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A Remote Sensing-Based Approach to Identifying Spatio-Temporal Changes in Coastal Morphology in Bhola District, Bangladesh

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ABSTRACT

Bhola, the largest island of Bangladesh located at the estuarine mouth bar of the Bay of Bengal is very dynamic and unique in nature due to its physiographical configurations and is experienced severe morphological i.e. erosion- accretion changes. Of late, monitoring of coastal morphology and changes in shoreline trend analysis has conveniently been done through the integration of remote sensing satellite imageries and GIS techniques. The present study is an endeavor to detect and analyze the morphological changes on Bhola Island. Multi-temporal satellite images are the main data sources to attain the objectives through the integration of RS and GIS. The study concludes from the recent 42 years (1974- 2016) satellite data that- the Island is in the losing phase since 1974. The erosion processes are still active along the eastern and northeastern parts of Bhola Island due to the direct influence of the Meghna Estuary on the land by the steep bank slope, high tidal water pressure, and loose bank materials. Erosion is the burning issue on Bhola Island and due to this a large number of people are landless every year. On another side, accretion is being operated in a large part surrounding the Island increasingly in the southern part due to backwash sediment deposition by channel and estuary with the favor of a gentle topographic slope along the bank.

Keywords: Coastal Morphology, Shoreline Change, GIS, Remote Sensing, Erosion, Accretion, Sediment Deposition.

1 Introduction

Bangladesh, located in the tropics between 20°34' and 26°38' north latitude and 88°01' and 92°41' east longitude, shares its borders with India to the west, north, and northeast and with Myanmar to the south-east. With its extensive coastline, the Bay of Bengal serves as the defining feature of Bangladesh's southern border. The Ganges, the Brahmaputra, and the Meghna, together referred to as the GBM, are the three primary rivers that flow into Bangladesh from India. Within Bangladesh, these rivers meet up and eventually empty into the Bay of Bengal by a single outfall. Around 2.4 billion tons of silt are carried into the Bay of Bengal each year by the Ganges-Brahmaputra River (GBM) [1]. These sediments influence the dynamic processes that take place in the bay, leading to accretion in certain regions and erosion in others. There is a possibility that the buildup of silt in inner rivers is caused in part by the heavy sediment load from GBM as well as the strong tidal flow that prevents debris from flowing directly into the Bay of Bengal.

The ecology and ecosystem of Bangladesh are of a diverse nature due to its placement along the narrowest funnel-shaped and shallowest stretch of the Bay of Bengal in the south and the Himalayan ranges [2]. As a result of its geographic location and high population density, the country is particularly vulnerable to natural and man-made calamities. Nearly a quarter of Bangladesh's 24-billion-person population lives along the country's seashore. These areas are important to many of our coastal countries because they represent the interface between marine and terrestrial ecosystems. Delineation and monitoring of coastal changes are crucial for effective management. This includes hazard zoning, erosion-accretion investigations and analysis and modeling of coastal morpho-dynamics in addition to the more traditional coastal research. Change detection applications have grown more dependent on the integration of GIS and remote sensing data in recent years. Change detection is the process of finding differences in the condition of an object or phenomenon by multiple observations [4]. Widespread use of remote sensing technology for identifying spatio-temporal changes in the environment via satellite photography holds the promise of frequent map updates. Remote sensing data may be used to assess coastal processes such as erosion-accretion and shoreline changes. The ability of GIS to detect the spatial link between quality and temporal changes within an area over time is the primary benefit of this tool. For this reason, an accurate and dynamic monitoring of the changing coastline and delta zone is essential for obtaining a better knowledge of how the surface system of the Earth reacts to human activities. [5]

1.1 Problem Statement

Coastal zones across the globe are vulnerable regions that demand special consideration due to heightened natural and human-caused disruptions [6]. Bhola is home to a wide range of ecosystems and a wealth of promising coastal resources. The estuary and tidal influences of the Bay of Bengal have had a significant impact on the morphology of the island throughout time. It has decreased in size from 6,400 km^2 in 1960 to 3,400 km^2 now. Bhola has lost a total of 3,000 km^2 [7] because of this. It has only taken a few decades for many households and commercially vital areas on the island Bhola like Daulatkhan and Mirzakalu to be entirely eroded. Bhola might be gone in the next 40 years if the current pace of erosion continues [7].

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Sediment discharges from the combined flow of the Ganges, Brahmaputra, and Upper Meghna Rivers, which flow into the Meghna Estuary in Bangladesh, occur at an annual rate of more than one billion tons. This kind of shoreline movement is only seen in this part of the world [8]. Bhola Island, a portion of the Meghna Estuary, exhibits a cycle of erosion and accretion. It is possible that both natural and human forces are responsible for the erosion and accretion of Bhola Island. Physical variables that might affect the Meghna estuary include the flow of water from the upstream Ganges-Brahmaputra–Meghna Rivers, sediment load, tide, wave, water current, etc. Furthermore, human activity contributes to shoreline change. In terms of coastline morphology and erosion-accretion on this island, there is a direct association. These findings will help scientists better understand the island's morphological variations, as well as their connections. Multi-temporal and multi-resolution satellite images are the key data sources for emphasizing goals via the integration of Remote Sensing and Geographic Information System techniques.

1.2 Literature Review

When it comes to the effects of global warming, Bangladesh is among the most affected. The southernmost portion of Bangladesh is bordered by the Bay of Bengal. It stretches through around 710 kilometers and passes through 19 of the country's 64 districts. Among these 19 districts, only 12 have a shoreline or lower estuary [3]. Coastal zones are the areas where land and sea meet. Deltaic (Ganges delta), estuarine (Meghna estuary), and intra-deltaic landforms make up the majority of the coastal zone of Bangladesh (Chittagong coastal plain belt) [9]. About 100 km^2 of land is damaged every year by rivers, and 1300 km^2 of land that was once used for farming is now used for something else [10].

Bangladesh is especially vulnerable to rising sea levels because it is a coastal country with a lot of people and a flat landscape with wide and narrow ridges and valleys [11]. If the sea level goes up by 10cm, 25cm, or 1m by 2020, 2050, or 2100, respectively, it will affect 2%, 4%, and 17.5% of all land mass [12]. Ten percent of the country is less than one meter above the mean sea level (MSL), and a third of the country is affected by tides [13]. Every year, the sea level goes up 1 centimeter in Bangladesh [14]. If the sea level rises 1.5 meters along the coast of Bangladesh by 2030, it will affect 22,000 km^2 (16% of the total land area) and 17 million people, which is 15% of the total population [15]. Based on gauge data from 1985 to 2000, it has been shown that the MSL is rising at a rate of 3.15 mm/year, which is much faster than the current global average sea level rise of 2 mm/year [16]. Both the World Bank's projection of an increase in sea level of one meter and the UNEP's prediction of a rise in sea level of one and a half meters might potentially have an impact on about the same number of people, which is around 17 million. The char area prevents flooding in inland regions that might otherwise be caused by high tides. In addition to this, it contributes to the expansion of the land along the mainland. When all the chars are gone, the mainland will erode swiftly, causing Bangladesh's land area to diminish every year. If char areas break apart, the tidal surge will have a significant impact on the mainland [17].

The morphology of the Meghna Estuary is undergoing profound changes at a breakneck pace. [18]. The ecology of the Meghna Estuary is one of a kind, characterized by a continuous cycle of land development and erosion. The high flow of major rivers, enormous sediment loads, powerful tidal forces, wind actions, waves, cyclonic storm surges, and estuarine circulation are all factors that contribute to this phenomenon. The way in which these hydrodynamic forces interact with one another and how they operate together determines the form of the Meghna Estuary and the islands that are located within it [19].

The Ganges Brahmaputra Meghna (GBM) river system contains a massive amount of sediment in its stream. During the monsoon, the GBM system moves about 1.7 billion tons of silts per year, which makes the river very rough. This happens when riverbanks are slowly worn away by erosion [5]. The Meghna estuary is not a good place for people to live because it is prone to cyclones and storm surges [18]. The only time they lost land was from 1989 to 1999, when they lost about 81 km^2. About 769 km^2 of new land has been added to this area [20]. A natural process called accretion is making new chars along most of Bangladesh's 710 km of coastline [21]. The system of the Ganges, Brahmaputra, and Meghna rivers would create about 200 km^2 of new land every year in the Meghna Estuary and might create new char land outside the estuary [20]. The Centre for Environment and Geographic Information Services (CEGIS) says that Bangladesh's land area has grown by 20 km^2 (12.5 square miles) every year and that this growth could add up to more than 1000 km^2 in the next 50 years [22]. Most of the 230 km^2 of erosion on Bhola Island was caused by the changing flow of the Meghna channel [23].

