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*Research Article*

# Shoreline Change Detection of Nizam Island, Bangladesh (1997–2022) Using GIS and Remote Sensing Techniques

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**Abstract**

Coastal shoreline changes are a natural process that forms and reshapes the coastal zone through sedimentation over time and space. Addressing the changes of the coastal shoreline in the Bay of Bengal, one can observe the magnitude of coastal changes over time. The aim of the study is to analysis the shoreline changes detection of Nizam Island. The satellite images were obtained from Landsat Satellite imagery, where 1997 and 2010 years of Landsat 4-5 Thematic Mapper (TM) and 2022 year of Landsat 8-9 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) were obtained. The data processing and analysis was done on ArcGIS 10.7 software application. The island showed considerable growth from 1997 to 2010, where the high accretion was 31.28 $km^2$/year, accretion rate was 2.41 $km^2$/year, with net sediment flux of 27.74 $km^2$/year respectively. From 2010 to 2022 year, the accretion rate had declined, and stable land area was found to be consistent of 29.81 $km^2$ in the study period. The accretion was 8.62 $km^2$ being lower than erosion of 12.25 $km^2$ from 2010 to 2022 year. Although net sediment flux for the 25-year study period is very high and favorable for stability and existence of Nizam Island. Vegetation growth has been prominent in the region as the NDVI values had shown. The evolution of Nizam Island and increasing growth and stability can indicate further sedimentation in the south of Bangladesh and the cause of heavy sedimentation in the region. The development and stability of Nizam Island signifies the sedimentation process in the Bay of Bengal region.

**Keywords:** Coastline change, Nizam Island, Erosion and accretion, Coastal morphology

## 1 Introduction

The coastline is one of the most significant features on the Earth’s surface, where land meets the ocean. The majority of the world's population lives in coastal regions; these regions are crucial

(Wang et al., 2013). Geomorphologically, Bangladesh's coastline region is more diversified and dynamic, with varying rates of land erosion and accretion (Brammer, 2014; Uddin et al., 2020). Each year, 2.4 billion tons of sediment are transported by these river systems to deposit across the Bay of Bengal (BoB) in Bangladesh (Islam et al., 1999: S M T Hassan et al., 2017).The natural process of coastal morphology shapes and reshapes the coastal zone across time and place. In this natural process, materials are formed and reshaped by the interaction of rainfall, sea level changes, ocean waves, erosion, sedimentation, wind, and tides (Brammer, 2014). On the other hand, coastal areas see a variety of environmental effects caused by people. As a result, human-caused coastal erosion is a growing issue for everyone. Information about the shoreline and its changes is necessary for managing the coastal zone's environmental factors (Wang et al., 2013).

Building up in the shallow Bay of Bengal basin, the massive amount of silt that is discharged from the Bay of Bengal through the Meghna estuary might lead to the development of island form. The dynamic processes in the north Bay and Bangladesh coast are primarily influenced by the bottom topography of the Bay of Bengal. Also, the shallow water in most of the northern Bay, especially in and around the Meghna estuary, aids in the amplifying of waves like tides and storm surges. These tides and storm surges plays a significant role in sediment movement, aid to the dynamic process of the region (Islam et al., 1999).

Human life, agriculture, and natural resources are all impacted by the processes of erosion and accretion along the coast, and in some places, rapid shoreline changes can have disastrous social and economic repercussions. A full understanding of regional shoreline dynamics (erosion and accretion) is necessary to develop sustainable land use and protection measures to reduce potential loss (Chu et al., 2006; Naji & Tawfeeq, 2011). Monitoring can support research on coastal erosion remedies and help understand how erosion risks are distributed geographically and how to predict their growth patterns (Jayson-Quashigah et al., 2013). Initiatives to monitor the coast are costly and labor-intensive. In which case, satellite imagery could help in understanding the erosion and accretion process remotely and over several time periods. Landsat imagery has been widely used for monitoring coastal zones, agricultural evaluations, water resource estimations, forest management inventories, geological surveys, and a variety of other applications due to the open-source nature of geographic information system (GIS) and remote sensing (RS) techniques.

The evolution of Nizam Island is notably worthy, as the island sits on the Meghna Estuary. In the years of fluctuating sea level from 1997 to 2022, Nizam Island and its environs were newly formed islands made of unconsolidated sediments of different thicknesses based on their accretionary level on pre-existing surfaces (S M T Hassan et al., 2017; Hossain et al., 2023). The relative pace of sea level rise slowed, and intertidal environments experienced the greatest accumulation of sediment, followed by supratidal and mangrove swamp environments (Islam et al., 1999). The sedimentary deposition through the Meghna estuary along the outskirts of Nizam Island from 1997 to 2010 was very high in amount, and the sediment deposition of the region accumulated as Nizam Island was very high (Islam et al., 1999). Evidently, the evolution of Nizam Island signifies the overall development of the region due to high sedimentation. The sedimentation being brought upon by high flow rate of water concludes heavy water discharges through the Meghna estuary from 1997 to 2010 year.

