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Arif Uddin Ahmad

Department of Geo-
Information Science and Earth
Observation, Patuakhali
Science and Technology
University, Patuakhali,
Bangladesh

Geospatial analysis of shoreline dynamics on Nijhum Dwip Island, Meghna estuary, Bangladesh

Arif Uddin Ahmad

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Abstract

This study aimed to examine the shoreline dynamics and erosion-accretion of an active estuarine island over a 45-year period utilizing GIS approaches. To extract the shoreline both automated band ratio and manual digitizing methods have been employed. The Digital coastal Analysis System, an extension of ArcGIS, has been utilized for the analysis of coastal displacement. The results show that Between 1972 and 2017, the island gained 35 square kilometers of land at a rate of 0.77 square kilometers (77 hectares) annually. Net Shoreline Movement shows that highest seaward movement is about 5,549 meters found in northern part of the island whereas highest landward movement is about 1,093 meters found in the southern part of the island. Highest End Point Rate towards the sea is about 125 meters per year and landward is about 24 meters per year. The overall result indicates that the island is moving towards the sea of about 34 meters per year.

Keywords: Shoreline, DSAS, remote sensing, Meghna estuary

1. Introduction

The seashore is a distinctive and highly dynamic habitat globally. The coastline is a strip of land with varying width. It extends inland from an aquatic area to a point where the terrain changes (Bouchahma & Yan, 2012) ^[4]. Shorelines are the transition zone between land and water, constantly changing with the shifting of the tides. This change creates different boundaries at low tide, mid tide, and high tide that delineate the transition zone from land to water. In addition, these changes are controlled by short-term and gradual processes. The morpho-dynamics of shoreline, which refers to the alterations in the coastal shape resulting from variations in sand volume and this plays a key role in the development of the shoreline (Harley *et al.*, 2014) ^[10]. As a lowland delta country, the coastal geology of Bangladesh is highly unstable and is subject to continuous erosion and deposition (Sarwar & Woodroffe, 2013) ^[16]. The coastline of Bangladesh is segmented into four regions from the western to the eastern end: the Sundarbans, the Clear Sundarbans, the Meghna, and Chattogram. Except for Chattogram, most of the coastline is low and swampy in nature, changing rapidly and formed by Quaternary sediments deposited in extensive river basins. The main sources of this sediment are the Ganges and Brahmaputra river systems (Schwartz, 2006) ^[17]. Most of the estuarine islands of Bangladesh are in are in the Meghna River estuary, a active area formed by sediment deposited over time from upstream flood waters and subject to ongoing erosion by river flow and wave action (Ghosh *et al.*, 2015; Sarwar & Woodroffe, 2013) ^[9, 16]. Understanding the dynamic nature of coastal environments, especially in the Meghna Mangrove region, and the complex relationship between human influence on coastal change requires extensive research (Chowdhury and Sikder, 2023) ^[6]. Natural and anthropogenic activities make significant changes in the shoreline and identify those changes that are crucial for coastal management and policy development. The coastline of Bangladesh is about 710 km long and extends over 1,320 km when including estuaries, islands, and tidal channels. Moreover, approximately 19 coastal districts in Bangladesh are situated in low-lying topography with the elevations ranging from 0.5 to 11.8 meters above sea level and this topographic setting makes the coastal area vulnerable to climate change and natural disasters (Ashrafuzzaman *et al.*, 2022) ^[1]. Complete shoreline assessment of coastal areas is critical for the local community to mitigate the risk associated with coastal hazards (Beverage *et al.*, 2020; Chowdhury and Sikder, 2023) ^[3, 6]. GIS and remote sensing have become essential tools which offer accurate and effective monitoring of shoreline (Islam *et al.*, 2023) ^[11].