Near the point where the Meghna River empties into the sea is an island known as Bhola. The location of Bhola Island indicates that the Meghna estuary and the tides of the Bay of Bengal have a significant impact on the island's form and the water around it. Since the year 1700, river and sea processes have been at work on this island, which was considerably smaller than it is today and has been changing as a result. While the Meghna estuary's large sediment channels contribute to the soil, the area is also being eroded by the enormous tidal surges that occur there. It is believed that the size and form of Bhola island have altered since the year 1960 as a direct consequence of the rise in sea level and the subsequent erosion of land [24]. The biggest problem in Bhola is that the river is eroding a lot of lands. Every year, 500 to 1,000 hectares of land are lost, along with the homes and means of survival of many people and water management equipment. On the shore of Bhola, scientists have measured erosion rates of up to 120 meters per year [25]. Bhola Island is the "ground zero" of climate change, and its residents are the first people in the world to have been forced to relocate as a direct result of the effects of climate change. Since 1995, increased wave energy and increasing water levels have eroded away almost half of the island [26].

1.3 Research Objectives

1. To detect and measure the coastal area (erosion-accretion) changes in Bhola Island from 1974 to 2016 using geospatial data.
2. To assess the trend of historical change by digital image processing and GIS techniques for quantification.
3. To identify the probable reason for the morphological change.

1.4 Hypothesis and Assumptions

Since 1960, it is likely that the shape and size of Bhola Island have changed because the sea level has been rising and the land around it has been eroding [24]. Due to changes in the island's shape, its shorelines and banks are eroding badly, and in a few places, new land is being added. As a result, the island loses more land every year than it gains. The erosion and growth of the island are both very much affected by both natural and human factors. People in the area had been in trouble for a long time because of the channel's fast erosion. The rate of reclamation is lower than the rate of attrition, which means that a lot of land area is lost every year.

2 Study Area

Bhola is an administrative district in southwest Bangladesh that includes Bhola Island. Its coordinates are between 21°54' and 22°52' North and 90°34' and 91°01' East. It is in the Barisal Division and is surrounded by the Lakshmipur and Barisal Districts to the north, the Bay of Bengal to the south, the lower Meghna and Shahabzpur Channel to the east, and the Patuakhali District and the Tetulia River to the west. The name of the island used to be "Dakhin Shahbazpur." According to BBS, the Bhola district covers about 3,659.21 km^2, making it the largest island in Bangladesh. The island is about 90 kilometers long and 20 kilometers wide, and its shape is almost an arc from north to south. Since 1700 [24], both river and sea processes have been happening on this island, which used to be much smaller than it is now. The area under investigation includes seven Upazilas: Bhola Sadar, Daulatkhan, Burhanuddin, Char Fasson, Lalmohon, Tazumuddin, and Monpura (See Fig. 1). The island was given the name "Queen Island of Bangladesh" by the government of Bangladesh to promote its tourism industry.

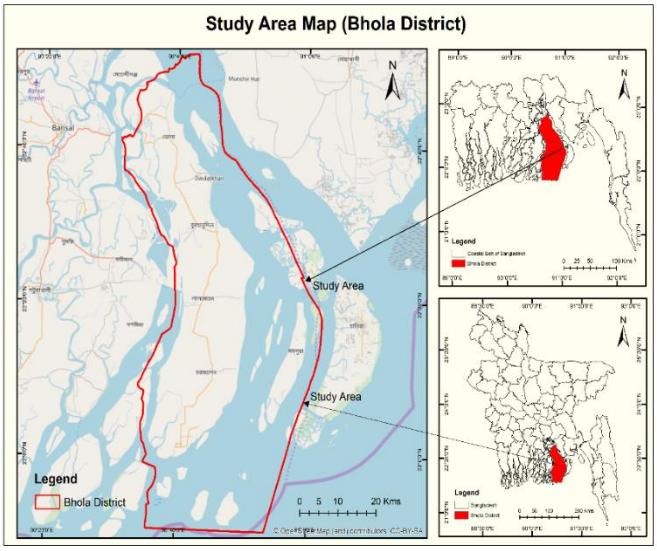

Fig. 1 Study Area Map (Bhola District, Bangladesh)

3 Materials and Methods

3.1 Satellite Data

Landsat satellite images from 1974 to 2016 were collected from the USGS-Glovis and Earth Explorer websites for this investigation. Cloud cover, scene visibility, satellite picture quality, and the availability of MSS, TM, ETM, and OLI-TIRS sensor satellite data were considered while selecting the images. In addition, all images were captured during the dry season (December through April) to avoid seasonal impacts (Appendix B: Table B1).

3.2 Image Processing

All images used in this research are USGS level-1 products, referred to as the World Geodetic System 1984 (WGS84) datum, in GeoTiff format, and projected using the Universal Transverse Mercator coordinate system (zone UTM 46 North). In this work, the McFeeters' normalized difference water index (NDWI), Xu's modified normalized difference water index (MNDWI), and land water mask (LWM) were utilized to identify changes in the coastline. The Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors collect data and store it as a digital number (DN) ranging from 0 to 255. McFeeters's NDWI and Xu's NDWI need physical units, such as at-sensor radiance or top-of-atmosphere (TOA) reflectance, rather than the raw quantized calibrated pixel value (DN) [27].

3.3 Converting to TOA Reflectance

TOA reflectance can be obtained from the quantized calibrated pixel value [28] :

$$P_{\lambda}=\pi * L_{\lambda} * d^2 / ESUN_{\lambda} * Cos\theta_s$$

L_λ can be obtained from the quantized calibrated pixel value [28] :

$$L_{\lambda} = ((LMAX_{\lambda} - LMIN_{\lambda})/(Qcalmax - Qcalmin)) * (Qcal - Qcalmin) + LMIN_{\lambda}$$

where,

$LMAX_\lambda$ is the maximum spectral at-sensor radiance scaled to Qcalmax [W/(m^2.sr.µm)], $LMIN_\lambda$ is the minimum spectral at-sensor radiance scaled to Qcalmin [W/(m^2.sr.µm)], Qcalmax is the maximum quantized calibrated pixel value corresponding to $LMAX_\lambda$ [DN], Qcalmin is the minimum quantized calibrated pixel value corresponding to $LMIN_\lambda$.

The Equations parameters may be retrieved from the header files of the ALI, TM, ETM+, and OLI datasets [27].

3.4 Image Classification/ Image Index

Classification of images is used to extract the required image attributes. Common approaches for extracting water bodies and mapping coastlines include the classification of general features. Nevertheless, the general classification approach assumes that the pixel is pure. When numerous characteristics are available inside a single pixel, the accuracy of such classification systems will rely on the landscape's complexity and the completeness of a lengthy training period [29]. In addition, the majority of these methods rely heavily on human skill and regional knowledge. Because water bodies, such as floods, tides, and storm surges, may move rapidly [30], they will encounter obstacles when attempting to execute a quick and repeatable extraction of water-body information. The spectral water index is a popular tool for identifying the boundary between water and land. Normalized difference water indices (NDWIs) computed from several band combinations (green, near-infrared (NIR), or shortwave-infrared (SWIR)) have been effectively implemented in land-water mapping. In reality, when Advanced Land Imager (ALI) data are utilized, additional NDWIs will become accessible, since the ALI sensor gives one green band (Band 4), two NIR bands (Bands 6 and 7), and three SWIR bands (Bands 8, 9, and 10). Therefore, choosing the best band or combination of bands is crucial when mapping Land-Water using ALI data [27]. Spectral water index methods, such as McFeeters's NDWI [31], which is calculated from one green-band image and one NIR-band image, and Xu's NDWI or MNDWI [32], which is calculated from one green-band image and one SWIR-band image, can extract water body information more precisely, quickly, and easily than general feature classification methods. In addition, McFeeters' NDWI and Xu's MNDWI have been effectively used to remotely sensed data to extract water information [26],[32]-[36]. Therefore, McFeeters' NDWI and Xu's MNDWI were utilized as the principal tools for this study on mapping coast lines using TM, ETM+, and OLI remotely sensed images. The NDWI of McFeeters forms two models, whereas the NDWI of Xu creates three models. The MSS image has been categorized using the Land Water Mask (LWM) index since the MSS sensor has just four bands (Band 6, Band 7, Band 8, and Band 9).