Bangladesh's coasts receive more sedimentary deposition than those of its neighbors, but they are nevertheless more susceptible to rapid coastal erosion (Brammer, 2014; Ahmed et al., 2018). The net gain area will be much higher if erosion can be reduced or stopped at the same time that new islands are gained (Brown & Nicholls, 2015; Haque et al., 2016; Dewan et al., 2017). A thorough regional study of coastal land dynamics is necessary for effective coastal land management ( Naji & Tawfeeq, 2011; Jayson-Quashigah et al., 2013). The southernmost districts of Bangladesh's Barishal division, Patuakhali, Borguna, and Bhola, are open to the BoB and are surrounded by the delta estuary. Due to the development of new islands, severe erosional dangers, and promising accretion and erosion potential, the areas have seen major morphological changes in recent years. The area has therefore been more susceptible to morphological alterations (Ahmed et al., 2018).

Using multi-temporal satellite images, the author examined river bank erosion and accretion along the Padma River in Bangladesh from 1975 to 2015; the results showed a total of 49,951 ha of erosion and 83,333 ha of accretion (Billah, 2018). (S M Tanvir Hassan et al., 2017) used remote sensing and GIS to study changes in land area in order to evaluate coastal erosion and accretion in Bangladesh's Ganges-Brahmaputra-Meghna Delta between 1973 and 2016. It documents various rates of erosion and accretion across different locations and indicates notable trends of net land gain in some areas, especially in the Meghna estuary. (Pahlowan & Hossain, 2015) uses remote sensing and GIS technology to examine the rates of erosion and accretion in Bangladesh's Sundarbans and neighboring east coast. According to the author's research, between 1980 and 2014, the Sundarbans' rates of erosion were greater than those of the nearby east coast's accretion.

For the coastal region of Bangladesh, a thorough and in-depth study is required to address the potential land loss and take the necessary precautions to lessen that loss. As an emerging island within the last 30 years, Nizam Island has become one of the most important to study as to understanding the coastal dynamics in the southern region of Bangladesh. Relatively, less study influences the current research as to provide a wider view on the coastal process. The research objectives of the study are to map and observe the geomorphological changing patterns Nizam Island from 1997 to 2022 year; while quantifying the amount of land loss, new land development, and net land gain, and determining the coastal stability of Nizam Island.

## 2 Methodology

### 2.1 Study Area Profile

Char Nizam is an island located in the Bay of Bengal, in the southern part of Bhola district in Bangladesh. The island is approximately 8 km long and 4 km wide, with a total area of approximately 28 square kilometers. It is situated in the estuarine region of the Meghna River delta and is surrounded by the Bay of Bengal on three sides (Figure 1).

Char Nizam is a low-lying island, with an average elevation of only 2 meters above sea level. The island is characterized by its flat terrain and sandy beaches and is frequently affected by tidal inundation and storm surges. The geographical coordinates of Char Nizam Island, Bhola, Bangladesh are Latitude: 22.30° N, Longitude: 90.53° E. The average temperature of Nizam Island is 27.43°C and the average precipitation of 44.73 millimeters (1.76 inches). The location of Char Nizam Island makes it an ideal site for studying coastal erosion and accretion processes and provides an opportunity to gain valuable insights into the dynamics of the Bay of Bengal coastlines.