Corresponding Author:

Arif Uddin Ahmad

Department of Geo-
Information Science and Earth
Observation, Patuakhali
Science and Technology
University, Patuakhali,
Bangladesh

The Digital Shoreline Analysis System (DSAS) extension of ArcGIS helps accurately assess the place of shoreline changes over several years and it provides powerful statistical information for shoreline change dynamics. The DSAS based shoreline analysis can be competent at Nijhum Dwip Island in the Meghna estuary where continuous geological evolution occurs due to river and tidal processes, along with large amounts of discharge (Shahid *et al.*, 2024) [18]. Therefore, the main objectives of the study are to analyze spatial and temporal changes of the shoreline of Nijhum Dwip Island and identify areas vulnerable to shoreline change from year 1972 to 2017. In this study the DSAS extension of ArcGIS was used to analyze the changes in different year intervals. The analysis will use Landsat satellite images, acquired from 1972 to 2017. This data selection ensures a broad and detailed understanding of long-term shoreline change which will provide valuable perceptions into the evolution of this dynamic island environment.

2. Material and Methods

2.1 Study Area: Nijhum Dwip Island is a significant

offshore island of Bangladesh, near the estuary of the Meghna River. The island extends from 22°02' N to 22°06' N latitude and from 90°58' E to 91°02' E longitude (Fig. 1). It is bounded by Hatiya Island to the north, Domar Char to the east, the Bay of Bengal to the south, and both the Bay of Bengal and Manpura Island to the west. The area of the island is about 81 square kilometers with its water body. It is an administrative unit of Hatiya Upazila. Nijhum Dwip Island is an offshore island under Hatiya upazila which is developed with planted mangroves. This island is almost flat with a round rectangular shape. The region experiences an average annual temperature of approximately 25.6°C, while the mean annual rainfall is about 3,302 mm. It is observed that May records the highest temperatures, averaging 40.6°C, while January is the coldest month, with an average temperature of 19.5°C. Precipitation is at its lowest in January, with only 8 mm, while July marks the peak of the rainy season, receiving an average of 671 mm of rainfall (Rahman, 2012) [15]. According to Bangladesh Bureau of Statistics population of the island has increased from 7835 in 2001 to 12796 in 2011 (BBS, 2015).