3.4.1 Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is produced from the same fundamentals as the Normalized Difference Vegetation Index (NDVI) (NDVI). In an NDVI (comparison of differences between two bands, red and near-infrared (NIR)), the presence of terrestrial plant and soil characteristics is accentuated while the presence of open water features is muted due to the various ways these features reflect these wavelengths [31]. Calculating the NDVI index is as follows:

NDVI= (ρNIR – ρRed) / (ρNIR +ρ Red)

If the equation is inverted and the green band is utilized in place of the red band, the result would likewise be inverted, with vegetation suppression and open water enhancement [31]. The formula for an NDWI is:

NDWI= (ρGreen – ρNIR) / (ρGreen + ρNIR)

Where, ρGreen and ρNIR represent the green and NIR reflectances, respectively. This equation yields positive values for aquatic features, whereas soil and terrestrial vegetation have zero or negative values [31]. McFeeters's NDWI is intended to (1) increase the reflectance of a water body by employing green wavelengths, (2) decrease the poor NIR reflectance of water bodies, and (3) make use of the high NIR reflectance of plant and soil characteristics [37]. As a consequence, the background (vegetation and soil characteristics) information in McFeeters' NDWI images will be limited and the water body information will be increased [27]. Consequently, the water bodies may be recognized by applying a threshold to McFeeters' NDWI images.

3.4.2 Modified Normalized Difference Water Index (MNDWI)

McFeeters's NDWI can increase information about water bodies and limit information about vegetation and soil characteristics, but it cannot discriminate entirely between water bodies and built-up features [27]. To solve this issue, Xu's NDWI or MNDWI (Xu, 2006) was created; it is defined as:

MNDWI= *(ρGreen – ρSWIR) / (ρGreen + ρSWIR)*

Where, ρSWIR is the reflectance in the SWIR band.

The NDWI developed by Xu may increase open-water features while suppressing and even deleting built-up features, vegetation, and soil features. The indices employed in the current investigation are reported in Appendix B: Table B2 for the best possible outcome.

3.5 Image Threshold

In order to identify changes in the coastline on a picture, the threshold between sea and land must be set. In this part, classification techniques for water-land lines were done. The setting of a threshold is a crucial step in determining McFeeters' or Xu's NDWIs. The threshold values for McFeeters' and Xu's NDWIs were set to zero [31][32], however, threshold change in certain circumstances may result in a more precise delineation of water bodies [38]. Therefore, dynamic or variation thresholds are required to recognize water body information [39] when various areas or phases of remote sensing data are utilized. The maximum between-class variance technique (Otsu method) is an example of a dynamic threshold approach [40]. In this work, the Otsu approach was employed to establish the separation threshold between water bodies and background characteristics.

Now, if it is assumed that the NDWI/MNDWI pixels range from $-1 \le a < b \le 1$

Using the Otsu method, the pixels can be divided into two classes: a non-water class ranging from [*a*, ..., *t*] and a water class ranging from [*t*, …, *b*], where *t* is the threshold value [27]. The between-class variance of the non-water class and water class can be obtained by:

$\sigma^2 = W_{nw}\sigma^2_{nw} + W_w\sigma^2_w$

Where, σ is the between-class variance of the non-water class and the water class; σ^2 is the variance of the non-water class; σ^2 is the variance of the water class; is the weighting of the non-water class, and is the weighting of the water class. The W_x is given by:

$$Wx = \sum_{a}^{b} P(i)$$

where, P (i) is the class probability; the total number of pixels in the image is divided by the number of pixels in the class.

Using equations, the Otsu technique determines the threshold based on the highest between-class variation of background variables (e.g., vegetation, soil, etc.) and water body features [27]. The larger the variance, the greater the contrast between the backdrop and water characteristics. Consequently, enhancing the variation between water body characteristics and background characteristics reduces the likelihood of misclassification. When the NDWI/MNDWI image has a significant between-class variation, a spectral water index model is better appropriate for enhancing and extracting water bodies.

4 Coastal Morphological Change Detection

The coastal morphology of Bangladesh experiences significant changes due to erosion and accretion. The coastline morphology change can be analyzed from two aspects: the change of coastline i.e. shoreline length and area, and the change of coastline types i.e. erosion-accretion [41]. All the shorelines are overlaid concurrently, and a baseline is manually established in the area. This baseline serves as a reference point for subsequent phases [42].

4.1 Images Interpretation and Coastal Morphology Change Analysis

4.1.1 Changes in Coastal Morphology from 1974 to 1980

The overall length of Bhola Island's coastline increased from 224.406 km in 1974 to 228.3 km in 1980. In 1974, the area of Bhola District was around 1846.75 km^2; by 1980, it had decreased to 1814.74 km^2. The overall area of Bhola Island expanded, although erosion processes were significant in the neighboring land areas (Appendix B: Table B3).

From 1974 to 1980, the satellite image reveals that the coastline expanded by 73.54 kilometers. The erosion and accretion were about 118.67 km^2 and 86.66 km^2 respectively, resulting in a net land loss of 32.01 km^2. On Bhola Island, the net loss was 55.35 km^2 (Appendix B: Table B4).

In the northern, northeastern, and western regions of Bhola Sadar Upazila, erosion processes were active. In the northern bend of Bhola Sadar Upazila in 1974, satellite imagery revealed the formation of char areas that vanished in 1980. In the northwestern bend, accretion was effective.

Due to Meghna River's direct effect, the eastern portion of Daulatkhan upazilla was severely degraded. In the northeastern portion of this Upazila, Char land was also produced. In Burhanuddin upazila accretion and erosion both processes were prominent in the time series of 1974-1980. Erosion was active along the shoreline and there also formed char land surrounding the bank of Tetulia River. In the northern tip of Tazumuddin Upazila erosion process was at a higher rate than in the other areas of Bhola District. Erosion was active along the shoreline and Char land which formed previously may disappear.

Southern bend of Charfasson upazilla was dominated by the erosional process. In the southern portion of Bhola Island, where a massive tidal current and a steep slope of the coastline (bank) were the most likely sources of erosion from 1974 to 1980, erosion was likely to have occurred (Appendix A: Fig. A1). This time period's satellite images reveal that erosion was effective in a portion of the southwestern and southern regions (Char Kukri Mukri, Dhal Char, and Char Sakuchi). Accretion also occurred in the northern portion of Char khukri-Mukri, Dhal Char, and their environs as a result of natural sediment deposition brought by the water of Shahbajpur canal, which is part of the Meghna estuary.

There was also accretion of land in the eastern part Manpura Island from 1974 to 1980 timespan that was dispersed from Bhola Island but included in Bhola administrative boundary (Appendix A: Fig. A1). Erosion process was also dynamic in the shoreline. The erosion processes were more effectively severe than accretion which resulted in the loss of about an overall 32.01 km^2 land area and 55.35 km^2 area from Bhola Island to become eroded. The rates of total erosion and accretion were 19.78 km^2 and 14.6 km^2 respectively.

4.1.2 Changes in Coastal Morphology from 1980 to 1990

In 1980 Bhola District had an area of about 1814.74 km^2 and the shoreline was 580.56 km which became respectively 1880.33 km^2 and 699.53 km in 1990. According to the table (Appendix B: Table B5), the accretion process was dynamic in this timespan.

The shoreline increased by 118.97 kilometers between 1980 and 1990, according to statistics on shoreline and area change. The Bhola mainland shoreline grew by 10.68 kilometers. During this time period, total erosion and accretion were approximately 109.52 km^2 and 211.56 km^2, respectively. Thus, the net increase in land area was about 68.26 km^2 (Appendix B: Table B6).

From 1980 to 1990 time period, erosion processes were active in both the eastern and western parts of Bhola Sadar, Daulatkhan, western Burhanuddin, and the eastern side of Tazumuddin, where huge tidal pressure water from the Meghna estuary through the Shahbazpur Channel in the east and Tetulia river from the west of the bankline were the probable causes for erosion to happened (Appendix A: Fig. A2).