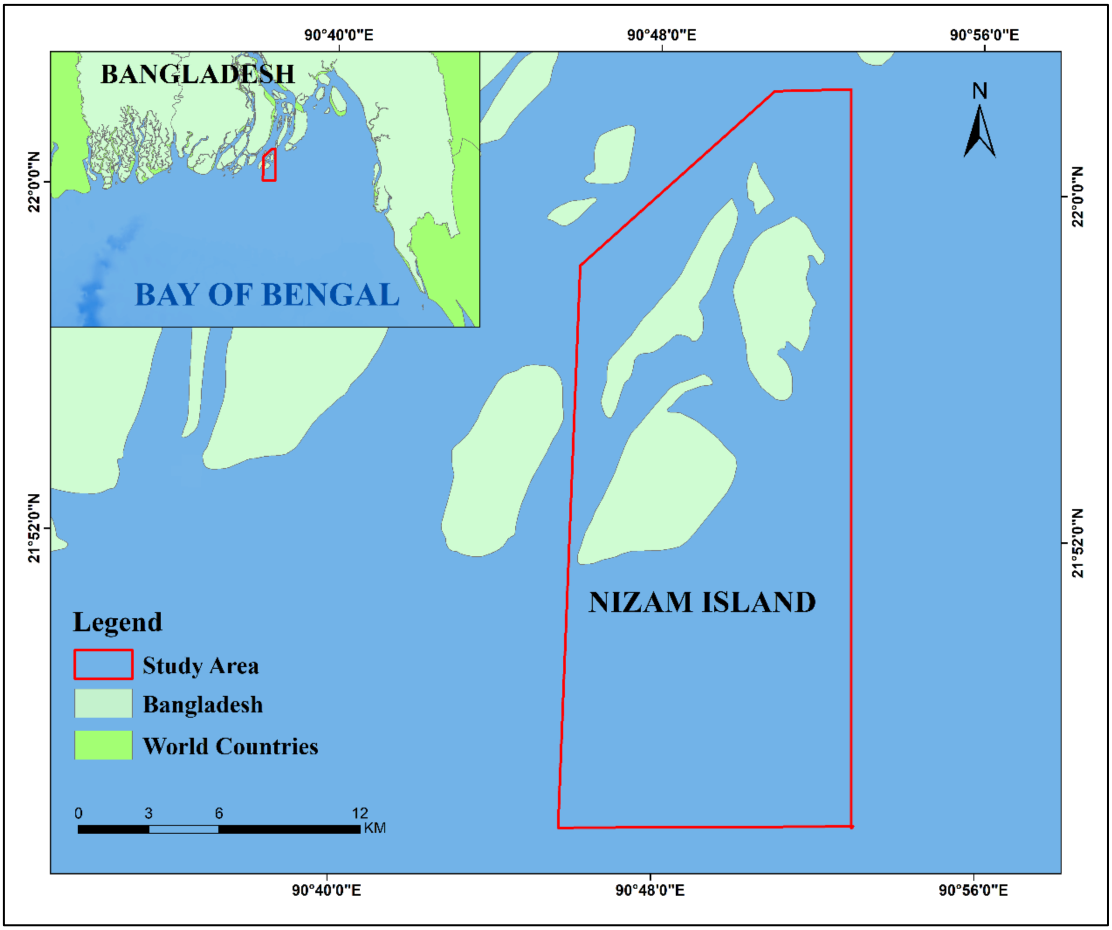


**Figure 1:** Area of Interest (AOI)

## 2.2 Data acquisition and Processing

Multi-spectral Landsat 8 Operational Land Imager-Thermal Infrared Sensor (OLI-TIRS) and Landsat 4-5 Thematic Mapper (TM) images were acquired from the United States Geological Survey (USGS) (webpage: http://earthexplorer.usgs.gov/) to quantify the changes along the coastline of the Char Nizam for the January Month in the year of over 22 years (1997–2022). Information of the Landsat 8 OLI-TIRS and Landsat 4-5 TM are shown in Table 1. The primary understanding of Nizam Dwip was find the stability of the island, as through surveying Google Earth Pro software; it was found that Nizam Dwip started became stable from 1997, for which 1997 was used for starting year. Three satellite images were used to understand the stability of the island as the island was new in formation and had less population habitat, due to unstable shoreline changes through the timeline; this study focused on development and stability of the island for which three satellite imagery year was necessary. The radiometric calibration, correction, image cropping was processed using ArcGIS 10.7 software, and mapping. Images were cropped according to the study area to minimize image coverage.

**Table 1:** Satellite imagery used in the study.

| Image Acquisition | Sensor Name | Path | Row | Resolution |
|---|---|---|---|---|
| January, 1997 | Landsat 4-5 TM | 137 | 45 | 30 m |
| January, 2010 | Landsat 4-5 TM | 137 | 45 | 30 m |
| January, 2022 | Landsat 9 OLI/TIRS | 137 | 45 | 30 m |

## 2.3 Approaches for shoreline extraction

Two approaches were utilized to extract the shoreline and detect changes i.e., (1) land and water separation using the water index algorithms and (2) on-screen digitization for mapping erosion/accretion patterns. The NDWI algorithm was used for the images of Landsat TM and Landsat OLI/TIRS of 1997, 2010 and 2022 year respectively to discriminate the land–water interface and the green and NIR bands were used for calculation in Equation (3). In ArcGIS 10.7 software we went to ArcToolbox > Spatial Analyst Tool > Map Algebra > Raster Calculator. The green and NIR bands were called with help of Equation (3), the NDWI was calculated.

These NDWI images were then classified into water and land by using the iso-cluster unsupervised classification tool in the ArcGIS v10.7 software. Finally, these classified raster images were converted into vector datasets and calculated the total areas of the period. To calculate erosion and accretion between two-time frames, from ArcToolbox; two tools named "Symmetrical Difference" and "Intersection" were used in ArcGIS v10.7 software. The areas were then exported and calculated in Microsoft Excel (Figure 2).

$$NDWI = (Green - NIR) / (Green + NIR) \quad \ldots\ldots(3)$$

## 2.4 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is prioritized as a standardized index that allows an image to display greenness (Atalaya et al., 2022). For the measurement of NDVI, equation (4) was used, and the reflectance values were used for the red band, and near-infrared (NIR) band. In ArcGIS 10.7 software we went to ArcToolbox > Spatial Analyst Tool > Map Algebra > Raster Calculator. The red and NIR bands were called with help of Equation (4), the NDVI was calculated.