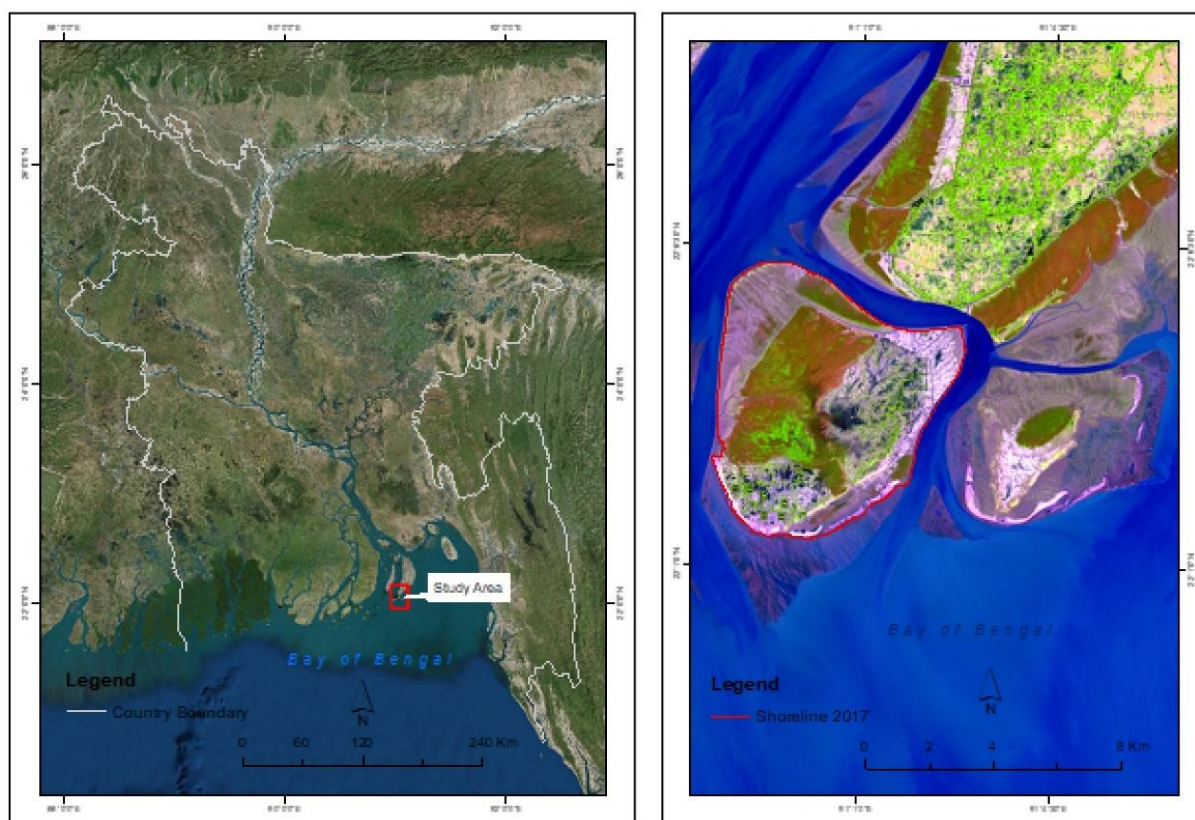


Fig 1: Study area map

2.2 Data

A comprehensive database forms the basis of all types of research, especially those related to local analysis. Currently, remotely sensed data is being widely used in global change detection studies. Selecting appropriate data is an important step in changing detection analysis. Acquisition of multiple date images in the period, season, and month are important parameters in image selection, as they are closely related to phenological stage, climatic location, and solar angle. Therefore, careful selection of multiple date images is crucial to minimize the influence of these factors (Li and Ke, 2014; Wang *et al.*, 2013; Wang *et*

al., 2014; Wei *et al.*, 2015) [12, 20, 21, 22]. This study used satellite imagery from multiple sensors to track coastal changes, such as erosion and deposition rates. We selected Landsat 1 MSS (1972), Landsat 5 TM (1989, 1991, 1999, and 2010), and Landsat 8 OLI-TIRS (2017) images. All images were downloaded from the USGS website (www.earthexplorer.usgs.gov and www.glovis.usgs.gov). All the images have a resolution of 30 meters despite the 1972 image having a resolution of 60 meters. These images were selected because of their quality, sensor type, visibility, low cloud cover (less than 5%), low tide level (less than 1 meter), and being taken during the dry season.

The table below (Table 1) shows an overview of the data used in this study.

Table 1: Details of Satellite Images Used in The Present Study

Satellite and Sensor	Path/Rows	Acquisition Date	Resolution
Landsat 8 OLI-TIRS	136/45	2017-03-15	30m
Landsat 5 TM	136/45	2010-01-23	30m
Landsat 5 TM	136/45	1999-01-09	30m
Landsat 5 TM	136/45	1991-12-05	30m
Landsat 5 TM	136/45	1989-11-29	30m
Landsat 1 MSS	146/45	1972-12-27	60m

2.3 Method

This study used satellite imagery and remote sensing techniques to assess coastline changes over time, following a series of steps to ensure data quality and accurate results. The first step involved radiometric correction to ensure consistency in the digital numbers (DNs) across all images. The images were converted to reflectance values using ENVI software, ensuring uniformity in the data. The Dark Object Subtraction (DOS) method was used to minimize atmospheric effects, eliminating negative and multiple values, making the images more reliable for land and water classification, which is crucial for accurate analysis (McFeeters, 1996) [13].

The second step was geometric correction, where the 2017 image was selected as the base map for alignment. The Autosync tool in Erdas Imagine was used to apply a third-order polynomial transformation, maintaining a Root Mean Square (RMS) error below 0.5, which is considered acceptable. Ground truth points collected via GPS were overlaid on the images to ensure spatial accuracy. This verification process confirmed that the images were suitable for further analysis and change detection (Emran *et al.*, 2016) [8].