Within this time span accretion was also dynamic in a large part of northern Bhola Sadar, there were also formed new char in the Tetulia River through accretion. Accretion was prominent in Daulatkhan, Tazumuddin, Burhanuddin Upazila. Monpura Upazila and the southern part of Bhola Island were also accreted due to the natural sediment deposition of the Meghna estuary through Shahbazpur channel compensated for the big erosion in the Bhola Sadar, Daulatkhan, and Burhanuddin upazila. Surrounding the Bhola Island, especially in Char Fasson upazilla, lots of char areas are created through accretion. The data from satellite images show that in this time period the island gained maximum sediment deposition (land area) which resulted in the formation of a new island (char) surrounding the Bhola Island (Appendix A: Fig. A2).

The erosion rate was 10.95 km^2 whereas the accretion rate was 21.15 km^2. In Bhola Island rate of erosion and accretion were 8.8 km^2 and 2 km^2 respectively. So erosion process was dominant in Bhola Island and the surrounding area was accreted due to sediment deposition. The erosion process was higher in Bhola Island due to the direct influence of the Meghna Estuary on the Bay of Bengal.

4.1.3 Changes in Coastal Morphology from 1990 to 1995

The total shoreline of Bhola Island was about 699.53 km in 1990 which became about 856.28 km in 1995. In 1990, the total land area of Bhola Island was 1880.33 km^2 and in 1995 it was 1974.98 km^2. In the Bhola mainland, the area was about 1447.43 km^2 in 1990 which became 1435.26 km^2 by losing 12.17 km^2 of land area (Appendix B: Table B7).

From 1990 to 1995, the total Shoreline change was 156.75 km. The erosion and accretion were about 97.28 km^2 and 155.17 km^2 respectively. Thus net gain of the land area was 57.89 km^2 and on the mainland, it was a net loss of about 12.17 km^2 (Appendix B: Table B8)

Erosion processes were active in northern and north-eastern (Bhola Sadar Upazila), eastern (Daulatkhan Upazila), eastern (Burhanuddin Upazila) eastern (Lalmohon and Tazumuddin Upazila) of the Bhola District, due to the Meghna estuary water in northern and north-eastern portion and steep slope of the shoreline (bank) of these areas were the probable causes for erosion to happen from 1990 to 1995 (Appendix A: Fig. A3). Char land were formed in the Tazumuddin and Daulatkhan Upazila along the Bhola Island which disappeared due to excessive erosion.

New char lands (accretion) evolved in the southern part of the Bhola district like Char Fasson Upazila and surrounding Monpura Island due to sediment deposition by the Shahbazpur Channel through Meghna Estuary (Appendix A: Fig. A3). There was also the formation of Char land in the northeastern bend of Bhola Island mainly in the Bhola Sadar Upazila and Daulatkhan Upazila.

During 1990-1995 in 5-year intervals, total erosion and accretion rate were about 19.46 km^2 and 31.03 km^2 respectively which represented the net gain rate was higher. On Bhola Island, the rate of erosion and accretion were 5.01 km^2 and 2.57 km^2. According to the statistics resulting from the satellite imageries, erosion was more dynamic in Bhola Island than accretion. The new island formed surrounding the Bhola Island which compensated for the net loss to gain of land area.

4.1.4 Changes in Coastal Morphology from 1995 to 2000

Appendix B: Table B9 shows that the total shoreline of Bhola Island was about 856.28 km in 1995 which has become about 914.58 km in 2000. The entire land area of Bhola Island was 1974.98 km^2 in 1995 and 1964.84 km^2 in 2000 (Appendix B: Table B9).

In the time period from 1995 to 2000, the total shoreline change was 58.3 km. On the mainland of Bhola, it was 11.79 km. The amount of erosion and accretion were about 140.98 km^2 and 131.40 km^2 respectively where the net loss was 9.58 km^2. In the Bhola Mainland erosion and accretion were 45.83 km^2 and 13.01 km^2 and the net loss was 32.82 km^2 (Appendix B: Table B10).

The satellite image results from 1995 to 2000 time period reveals that in Bhola Sadar Upazila erosion processes were active in the north-eastern, eastern, and south-western part. The Eastern part of Daulatkhan Upazila, Burhanuddin Upazila, Tazumuddin Upazila were highly erosion-prone. In the northeastern part of Bhola Island, many new islands (Char) were created which became fragmented due to erosion through the pressure of tidal water. Islands located in the southern Bhola Island including Char Kukri-mukri, Dhal Char, Char Nizam, char Sakuchi were eroded along its shoreline in the southern part.

From 1995 to 2000, accretion was active in the northern and western part of Bhola Sadar Upazila, eastern Daulatkhan, eastern and southern Tazumuddin, upper part and surroundings of Manpura Island due to sediment deposition by Meghna estuary (Appendix A: Fig. A4).

Bhola Island's morphology was approximately the same between 1995 to 2000-time span. On Bhola Island, the net loss was about 32.82 km^2 and the rate of erosion and accretion were about 9.16 km^2 and 2.60 km^2. The erosion rate was always higher than the attrition in Bhola Island due to the high tidal pressure of the Meghna Estuary. In Bhola District net loss was 9.58 km^2 whereas erosion and accretion rates were 28.19 km^2 and 26.28 km^2.

4.1.5 Changes in Coastal Morphology from 2000 to 2005

According to the Appendix B: Table B11 below from 2000 to 2005, the total land area of Bhola reduced from 1964.84 km^2 to 1921.22 km^2 whereas the mainland of Bhola reduced from about 1402.43 km^2 to 1370.18 km^2. The total shoreline was about 914.58 km which became 962.04 in 2005 (Appendix B: Table B11).

Total Shoreline change was about 47.46 km whereas in the Bhola mainland it was less in amount. According to the Satellite image from 2000 to 2005 timespan erosion and accretion were 134.22 km^2 and 90.60 km^2 respectively. On Bhola Island, it was 41.72 km^2 and 9.48 km^2. So a net loss of land area was active due to shoreline or bank line erosion. The total net loss was 43.62 km^2 (Appendix B: Table B12).

From 2000 to 2005 timespan erosion process was active in the northeastern and southwestern part of the Bhola Sadar, eastern and western Burhanuddin, and eastern Daulatkhan, both eastern and western Tazumuddin, eastern Lalmohon, northern Manpura, and some parts of Char Fasson Upazila. The Eastern part of Bhola Island was more vulnerable to erosion than the western part due to the direct influence of tidal pressure of Meghna Estuary and Shahbazpur Channel. The erosion process remained active during the monsoon period (Appendix A: Fig. A5).

Accretion was also active but in less intensity than erosion in this time span. The western part of Tazumuddin, the periphery area of Manpura Island, and the lower part of Char Fasson Upazila including Char Kukri-Mukri, Dhal char, Char Momtaz; accretion were dynamic in this area. In the northwestern part of Bhola Island, both accretion and erosion were active simultaneously. But in 2000 to 2005 timespan net loss of land area happened and there was a total 43.62 km^2 area which became lost where the amount of net loss was about 32.24 km^2 for Bhola Island. The total rate of erosion and accretion in this time period were about 26.84 km^2 and 18.12 km^2 respectively.

4.1.6 Changes in Coastal Morphology from 2005 to 2010

The total shoreline area of the mainland of Bhola Island was about 231.14 km in 2005 and it became 235.73 km in 2010. Total Bhola Island was about 1370.18 km^2 in 2005 and in 2010 it reduced to 1357.94 km^2. The mainland of the Bhola island area has also been eroded (Appendix B: Table B13).

The satellite image reveals that the shoreline increased by 147.3 kms between 2005 and 2010. The erosion and accretion throughout this time period were about 74.21 km^2 and 215.33 km^2, resulting in a net increase of 141.12 km^2 of land area. However, the Bhola mainland region had a net loss of 12.25 km^2 (Appendix B: Table B14).

According to the Satellite image data in the time period, 2005 to 2010 accretion was more dynamic than erosion. Erosion was active in northern and north-eastern Bhola Sadar, eastern Daulatkhan and Burhanuddin, north-eastern Lalmohon, the southern part of Char Fasson, and the northern tip of Monpura Island. The overall erosion rate was 5.05 km^2/year, whereas on Bhola Island it was 5.07 km^2/year (Appendix A: Fig. A6).

Conversely, accretion was noticeable in most of Bhola Island including the eastern part of Bhola Sadar, Daulatkhan, Tazumuddin, Manpura Upazila, the western part of BurhanUddin, Lalmohon, and the southern part of Char Fasson Upazila including Char Nizam, Char Kukri Mukri due to the sedimentation through the Meghna estuary which got hindrance to passes its channel to the Bay of Bengal. Sediment accumulated and aggregated alongside char lands which caused the addition of land.