NDVI = (NIR-R)/ (NIR + R)……………………………………………………………(4)

## 2.5 Validation of Shoreline Change of AOI

The confusion matrix was done on ArcGIS 10.7 software of the shoreline of AOI in all three years. The validation was done with the help of Google Earth Pro software. Authors could not validate the change of shoreline as the change was defined by the difference of two images from different years. So the Iso cluster image extracted from NDWI image, which defines land and water of the image in this study and data analysis of AOI; were taken as input for validation of respective year. In ArcGIS 10.7 software, the author went to ArcToolbox > Spatial Analyst Tool > Segmentation and Classification > Create Accuracy Assessment Points, to create random points for the study area and Iso cluster image of respective year were taken as input for creating points. The random points were then compared with the help of Google Earth Pro software whether the points was Land or waterbody. Then the random points were taken to ArcToolbox > Spatial Analyst Tool > Segmentation and Classification > Compute confusion matrix. The confusion matrix then copied to excel for further processing and obtaining Overall accuracy. The process was repeated for respective years.

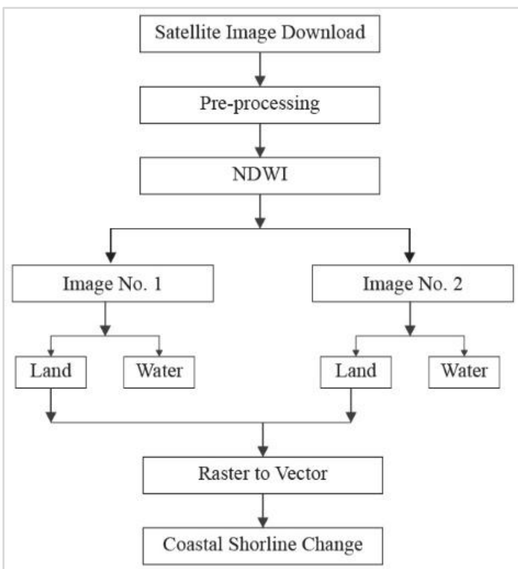


**Figure 2:** Flowchart of extracting coastal shoreline change from satellite images.

# 3 Results and Discussion

## 3.1 Coastal Change Analysis

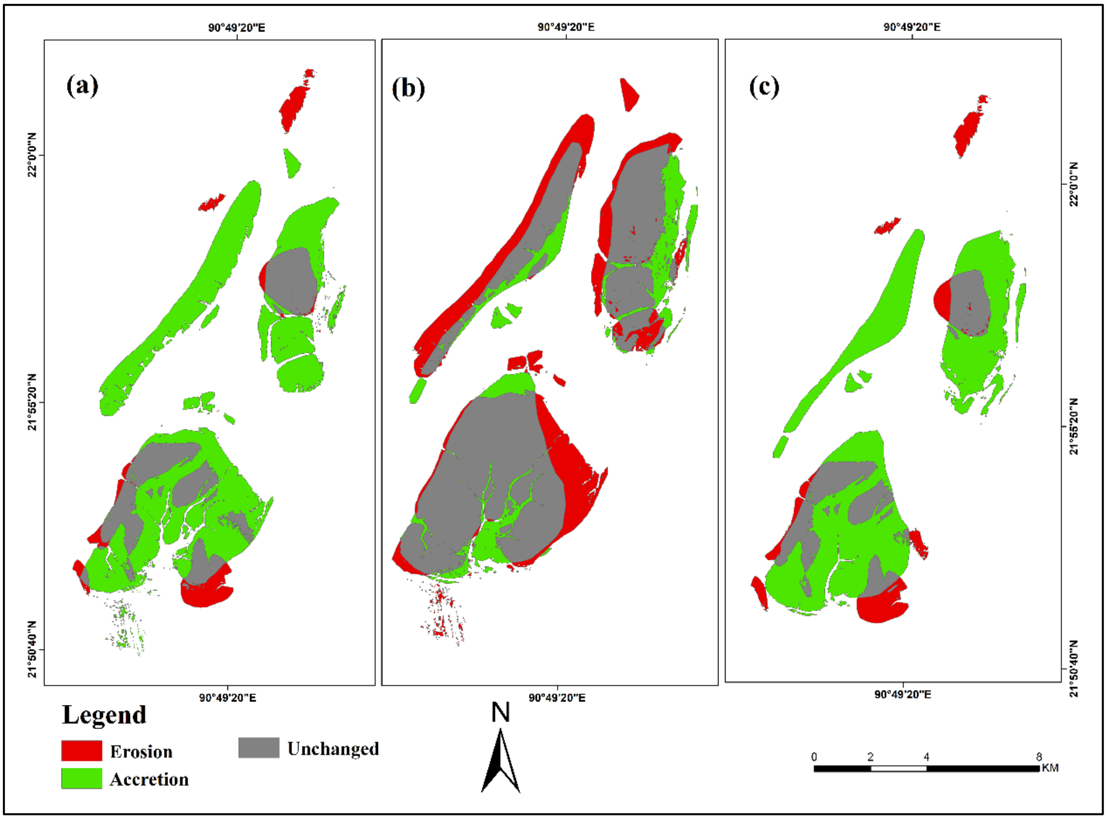


**Figure 3:** Shoreline Changes of Char Nizam Island (a) from 1997 to 2010 year, (b) from 2010 to 2022 year, and (c) from 1997 to 2022 year respectively.

