DYNAMIC MORPHOLOGICAL CHANGE ANALYSIS OF SANDWIP ISLAND AT MEGHNA ESTUARY USING REMOTE SENSING AND GIS TECHNIQUES

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ABSTRACT

The Meghna estuary is the largest estuary along the Bangladesh coast where major rivers of the country discharges into Bay of Bengal. Sandwip is a major island in the Meghna estuary. Cyclone, storm surge, salinity, erosion-accretion are some common occurrences in coastal region of Bangladesh. These makes the island very much vulnerable. In this study, amount of erosion-accretion, rate of shoreline change of Sandwip Island is determined during the period of 2000-2020 with an interval of 5 years. The study has been done using ArcGIS 10.5 and DSAS 5.0 (an extension of ArcGIS) with the satellite images. This study aims to study the physical conditions of the study islands, historical erosion and accretion and to estimate the rate of shoreline changes. The study reveals that the island is largely vulnerable to cyclone, storm surge, tidal flooding, erosion, salinity and wave actions. From the analysis of historical satellite images, it is found that Sandwip is accretion-dominated islands for last 20 years. It has been extended nearly 2.01% than the year 2000. The average deposition rate ranges from 18.8 m/year to 30 m/year across 51.5% peripheral length, with the maximum rate of 146.7 m/year in northern direction. On the other hand, the erosion rate ranges from 11.4 m/year to 31.4 m/year across 49.5% peripheral length, with the maximum erosion rate of 47.8 m/year in western direction. From the results, it prevails that the Sandwip Island has been moved towards north-east direction.

Keywords: *ArcGIS, DSAS, Estuary, Satellite Images, Shorelines*

1. INTRODUCTION

The coastal zone is defined as the transitional region where the land and water meet. The coastal zone includes a range of land types such as beaches, wetlands, rivers and estuaries, islands, transitional and intertidal areas (Cicin-Sain & Knecht, 1998). Bangladesh's coastal zone comprises 47,201 km^2, which is almost 32% of the country, and is comprised of 19 districts. The coastal zone is home to around 35 million people which is about 29% of the population. Jessore, Narail, Gopalganj, Shariatpur, Chandpur, Satkhira, Khulna, Bagerhat, Pirozpur, Jhalakati, Barguna, Barisal, Patuakhali, Bhola, Lakshmipur, Noakhali, Feni, Chittagong, and Cox's Bazar are among the 19 coastal districts of Bangladesh (MoWR, 2005). The Meghna estuary is the largest estuary along the coast of Bangladesh. The Meghna Estuary comprises the dynamic confluence of the Ganges, Brahmaputra, and Meghna rivers. The combined discharge of the Ganges-Brahmaputra-Meghna (GBM) river system passes through the Lower Meghna River, finally discharging into the Bay of Bengal. The Lower Meghna has the highest sediment load (Coleman, 1969) and the third highest water discharge in the world after the Amazon and the Congo (Milliman, 1991). Due to the massive amount of water and sediment provided by the rivers, the estuary is a tremendously active area of land erosion and accretion, as well as dynamic water circulation. The combination of rising sea levels, high tides, storms, and flooding leaves coastal and island communities in an increasingly vulnerable position as the climate changes. Therefore, study of erosion-accretion and rate of shoreline change is very much significant for populated country like Bangladesh where land is limited.