There new Islands (chars) were created surrounding Bhola Island. The rate of accretion was about 43.66 km^2/year. The total net gain was 141.12 km^2 which was a vast area. Due to the accretion process total shoreline area also increased and it became 147.5 km. In Bhola Island, the rate of total erosion and accretion was 5.07 km^2/year and 2.62 km^2/year.

4.1.7 Changes in Coastal Morphology from 2010 to 2016

The total shoreline area of the mainland of Bhola Island was about 235.73 km in 2010 and it became 248.25 km in 2016. Bhola Island was about 2062.34 km^2 in 2010 and in 2016 it reduced to 2001.61 km^2. The total Shoreline was 1109.34 km^2 in 2010 which became 1117.99 km^2 in 2016 (Appendix B: Table B15).

From 2010 to 2016, the shoreline changed a total of 8.65 km. On the Bhola mainland, it was 12.52 km. The quantity of erosion and accretion was between 168.42 km^2 and 107.70 km^2, with a net loss of 60.72 km^2. The Bhola Main Island had 35.03 km^2 of erosion and 5.46 km^2 of accretion, for a net loss of 29.57 km^2 (Appendix B: Table B16).

During the year from 2010 to 2016 erosion was active in the northeastern part of Bhola Sadar. As a result, the land area formed in 2010 by the accretion process might be fragmented through erosion. The erosion process was prominent in eastern Tazumuddin, Daulatkhan, Burhanuddin, Manpura Island, and southeastern Lalmohon. Erosion also occurred in the eastern part of Tazumuddin in the Char area named Char Munshi, char Hazari. The additional area created in the 2005 to 2010 time period got fragmented due to erosion by the high tidal influence of Meghna Estuary.

Accretion was also active in a small portion of the erosion-prone area including the eastern and south-western parts of Bhola Sadar, and eastern Daulatkhan Upazila. Accretion has been placed in the southern part of Bhola Island including southern Char Fasson like Char Sakuchi, Dhal Char, the upper part of Char Kukri-mukri, and both the southeastern and western side of Manpura Island. Due to the direct influence of the Meghna estuary, the transformation of the land area was more active in the eastern part of Bhola Island. (Appendix A: Fig. A7).

Rate of total erosion and accretion were about 33.68 km^2/year and 21.72 km^2/year which represented the dominance of the losing process. The total net loss in Bhola District was about 60.72 km^2 area. During the time period, 2010 to 2016 common land area was 1893.91 km^2. In Bhola Island, the rate of erosion and accretion were about 7 km^2/year and 1.09 km^2/year whereas the erosion rate is 6 times higher than accretion. In Bhola Island shoreline increased due to the creation of a bend area through the erosional process done by the estuary. The total net loss in Bhola Island was about 29.57 km^2 whereas the overall district lost about 60.72 km^2.

4.1.8 Changes in Coastal Morphology from 1974 to 2016

The final result from satellite image analysis (1974- 2016) revealed that the total shoreline of Bhola Island was about 507.017 km in 1974 which increased to about 1117.99 km in 2016 (Appendix B: Table B17).

In 1974, the total land area of Bhola Island was 1846.75 km^2 whereas in 2016 it increased to 2001.61 km^2 (Appendix B: Table B17). Total shoreline area and total land area increased over these 42 years of time span.

The data of change in shoreline and area of Bhola district from 1974 to 2016 concludes that the shoreline gain was 610.98 km in this time period. The erosion and accretion were about 343.30 km^2 and 498.15 km^2 respectively. Common land between 1974 to 2016 was 1503.46 km^2. Therefore, the net gain of the land area is about 154.85 km^2 from 1974 to 2016 (Appendix B: Table B18).

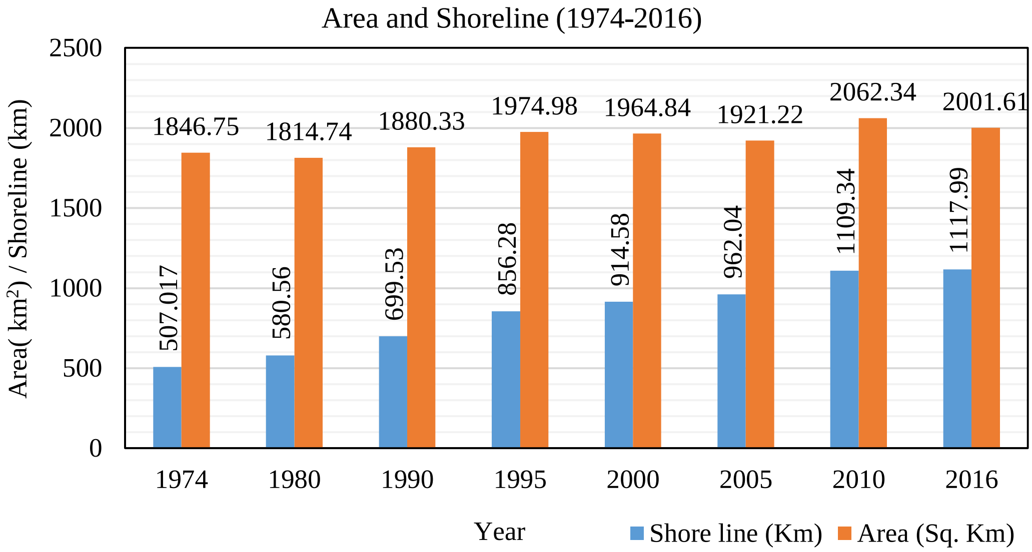

Fig. 2 Area and Shoreline Changes of Bhola District in 1974 and 2016

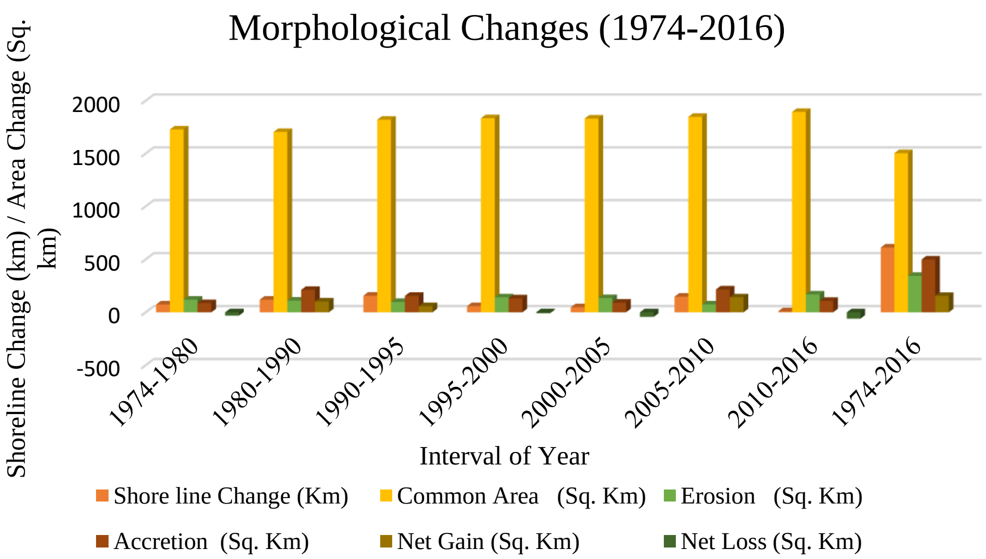

Fig. 3 Changes in Bankline/Shoreline and Area of Bhola District from 1974 to 2016

The composite or final result of the last 42 years from 1974 to 2016 (present time period) satellite image data concludes that substantial erosion processes were underway in the northern part of Bhola Sadar, eastern (Bhola Sadar, Daulatkhan, Lalmohon, Burhanuddin, Tazumuddin Upazila), southwestern (Char Fasson Upazila and Daulatkhan Upazila), and some of northern Monpura Island, where huge tidal pressure water from Meghna estuary and Bay of Bengal and steep slope of the shoreline (bank) were the probable causes for erosion to operate in these erosion prone areas (Appendix A: Fig. A8). In the eastern portion of Bhola Island, intense erosion processes led to the loss of a wide area around the island.