All the images were taken on January month due to least sedimentation influx in winter season. From 1997 to 2022 year, the stable land area was 9.51 km$^2$, accretion area was 28.92 km$^2$, and erosion area was 4.81 km$^2$, with net sediment influx 24.11 km$^2$ (Figure 3- c, Figure 5, Figure 7, Table 2).

From 1997 to 2010, accretion rate was very high in 25-year study periods. The stable land area was found to be 10.78 km$^2$, accretion area was 31.28 km$^2$, and erosion area was 3.53 km$^2$, with net sediment flux of 27.74 km$^2$ (Figure 3- a, Figure 5, Figure 7, Table 2). The last total land area in 2010 was 42.06 km$^2$. Observing the coastal changes, the author can find the accretion percentage was 74.36%, erosion percentage was 8.40 %, net sediment flux percentage was 65.96%, with net sediment flux/year percentage of 5.07% (Figure 4). The accretion rate was 2.41 km$^2$, the erosion rate was 0.27 km$^2$ and the net sediment flux/year was 2.13 km$^2$ respectively (Figure 6).

**Table 2:** Area and percentages of coastline changes of Nizam Island

| Time Period | Unchanged Land ($Km^2$) | Accretion ($Km^2$) | Erosion ($Km^2$) | Net Sediment Flux ($Km^2$) | Accretion % | Erosion % | Net Sediment Flux % | Net Sediment Flux/year % |
|---|---|---|---|---|---|---|---|---|
| 1997-2010 | 10.78 | 31.28 | 3.53 | 27.74 | 74.36 | 8.4 | 65.96 | 5.07 |
| 2010-2022 | 29.81 | 8.62 | 12.25 | -3.63 | 22.43 | 31.87 | -9.45 | -0.79 |
| 1997-2022 | 9.51 | 28.92 | 4.81 | 24.11 | 75.26 | 12.51 | 62.75 | 2.51 |

From 2010 to 2022, the stable land area was very high, accretion and erosion of Nizam Island was found to be very low in respect to accretion and erosion of 1997-2010 year. The stable land area was 29.81 $km^2$, the accretion area was 8.62 $km^2$, erosion area was 12.25 $km^2$, with a negative sediment flux of 3.63 $km^2$. The last total area in 2022 year was 38.43 $km^2$ (Figure 3- b, Figure 5,Figure 7, Table 2). The accretion percentage was 22.43 %, the erosion percentage was 31.87 %, the net sediment flux had a negative flux of 9.45%, with the net sediment flux/year percentage having a negative value of 2.51% respectively (Figure-4). The accretion rate was 0.72 $km^2$, the erosion rate was 1.02 $km^2$, and the net sediment flux/year had a negative value of 0.30 $km^2$ respectively (Figure 6).