Table 2: Errors of Geometric Correction

Year	1972	1989	1991	1999	2010	2017
RMS Error	0.409311	0.278338	0.602931	0.443991	0.288627	Basemap

For coastal boundary delineation, water indices such as NDWI and MNDWI were employed. NDWI was applied to the 1972 image to define the coastal boundary, distinguishing water (positive values) from land (negative or

zero values) (McFeeters, 1996) [13]. For subsequent images, MNDWI was used due to its effectiveness in distinguishing water from built-up land, utilizing the fact that water absorbs more mid-infrared light compared to near-infrared light. This index allowed for a clearer separation of water and land, which was essential for accurate boundary delineation. Once the coastal boundaries were defined, the classified images were then converted to vector format using ArcGIS 10.0. Manual digitization was performed at a scale of 1:1000 to address any discrepancies from the automated land-water index method, ensuring the accuracy of the coastal boundary.

For coastal change detection, the Digital Shoreline Analysis System (DSAS) 4.3 was employed to assess the changes in the shoreline over time. DSAS generates reference points and transects at 150-meter intervals along the coastline, calculating the location and rate of coastal change. Additional calculations were performed in MATLAB to analyze the historical coastal data (Emran *et al.*, 2016; Thiller *et al.*, 2008) [8, 19].

Finally, two key metrics were used to quantify coastal migration: Net Shoreline Movement (NSM), which quantifies the distance between the most landward and most seaward shoreline positions per transect, and Endpoint Rate (EPR) that measures the rate at which the shoreline moves over time (Dolan *et al.*, 1980) [7]. Statistical analyses also examined the relationship between shoreline shifts and environmental factors such as rainfall and water levels, with all analyses conducted using Microsoft Excel.

3. Results and Discussion

3.1 Erosion and Accretion

Erosion and accretion are frequent in coastal areas because coastal environments are highly dynamic. The Nijhum Dwip Island is in Meghna estuary which is constantly changing due to the heavy sediment load carried by the Ganges-Brahmaputra-Meghna (GBM) river system. The island first appeared in around 1940. After that human intervention started around 1950. The island is morphologically very dynamic as it is located at the mouth of an active delta, and it is also at the southernmost island of Bangladesh. It is dominated by the deposition process. Sediments carried by the Meghna River deposited here with the confluence of the Bay of Bengal.

Table 3: Erosion accretion of Nijhum Dwip Island (in sq. km)

Parameter	1972-1989	1989-1991	1991-1999	1999-2010	2010-2017	1972-2017
Accretion	22.19	1.10	1.07	14.04	3.33	41.74
Erosion	2.46	0.75	1.27	0.80	1.03	6.33
Net Loss/Gain	19.72	0.35	-0.20	13.24	2.30	35.41
Unchanged	9.60	31.04	30.87	31.14	44.15	-

The most accretion took place between the year 1972 and 1989. About 22 square kilometers added in this period (in 17 years) (Table 3, Fig. 2 and Fig. 3). Second highest accretion occurred between the year of 1999 and 2010 (about 14 square kilometers in 11 years) (Table 3, Figure 2 and 3). The island lost highest 2.46 square kilometers in first time span and a total of 6.33 square kilometers in last 45 years and deposited about 41 square kilometers (Table 3). The island gained about 35 square kilometers in last 45 years. It gained landmass in every interval period except 1991-1999 (Table 3). In this period erosion process is dominated and net loss was 0.20 square kilometers which is

very insignificant. The rate of accretion is about 0.93 square kilometers per year; erosion is about 0.14 square kilometers and net loss or gain rate 0.79 square kilometers per year (Table 3). From the figure below, it is found that most of the erosion took part in the southernmost of the island which side is open ocean. And it is also seen clearly that most erosion took place in the north, northeast and northwest parts of the island due to the cumulative effect of Hatiya and Domar Char islands. Both islands helped Nijhum Dwip Island in accretion process. Fig. 3 shows the erosion and accretion process of the island in different time periods.