In contrast, accretion was effective in a significant portion of the north-eastern region of Bhola Sadar (Char Munsi, Hazari), the northern region of Monpura Island, and the southern region of Char Fasson Upazila. In the southern part of Bhola Island, there was the accretion of the land area surrounding Char Kukri-mukri, Dhal Char, Char Nizam, etc. Addition of some new Char lands, surrounding the Bhola Island that was not authorized by the Government for its unstable condition. Some Char areas were not permanent and sank under water during the period of high tide. The accretion process likely happened as a result of the relatively mild slope of the bank, which permits natural silt deposition transported by water from the Shahbazpur canal and the Meghna estuary. This pattern of high accretion is not uniform throughout the coast, since major erosion has occurred on the western shore of the Meghna River estuary and along the northern sections of Manpura and Hatiya Islands, perhaps as a result of the influence of strong river currents. In addition, engineering activities, such as dam and dyke building, have restricted downstream water flows and sediment transport for deposition, but high tidal flows may aid sediment movement away from the shore.

The shoreline of Bhola District increased from 1974 to 2016 and it became 610.98km. Increasing of shoreline doesn’t indicate the addition of land area to the island, the length is increasing due to the erosional process which creates a bend into the shoreline. The shoreline of Bhola Island increased at a rate of 14.54 km/year. From 1974 to 2016 in 42 years timespan, there were 1503.46 km^{2} of common land areas.

The data from satellite images showed that in this time period the island gained 498.15 km^{2} with the rate of 11.86 km^{2}/year of new land through natural sediment deposition resulting in the formation of a new island (char) in various parts of Bhola and loosed about 343.30 km^{2} with the rate of 8.17 km^{2}/year due to erosion along the shoreline of eastern, southern, and some of south-western part of the island (Appendix A: Fig. A8). The net gain of land due to the predominant accretion process than erosion results in about 154.85 km^{2} with the net gain rate of 3.7 km^{2}/ year area to be added. Primarily, physical e.g. geomorphic, hydrologic, etc. causes were responsible for erosion and accretion. Human effects had little impact on coastal morphology change. Due to the variable current conditions of the Shahbazpur canal and the Tutulia River, accretion is occurring in the northern and western portions of Bhola Island. The Tetulia River in the west erodes less than the Shahbazpur River in the east due to its slower flow rate. On the other side, in the eastern portion, substantial sediment erosion is occurring. If the cross dam project is implemented on the eastern part of the island, the sediments transported by the Meghna estuary may be stopped, which might lead to the development of a vast land area surrounding the offshore island.

5 Conclusion

Analysis of Landsat images taken at different times from 1974 to 2016 showed that Bhola Island seemed to have changed mostly in the erosional phase. There are many things that affect how the Bhola Island changes. Some of these are hydrologic (river discharge, sediment load, minimum dry period flow, and the amount of sediment moved), marine hydraulic (tides, sea level rise, storm surge, currents, and wave action), geomorphologic and geological, climatic, land use, and human activities (embankments, sand extraction, irrigation, etc.). It is clear that recent human actions have had a big effect on how the island has grown and changed. In general, the effects of human activity on a coastal island include things like artificial diversion, building embankments, making channels, dredging, and irrigation. But these things don't happen very much in the study area. But taking sand from the southeast side of Bhola Island has caused erosion in a small area there. Most of the changes to the island are happening at the bend of the shoreline, where the shore meets the river flow, where the bank is weak, where a bank side has fallen, and when a tidal surge hits (evidence of field visit). On Bhola Island, erosion is always happening, but it is most noticeable during the wet season. Bankline and shoreline erosion became a common problem on Bhola Island as a result.

