (Aboda et al., 2019). Therefore, the results emphasize the urgent need for comprehensive adaptation strategies that combine geospatial monitoring with social protection policies to address the intertwined challenges of environmental change and forced migration in Bhola.

Riverbank erosion on Bhola Island has forced nearly 95% of surveyed households to relocate, with 54% displaced two to four times over the past five years, illustrating the chronic instability faced by communities in erosion-prone zones. Displacement destinations vary: 30% of households moved to embankments, while 22% sought shelter in relatives' homes, underscoring the piecemeal and informal nature of resettlement (Islam and Filho, 2023). A community in Ramdaspur village of Bhola District, situated along the Meghna River, has endured severe riverbank erosion—up to 100 m per year in its southern zone—with no observed accretion between 2008 and 2014, while past periods (1998–2004) experienced moderate accretion of around 215 m per year. Despite repeated displacement, more than 55 % of households chose to remain in situ, prioritizing social support networks, community bonds, and the affordability of staying over the prospect of migrating elsewhere (Mallick and Mallick, 2021). Over the past decades, coastal erosion has displaced thousands of households in Bhola Island, forcing families to abandon their farmland and homesteads to the encroaching Meghna River (Doerr, 2021). Many of the displaced initially seek shelter on embankments or recently accreted char lands, though these spaces are precarious and equally vulnerable to future erosion. While a large proportion of households attempt to resettle within the Island, a considerable number migrate to major urban centers such as Dhaka and Chattogram, where they often end up in informal settlements while struggling to rebuild their livelihoods (Doerr, 2021).

5. Conclusion and Recommendation

Tidal forces and hydrodynamic processes have largely dominated erosion on Bhola Island. The eastern part of the Island experienced particularly severe erosion during 2010-2025 compared to the earlier period of 2000-2010, primarily due to the strong monsoonal currents originating from the Ganges–Meghna–Brahmaputra (GMB) system. Additionally, the complex hydrodynamic interactions between river discharge and oceanic forces appear to play a significant role in accelerating shoreline retreat. Coastline erosion in Bhola Island has emerged as a persistent environmental hazard, reshaping landforms and repeatedly displacing vulnerable communities. The result shows that erosion not only destroys homesteads and farmland but also forces families into cycles of internal relocation within the Island or migration to urban centers. Such displacements disrupt livelihoods, weaken social networks, and create new socioeconomic vulnerabilities.

To mitigate displacement, sustainable embankment projects and riverbank protection measures should be prioritized alongside community-based disaster risk reduction programs. To enhance the accuracy of future assessments, further research focusing on key hydrodynamic parameters—such as flow velocity, water depth, and tidal dynamics—will be essential. This study relied exclusively on secondary data sources, including census reports, journal articles, and existing remote sensing data from the USGS. While these sources provide valuable insights into patterns of erosion and displacement, they limit the ability to capture the lived experiences, coping strategies, and nuanced migration trajectories of affected households. Primary field surveys, participatory mapping, and qualitative interviews would have enriched the analysis by adding perspectives from local communities.***Acknowledgements:*** The authors thank the Department of Geography and Environment at Jagannath University for their cooperation in data analysis through the GIS Lab.

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