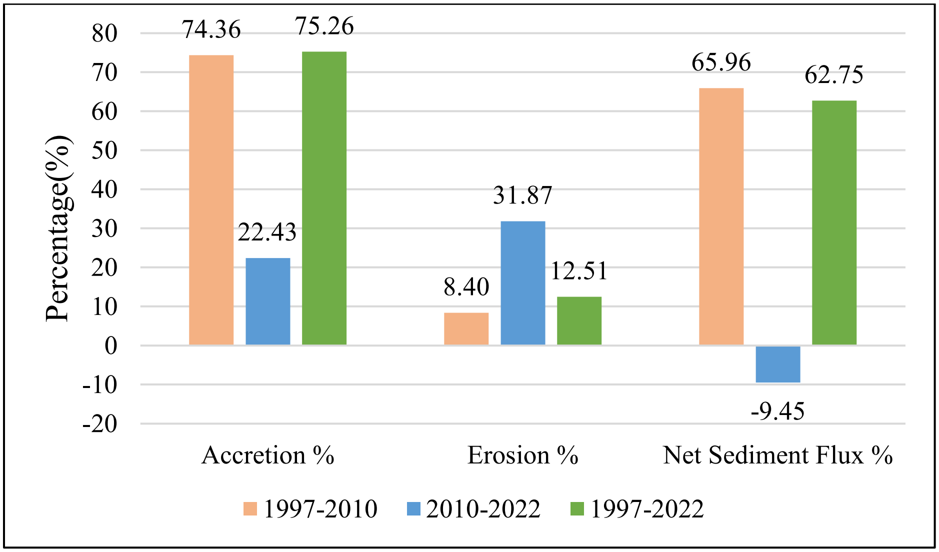


**Figure 4:** Percentages of coastline changes of Nizam Island

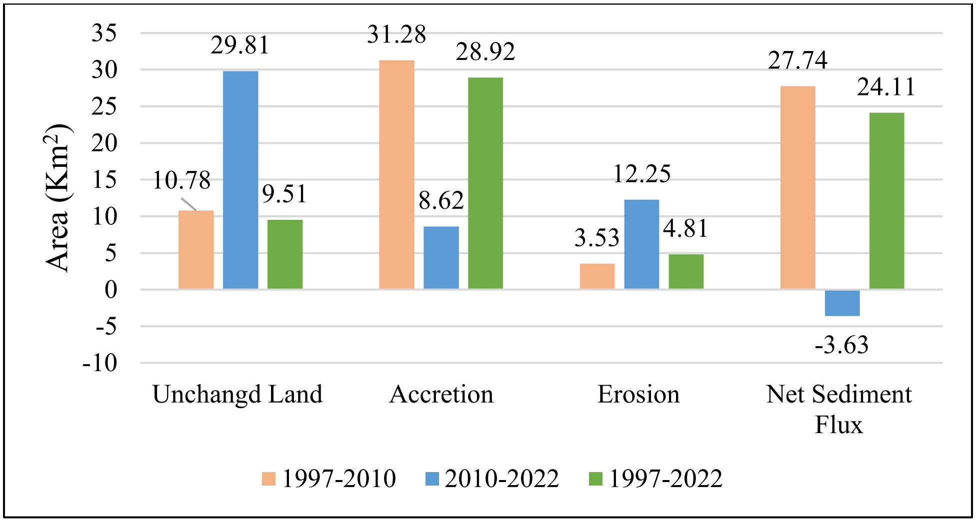


**Figure 5:** Area of coastline changes of Nizam Island

From 1997 to 2022, the most stable state of Nizam Island was found from 2010 to 2022 year, most accretion rate was observed from 1997 to 2010 year. The accretion percentage was 75.26% from 1997 to 2022 year, the erosion percentage was 12.51%, the net sediment flux percentage was 62.75%, and with the net sediment flux/year percentage of 2.51% (Figure 4). The accretion rate was 1.16 km$^2$, erosion rate was 0.19 km$^2$, and the net sediment flux/ year was 0.96 km$^2$ respectively (Figure 6, Figure 7).

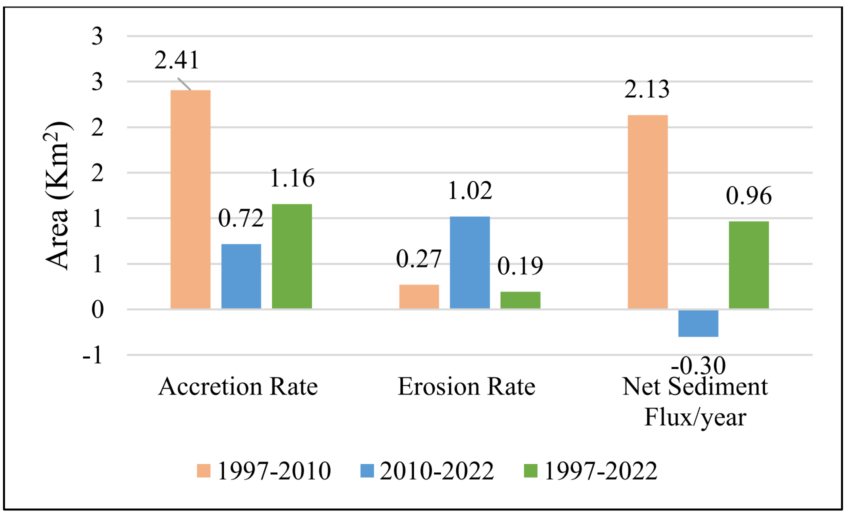


**Figure 6:** Percentage of Area of coastline changes of Nizam Island

### 3.2 Factors Influencing Coastal Shoreline Changes

The Nizam Island was found to be stable afterwards from 1997 year. The coastal changes were found to be rapid from 1997 to 2010 year, where the accretion of AOI was found to be increasing in regard to the accretion from 2010 to 2022 year. Most of the area of Nizam Island have been formed from 1997 to 2010, which almost stayed stable during the study periods. The erosion of Nizam Island was very low from 1997 to 2010 year. The accretion rate was higher than erosion rate from 1997 to 2010 year.

On the other hand, the amount of stable land area was most from 2010 to 2022 year, in respect to the 1997 to 2010 year, where the stable land area was low. The erosion from 2010 to 2022 year surpasses the accretion of Nizam Island. The accretion rate is lower than the erosion rate. Hence, the AOI had negative net sediment influx from 2010 to 2022 year. High amount of sedimentation in the region and high amount of sediment capture had caused the evolution and rise of Nizam Island.

Although the net result of accretion /erosion process, it is very difficult to identify separately the contribution to coastal dynamism. The main causes of coastal erosion in Bangladesh are discharge current, astronomical tides, monsoon water current, and storm surges (Islam et al., 1999: S M T Hassan et al., 2017). The Bay of Bengal receives enormous water discharges from Bangladesh and through Bangladesh. The strong discharge current caused considerable erosion in the coastal area in the nizam island region. Semi-diurnal tides in the Bangladesh region gradually recede in a south-easterly direction along Bangladesh's east coast. The nonlinear shallow water effect and the northward convergence of the Bay of Bengal play major roles in the amplifying of tides in the Bay of Bengal, which originate in the Indian Ocean. Thus, Bangladesh's problem with erosion is exacerbated by the significant tidal water action (Islam et al., 1999).Strong water waves and water current are produced in the area by the south-west monsoon wind that passes across the Indian Ocean and the nearby land areas. Especially in the Meghna estuary, where water surges as a result of the south-west wind piling up water, the water waves and current severely erode Bangladesh's coastline (Ali, 1995).