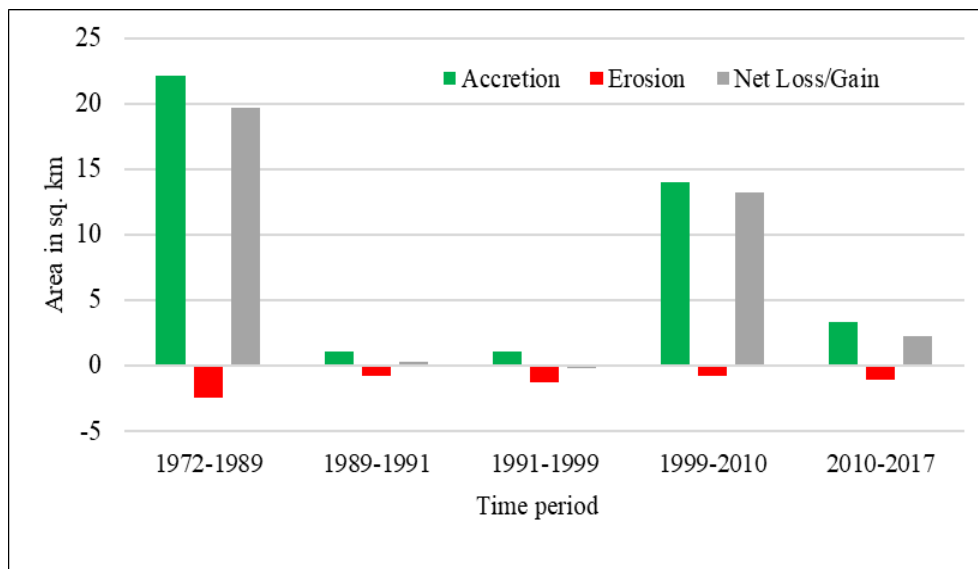


Fig 2: Erosion and Accretion of Nijhum Dwip Island

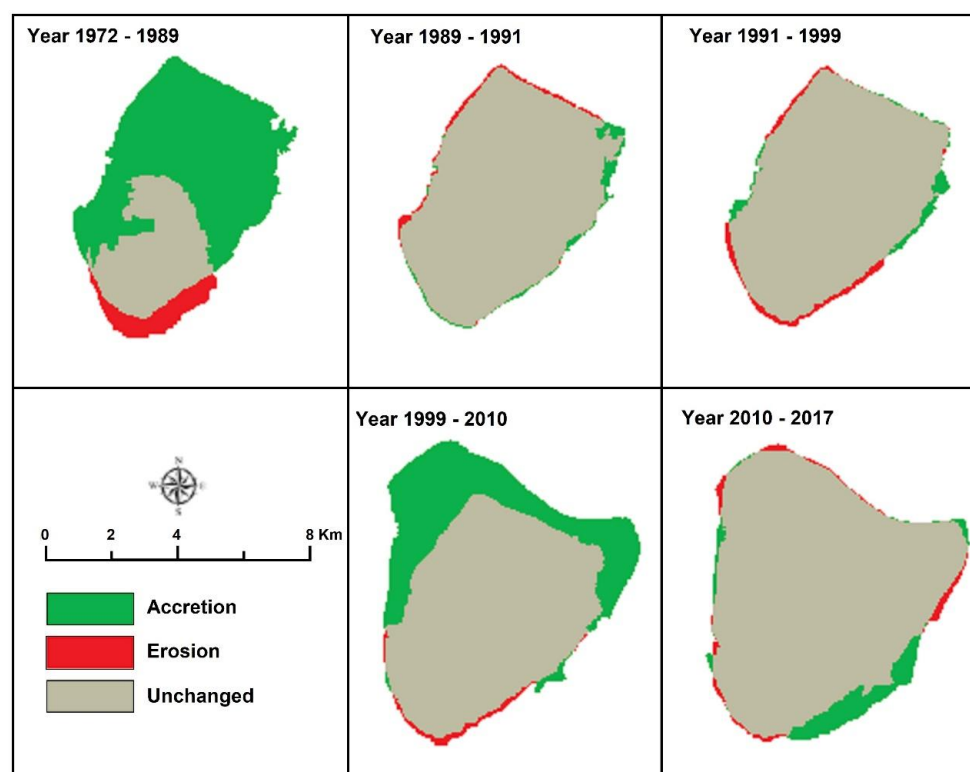


Fig 3: Erosion and Accretion map of Nijhum Dwip Island

3.2 Shoreline Shifting Rate and Pattern

To enhance understanding of the island's dynamic nature, the DSAS extension was utilized in conjunction with erosion and accretion measurements. A total of 53 transects were automatically generated using the DSAS extension within the ArcGIS environment. Both Net Shoreline Movement (NSM) and End Point Rate (EPR) were calculated. NSM quantifies how far the shoreline has shifted between its oldest and most recent positions in meters, while EPR represents the rate of change, calculated by calculating the distance change over the period in meters per year.