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Appendix A

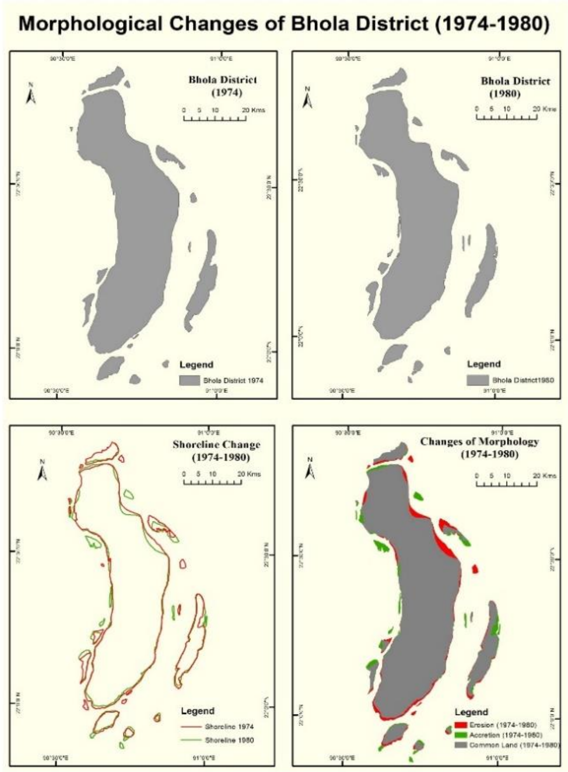

Fig. A1 Changes in Shoreline and Area of Bhola District in 1974 and 1980

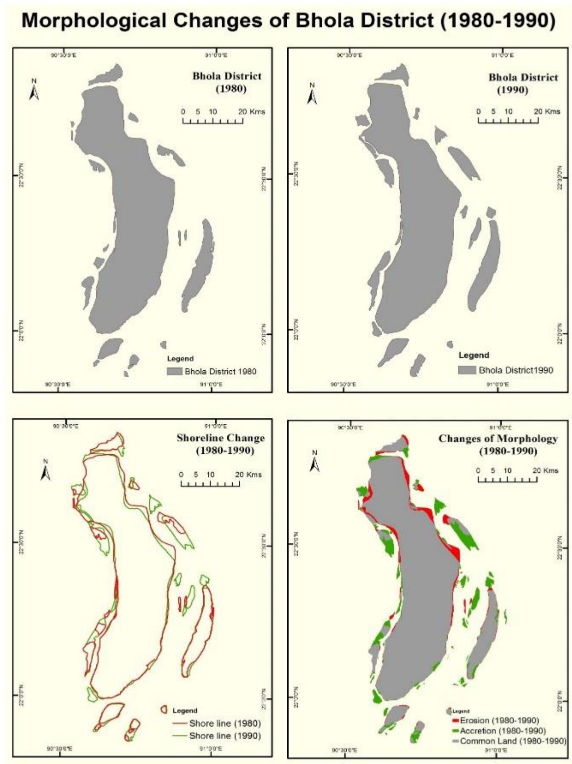

Fig. A2 Changes in Shoreline and Area of Bhola District in 1980 and 1990

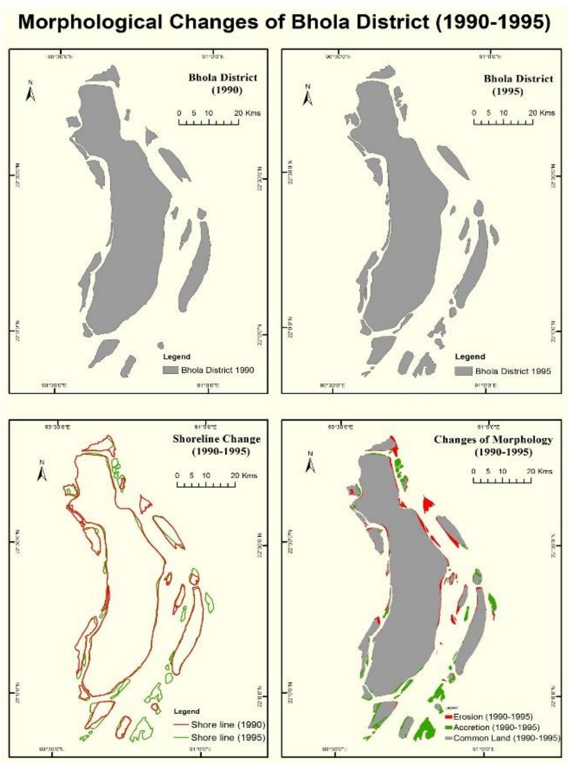

Fig. A3 Changes in Shoreline and Area of Bhola District in 1990 and 1995

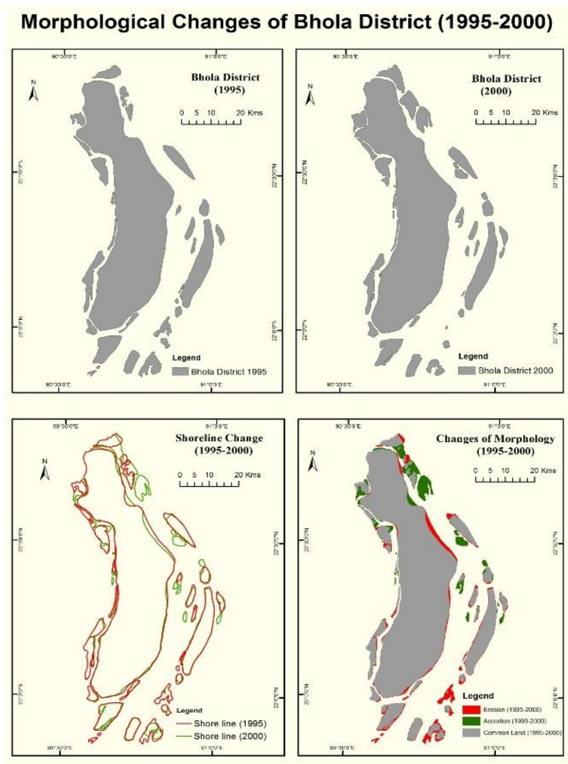

Fig. A4 Changes in Shoreline and Area of Bhola District in 1995 and 2000

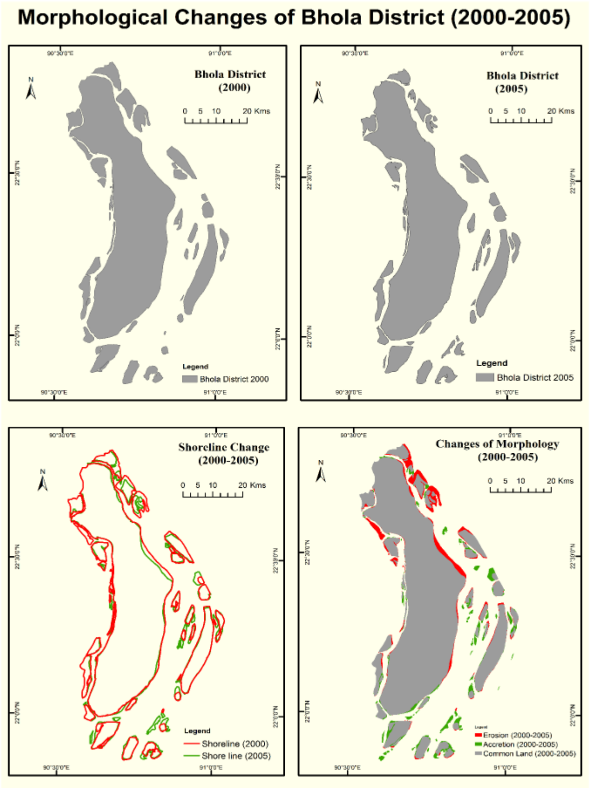

Fig. A5 Changes in Shoreline and Area of Bhola District in 2000 and 2005

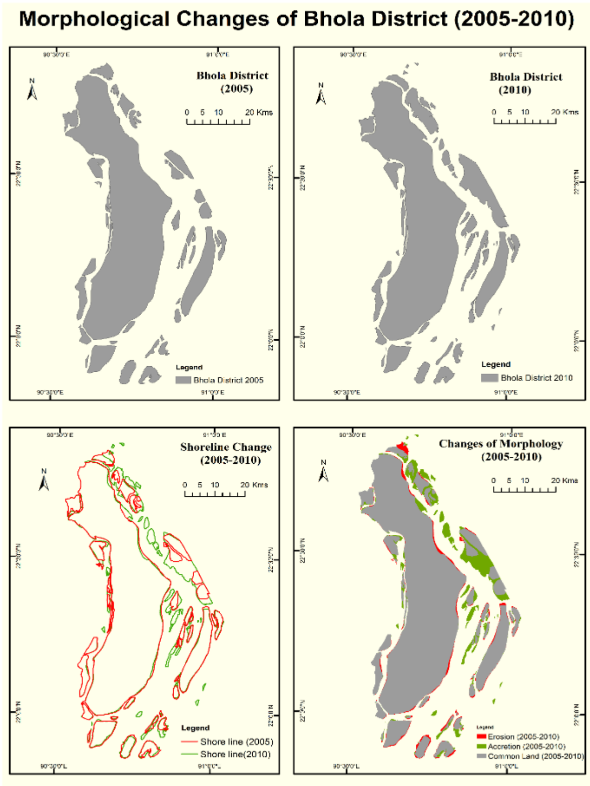

Fig. A6 Changes in Shoreline and Area of Bhola District in 2005 and 2010.

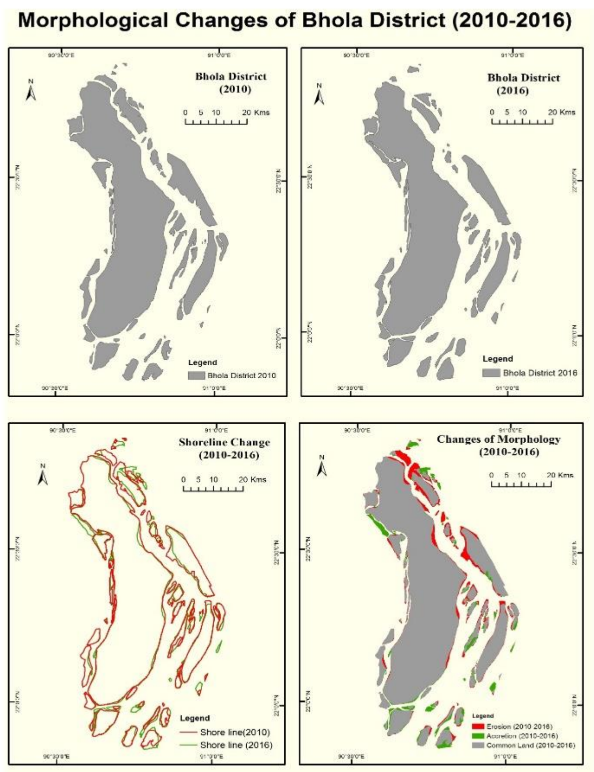

Fig. A7 Changes in Shoreline and Area of Bhola District in 2010 and 2016.

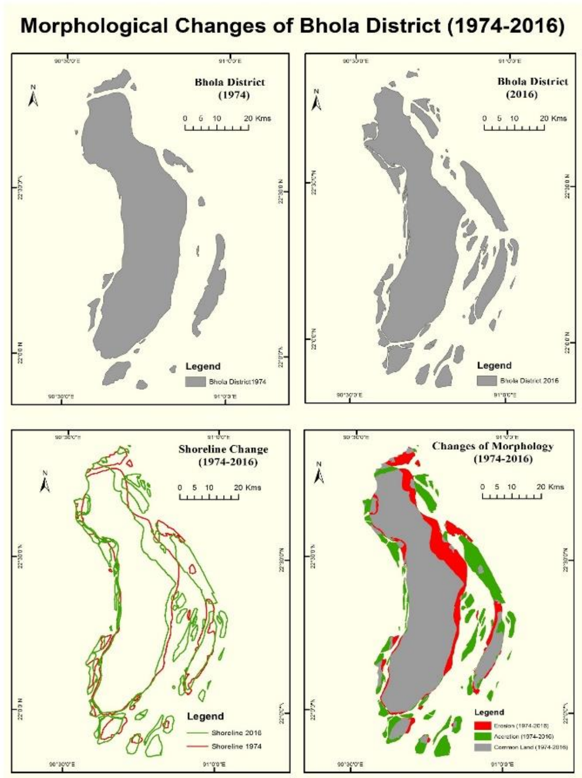

Fig. A8 Changes in Coastal Morphology of Bhola District from 1974 to 2016.