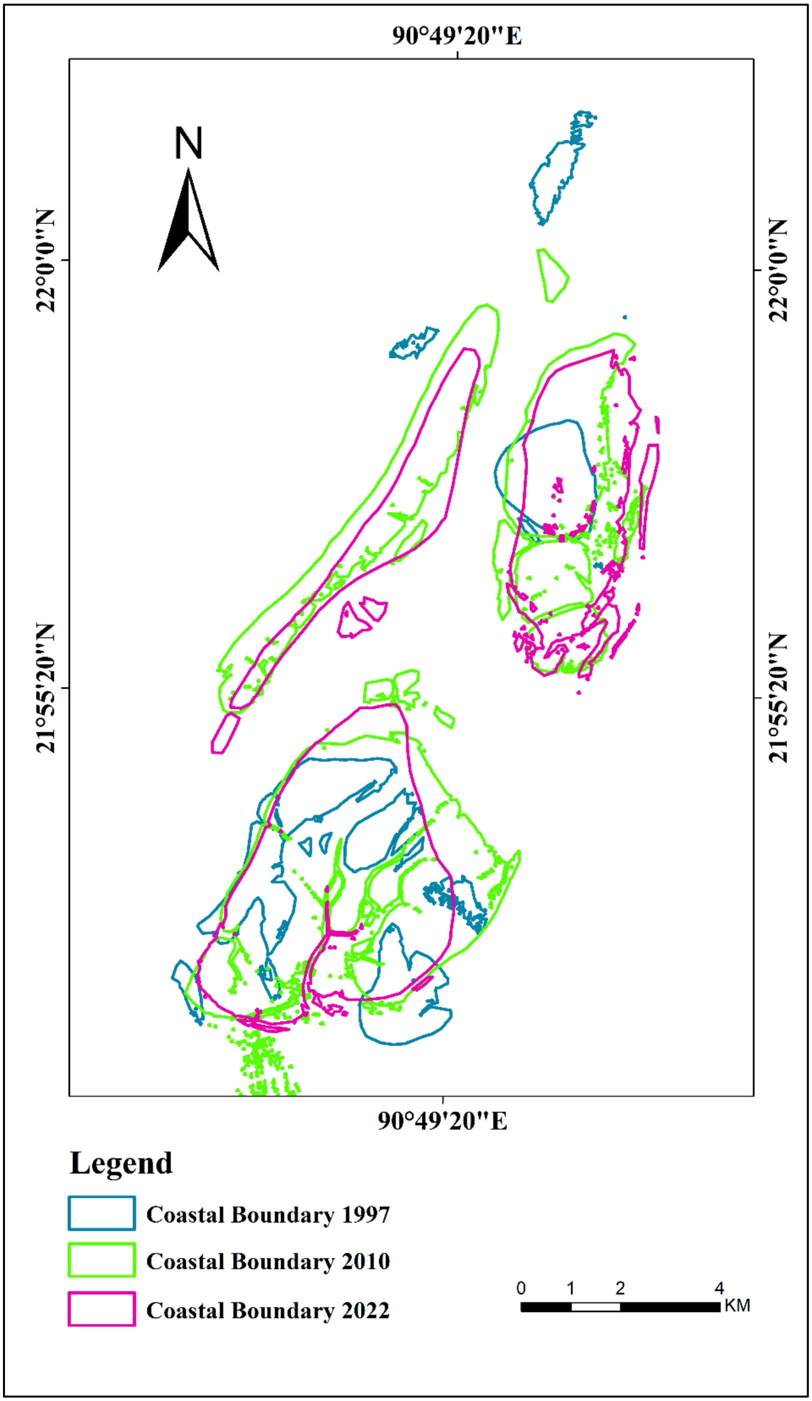


**Figure 7 :** Coastal shoreline change of Nizam Island of 1997, 2010, and 2022 year respectively.

### 3.3 Normalized Difference Vegetation Index (NDVI)

The NDVI in 1997 showed considerable vegetation in the region, and it was observed that the island had formed and rose around the vegetation in 1997 and grew from there further increasing the island's area. The NDVI value of 1997 year had a high of 0.62 and a minimum of -0.47. The NDVI value of the year 2010; maximum as 0.62 and minimum as -0.48; the NDVI value of the year 2022; maximum as 0.67 and minimum as -0.41. The value above shows vegetation and below shows non-vegetation. The maximum value of NDVI is observed to stay static for 1997 and 2010 and had increased for 2022 year (Figure 8). The root of the vegetation allows more sediment capture in the region, which indicates the stability of the island. From Figure 8, the vegetation had influenced potential growth of Nizam Island and adjacent islands.