The shoreline is not uniform every year. It was found that highest seaward movement was more than 5 km. Which is found in northeast and northwest part of the island. The northern part of the island experiencing movement of more than 3.5 km (Table 4, Fig. 4 and Fig. 5). Maximum

landward movement was found about 1 km. Which is found in the southern part of the island. Highest seaward shifting rate was found to be about 125 meters per year and highest landward movement rate at about 24 meters per year (Table 4, Fig. 4 and Fig. 6). The island shows a positive shifting as it is found the average NSM of more than 1.5 km and average EPR of about 34 meters per year. Which indicates the island is shifting towards the sea by one pixel every year (Table 4).

Table 4: Shifting of Nijhum Dwip Island

Parameter	NSM (meter)	EPR (meter per year)
Number of Transect	53	53
Maximum Landward Movement	-1093.97	-24.74
Maximum Seaward Movement	5549.14	125.51
Average Shifting	1539.23	34.81

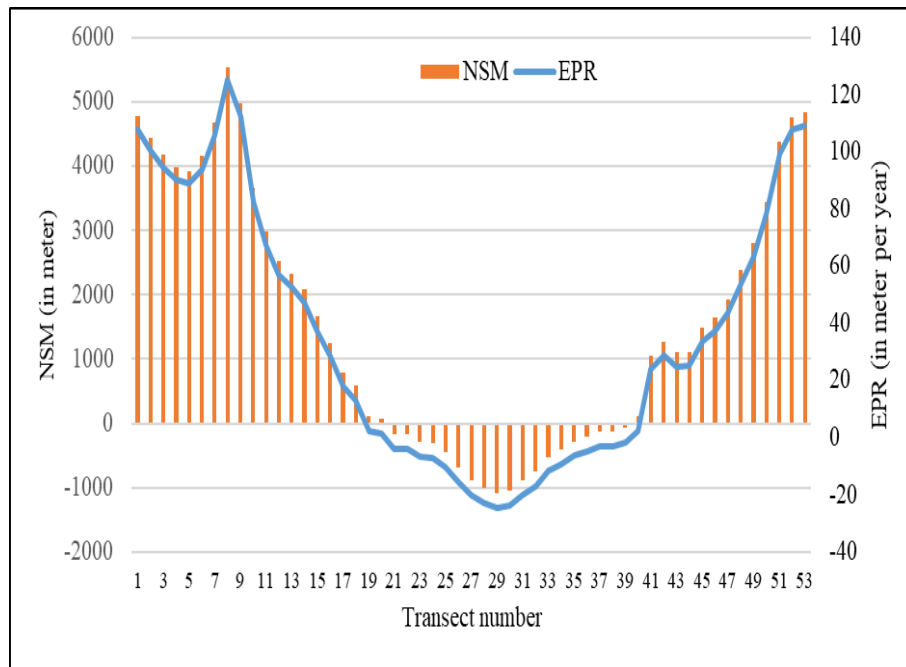


Fig 4: Shoreline Shifting Pattern of Nijhum Dwip Island

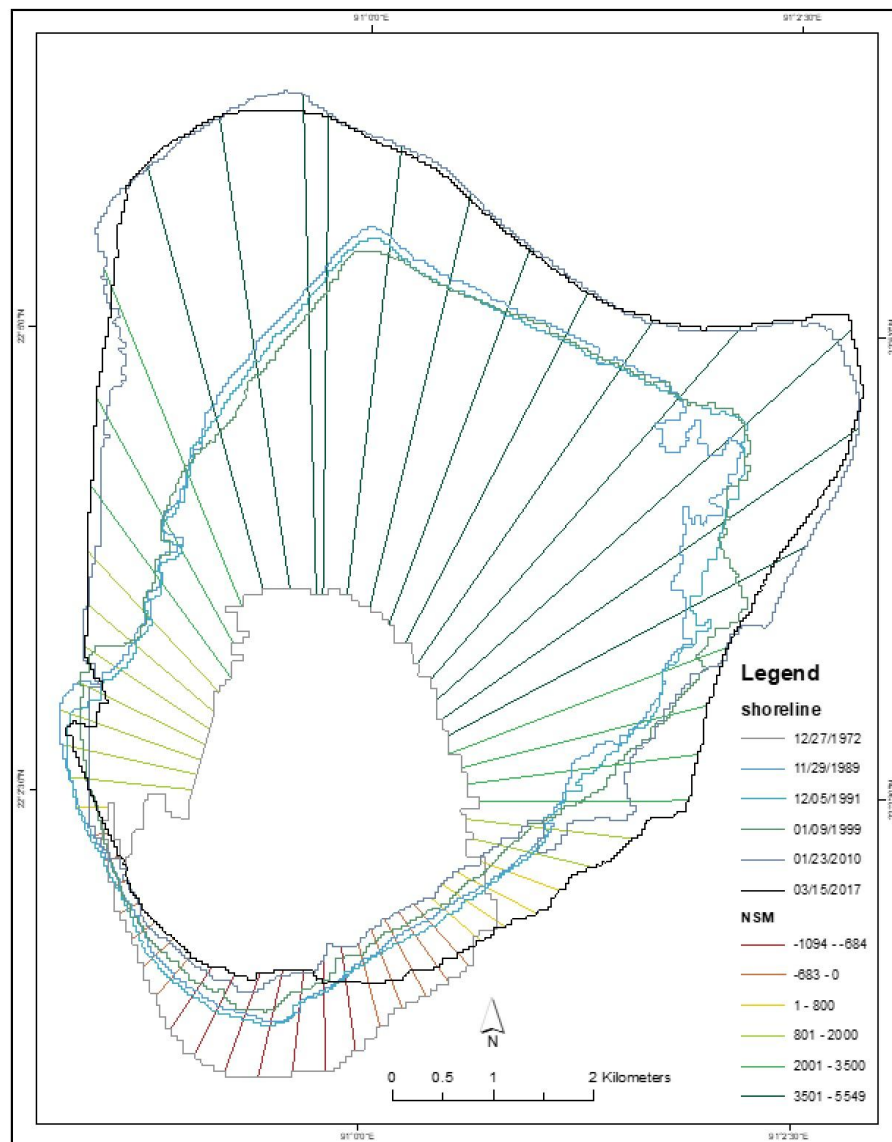


Fig 5: Net Shoreline Movement of Nijhum Dwip Island

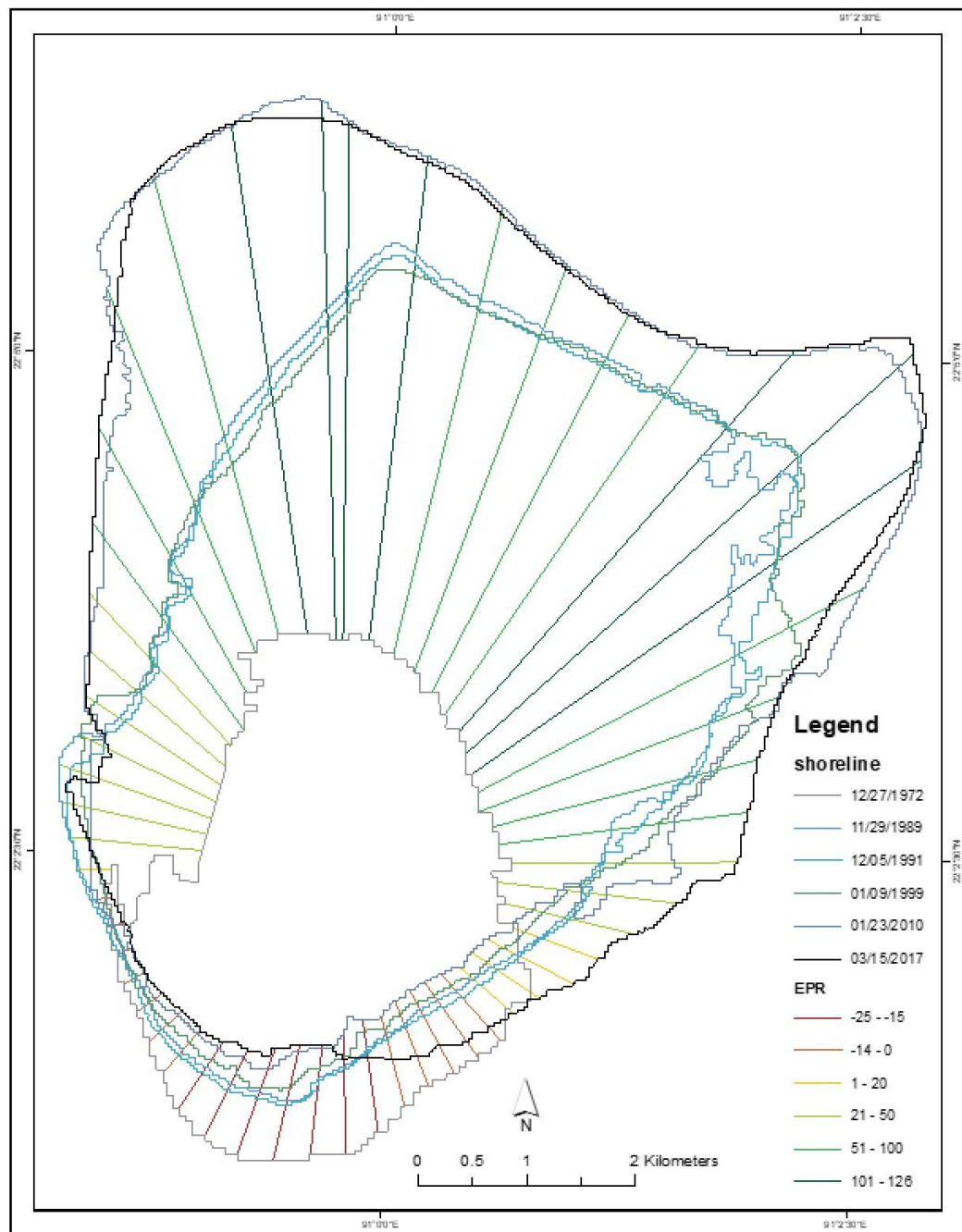


Fig 6: End Point Rate of Nijhum Dwip Island

4. Conclusion

Both erosion and accretion have taken part in every year, and the consistently unchanged land suggests that the island has experienced overall land growth. The seaward movement and rate of the shifting of shoreline shows stronger movement in the northeastern, northern, and northwestern regions. On the other hand, landward movement and rate of the shifting of shoreline is higher in the south and southeastern part of the island. This dynamic nature is largely due to its position at the mouth of the Meghna River estuary. From the analysis of the last 45 years, it is found that the accretion rate is 0.93 square kilometers (93 hectares) every year. Whereas erosion rate is found to be 0.14 square kilometers (14 hectares) each year. As accretion rate is higher than erosion the island is gaining land area of about 0.78 square kilometers (78 hectares) every year. Most accretion was taken in places between 1972 and 1989. The Meghna River delivers vast amounts of

sediment from the Ganges-Brahmaputra-Meghna (GBM) river system, which are deposited in this region. The erosion process is more active at the open sea. This was because of the tidal water pressure, loose bank materials and shoreline configuration. The accretion is more active in the estuarine area where slope is gentle due to deposition of the sediment carried by the Meghna River. Systematic monitoring is mandatory for change detection investigation in coastal morphology for implementing a long-term development plan like Bangladesh Delta Plan 2100.

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