Appendix B

Table B1 Satellite imageries used in the study

Serial No	Satellite & Sensor	Acquisition Date	Path	Row	Spatial Resolution
1.	Landsat MSS	1974-01-10	147	044	60
2.	Landsat MSS	1980-01-15	147	044	60
3.	Landsat TM	1990-2-24	137	044	30
4.	Landsat TM	1995-01-21	137	044	30
5.	Landsat TM	2000-01-19	137	044	30
6.	Landsat TM	2005-01-19	137	044	30
7.	Landsat TM	2010-01-30	137	044	30
8.	Landsat OLI-TIRS	2016-01-15	136	044	30

Table B2 Image indices used in the study

Year	Sensor	Index	Formula
1974	MSS	NDWI	*ρIR+(ρGreen+.0001)*100*
1980	MSS	NDWI	*ρIR+(ρGreen+.0001)*100*
1990	TM	NDWI	(*ρGreen – ρNIR*) / (*ρGreen* + *ρNIR*)
1995	TM	NDWI	(*ρGreen – ρNIR*) / (*ρGreen* + *ρNIR*)
2000	TM	NDWI	(*ρGreen – ρNIR*) / (*ρGreen* + *ρNIR*)
2005	TM	NDWI	(*ρGreen – ρNIR*) / (*ρGreen* + *ρNIR*)
2010	TM	NDWI	(*ρGreen – ρNIR*) / (*ρGreen* + *ρNIR*)
2016	OLI	MNDWI	*(ρGreen – ρSWIR) / (ρGreen + ρSWIR)*

Table B3 Shoreline and Area of Bhola District in 1974 and 1980

Item/Year	1974	1980
Mainland Shore Line (km)	224.406	228.37
Total Shore Line (km)	507.017	580.56
Mainland Area (km^2)	1571.02	1515.68
Total Area (km^2)	1846.754	1814.74

Table B4 Change in Shoreline and Area of Bhola District in 1974 and 1980

Item/ Interval of Year	1974-1980
Total Shore line Change (km)	73.54
Mainland Shore line Change (km)	3.9
Total Common Area (km^2)	1728.08
Mainland (Common Area (km^2)	1500.06
Total Erosion (km^2)	118.67
Mainland Erosion (km^2)	70.96
Total Accretion (km^2)	86.66
Mainland Accretion (km^2)	15.61
Total Net Loss/Gain (km^2)	-32.01
Mainland Net Loss/Gain (km^2)	-55.35

Table B5 Shoreline and Area of Bhola District in 1980 and 1990

Item/Year	**1980**	**1990**
Mainland Shore Line (km)	228.37	239.05
Total Shore Line (km)	580.56	699.53
Mainland Area (km^2)	1515.68	1447.43
Total Area (km^2)	1814.74	1880.33

Table B6 Change in Shoreline and Area of Bhola District in 1980 and 1990

Item/ Interval of Year	1980-1990
Total Shore line Change (km)	118.97
Mainland Shore line Change (km)	10.68
Total Common Area (km^2)	1704.26
Mainland Common Area (km^2)	1427.33
Total Erosion (km^2)	109.52
Mainland Erosion (km^2)	88.35
Total Accretion (km^2)	211.56
Mainland Accretion (km^2)	20.09
Total Net Loss/Gain (km^2)	102.04
Mainland Net Loss/Gain (km^2)	68.26

Table B7 Shoreline and Area of Bhola District in 1990 and 1995

Item/Year	**1990**	**1995**
Mainland Shore Line (km)	239.05	222.83
Total Shore Line (km)	699.53	856.28
Mainland Area (km^2)	1447.43	1435.26
Total Area (km^2)	1880.33	1974.98

Table B8 Change in Shoreline and Area of Bhola District in 1990 and 1995

Item/ Interval of Year	1990-1995
Total Shore line Change (km)	+156.75
Mainland Shore line Change (km)	-16.17
Total Common Area (km^2)	1820.12
Mainland Common Area (km^2)	1422.37
Total Erosion (km^2)	97.28
Mainland Erosion (km^2)	25.05
Total Accretion (km^2)	155.17
Mainland Accretion (km^2)	12.88
Total Net Loss/Gain (km^2)	+57.89
Mainland Net Loss/Gain (km^2)	-12.17

Table B9 Shoreline and Area of Bhola District in 1995 and 2000

Item/Year	**1995**	**2000**
Mainland Shore Line (km)	222.83	234.62
Total Shore Line (km)	856.28	914.58
Mainland Area (km^2)	1435.26	1402.43
Total Area (km^2)	1974.98	1964.84

Table B10 Change in Shoreline and Area of Bhola District in 1995 and 2000

Item/ Interval of Year	1995-2000
Total Shore line Change (km)	+58.3
Mainland Shore line Change (km)	+11.79
Total Common Area (km^2)	1834.19
Mainland Common Area (km^2)	1389.42
Total Erosion (km^2)	140.98
Mainland Erosion (km^2)	45.83
Total Accretion (km^2)	131.40
Mainland Accretion (km^2)	13.01
Total Net Loss/Gain (km^2)	-9.58
Mainland Net Loss/Gain (km^2)	-32.82

Table B11 Shoreline and Area of Bhola District in 2000 and 2005

Item/Year	**2000**	**2005**
Mainland Shore Line (km)	234.62	231.14
Total Shore Line (km)	914.58	962.04
Mainland Area (km^2)	1402.43	1370.18
Total Area (km^2)	1964.84	1921.22

Table B12 Change in Shoreline and Area of Bhola District in 2000 and 2005

Item/ Interval of Year	2000-2005
Total Shore line Change (km)	+47.46
Mainland Shore line Change (km)	-3.48
Total Common Area (km^2)	1830.62
Mainland Common Area (km^2)	1360.71
Total Erosion (km^2)	134.22
Mainland Erosion (km^2)	41.72
Total Accretion (km^2)	90.60
Mainland Accretion (km^2)	9.48
Total Net Loss/Gain (km^2)	-43.62
Mainland Net Loss/Gain (km^2)	-32.24

Table B13 Shoreline and Area of Bhola District in 2005 and 2010

Item/Year	**2005**	**2010**
Mainland Shore Line (km)	231.14	235.73
Total Shore Line (km)	962.04	1109.34
Mainland Area (km^2)	1370.18	1357.94
Total Area (km^2)	1921.22	2062.34

Table B14 Change in Shoreline and Area of Bhola Island in 2005 and 2010

Item/ Interval of Year	2005-2010
Total Shore line Change (km)	+147.3
Mainland Shore line Change (km)	+4.59
Total Common Area (km^2)	1847.00
Mainland Common Area (km^2)	1344.83
Total Erosion (km^2)	74.21
Mainland Erosion (km^2)	25.35
Total Accretion (km^2)	215.33
Mainland Accretion (km^2)	13.10
Total Net Loss/Gain (km^2)	+141.12
Mainland Net Loss/Gain (km^2)	-12.25

Table B15 Shoreline and Area of Bhola Island in 2010 and 2016

Item/Year	**2010**	**2016**
Mainland Shore Line (km)	235.73	248.25
Total Shore Line (km)	1109.34	1117.99
Mainland Area (km^2)	1357.94	1328.36
Total Area (km^2)	2062.34	2001.61

Table B16 Change in Shoreline and Area of Bhola Island in 2010 and 2016

Item/ Interval of Year	2010-2016
Total Shore line Change (km)	+8.65
Mainland Shore line Change (km)	+12.52
Total Common Area (km^2)	1893.91
Mainland Common Area (km^2)	1322.90
Total Erosion (km^2)	168.42
Mainland Erosion (km^2)	35.03
Total Accretion (km^2)	107.70
Mainland Accretion (km^2)	5.46
Total Net Loss/Gain (km^2)	-60.72
Mainland Net Loss/Gain (km^2)	-29.57

Table B17 Shoreline and Area of Bhola Island in 1974 and 2016

Item/Year	Shore line (km)	Area (Sq. km)
1974	507.017	1846.75
1980	580.559	1814.74
1990	699.53	1880.33
1995	856.28	1974.98
2000	914.58	1964.84
2005	962.04	1921.22
2010	1109.34	2062.34
2016	1117.99	2001.61

Table B18 Change in Shoreline and Area of Bhola District in 1974 to 2016

Type/Interval of year	Shore line Change (km)	Common Area (Sq. km)	Erosion (Sq. km)	Accretion (Sq. km)	Net Loss/Gain (Sq. km)
1974-1980	+73.54	1728.08	118.67	86.66	-32.01
1980-1990	+118.97	1704.26	109.52	211.56	+102.04
1990-1995	+156.75	1820.12	97.28	155.17	+57.89
1995-2000	+58.3	1834.19	140.98	131.40	-9.58
2000-2005	+47.46	1830.62	134.22	90.60	-43.62
2005-2010	+147.3	1847.00	74.21	215.33	+141.12
2010-2016	+8.65	1893.91	168.42	107.70	-60.72
1974-2016	+610.98	1503.46	343.30	498.15	+154.85