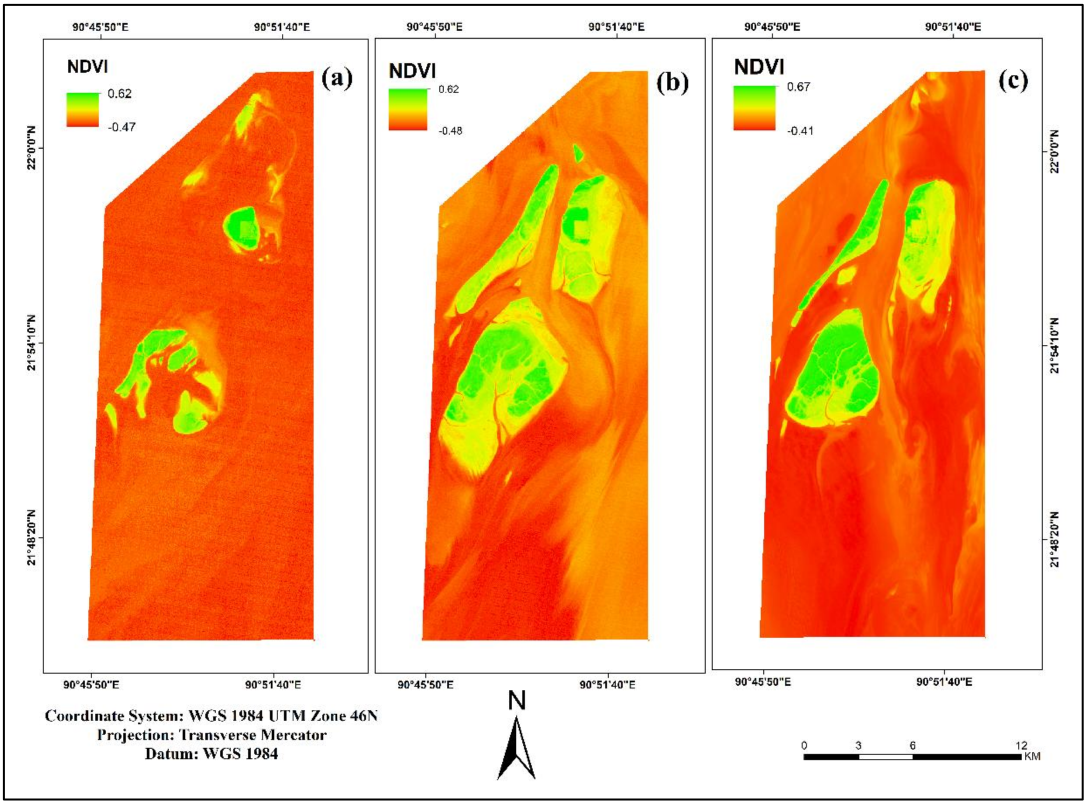


**Figure 8:** Normalized Difference Vegetation Index (NDVI) of Char Nizam Island of the year (a) 1997 year, (b) 2010 year, and (c) 2022 year respectively

### 3.4 Validation of shoreline of AOI

The validation of shoreline of AOI of 1997,2010 and 2022 years showed positive results. The overall accuracy of the years was 98.61, 98.57 and 97.14 respectively and Kappa Coefficient were 88.16, 90.14 and 85.92 respectively. The user accuracy and producer accuracy showed strong results as well (Table 3). The overall accuracy was always found above 95%, which dignifies the accuracy of availability of land and water to found in the ISO cluster of NDWI image for each year. Kappa coefficient dignifies strong agreement between classified image and ground truthing of the sample points.

**Table 3:** Accuracy Assessment of the shoreline of AOI

| Year | Producer Accuracy | | User Accuracy | | Overall Accuracy | Kappa Coefficient |
|---|---|---|---|---|---|---|
| | Land | Waterbody | Land | Waterbody | | |
| 1997 | 80.00 | 100.00 | 100 | 98.53 | 98.61 | 88.16 |
| 2010 | 83.33 | 100.00 | 100 | 98.46 | 98.57 | 90.14 |
| 2022 | 77.78 | 100.00 | 100 | 96.83 | 97.14 | 85.92 |

# 4 Conclusion

The Nizam Island was studied from 1997 to 2022 year. The island showed considerable growth from 1997 to 2010 year, where the high accretion rate was observed. From 2010 to 2022 year, the accretion rate had declined, and stable land area was found to be consistent in the study period. The accretion rate was lower than erosion rates from 2010 to 2022 year. Although net sediment flux for the 25-year study period is very high and favorable for stability and existence of Nizam Island. Vegetation growth has been prominent in the region as the NDVI values had shown. The evolution of Nizam Island and increasing growth and stability can indicate further sedimentation in the south of Bangladesh and the cause of heavy sedimentation in the region.

An extensive topographic assessment of the coastal area, including both land and water, should be carried out to better understand erosion and accretion. The topographic data for the land survey should be of high resolution. Among other things, a high-resolution topographic map will assist in determining the degree of coastal inundation brought on by modest SLR increments as well as other vulnerabilities. Bangladesh's coastline should undergo a frequent and systematic assessment to look for signs of sea level change. For a given time, the wind and wave velocities should be noted for the shoreline's erodible area.

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