Remote sensing technology, such as satellite images and aerial photography, can gather high-resolution spatial data across time, allowing for extensive investigation of landform changes. Furthermore, Geographic Information System (GIS) tools are used to analyze, organize, and show the obtained data, allowing for an in-depth understanding of the changing morphology of an island (Balopoulos et al., 1986; Mumby et al., 1999; Ryuet al., 2002; Stauble, 2002; Zuzek et al., 2003; Yamano et al., 2006). Numerous research have demonstrated the effectiveness of remote sensing data in understanding shoreline dynamics (Ahmad & Neil, 1994; Anbarasu et al., 1999; Murali et al., 2009; Boutiba & Bouakline, 2011). Emch and Peterson (2006) made a study on mangrove forest cover change which is on the southwestern side of Bangladesh using remote sensing technique. They used multi-temporal satellite images (Landsat Thematic Mapper satellite imagery) and normalized differential vegetation index (NDVI), maximum likelihood classification, and subpixel classification for change detection during the year 1989 to 2000. Mullick et al. (2020) assessed the positional change of the Ganges deltaic shoreline from 1977 to 2017 using GIS and multi temporal Landsat imagery. They used the normalized difference water index (NDWI) to distinguish between water and land features. Using multi-temporal satellite images and GIS, Salauddin et al. (2018) tried to figure out how the shoreline and a newly formed island at the mouth of the Meghna river estuary in Bangladesh had changed over time. The study used NDWI and MNDWI to find the shoreline by separating the land from the water. Sarwar and Woodroffe (2013) attempted an analysis on the rates of shoreline change along the coast of Bangladesh. They applied a Band ratio technique to differentiate the water and land and found erosion rates of up to 120 m/yr along much of the shoreline in Bhola during 1989 to 2009. Ghosh et al. (2015) used remote sensing and GIS techniques to measure the coastal changes on Hatiya Island, Bangladesh, from 1989 to 2010. They used Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) and MNDWI algorithm to digitize and differentiate land and water in their work. They found erosion of 6476 hectares and accretion of 9916 hectares. Akhand et al. (2014) studied land-use changes on Bangladesh's Manpura Island. Land-use changes are frequently caused by erosion and accretion. They found accretion of 1270 hectares of land during 1973 to 2010. Taguchi et al. (2013) investigated the seasonal and annual changes in the shoreline surrounding Urir-Char Island using PALSAR satellite. They found that the island's total land area expands more during the monsoon season, with an annual rate of expansion of roughly 3.43 km2 from 2007 to 2011. Emran et al. (2019) investigated Sandwip Island using Remote Sensing (RS) and Geographic Information Systems (GIS) data over the last 30 years. The annual net loss of coastline area is around 0.8 km^2. They showed that erosion processes were active along the western and south-western coastlines of the island, and that this erosion is aided by the steep slope of the bank, strong tidal water pressure, and loose bank materials. Gazi et al. (2022) applied geospatial techniques with Digital Shoreline Analysis System (DSAS) to determine the rate of shoreline changes in Bhasan Char. They found the island has gained 68 km^2 during 2003 to 2020. A thorough literature review on the Meghna estuary reveals that some studies has been done on the islands of Meghna estuary. Some shoreline extraction techniques has been used such as NDVI, NDWI, MNDWI and TCT (Tasseled Cap Transformation) in that area. The upstream river is transporting huge sediment load and discharges in into Bay of Bengal through Meghna Estuary. Chen et al. (2019) suggested that when the total suspended sediment content is high, the wetness component of the Tasseled Cap Transformation is more effective to separate land and ocean than the other remote sensing methods for shoreline extraction. Hence, the primary objective of this research is to investigate the amount of erosion and accretion, as well as assess the rate of shoreline change and net change experienced by a major coastal island at Meghna Estuary, Sandwip, throughout a 20-year timescale (2000-2020). This investigation will utilize Remote Sensing such as Tasseled Cap Transformation (TCT) wetness index and color infrared image for shoreline extraction and then geographic information systems (GIS), along with automated calculation with the digital shoreline analysis system (DSAS).

2. STUDY AREA

Sandwip is a small island off Bangladesh's southeast coast, in the Chittagong District. It is located on the Bay of Bengal, at the mouth of the Meghna River, and is separated from the Chittagong coast by the Sandwip Channel. It is located near the main port city of Chittagong on the north-east coast of the Bay of Bengal. The study area is located at 22°29′N 91°29′E (Figure 1). Sandwip Island covers a total area of 762.42 square kilometres (294.37 square miles), with 317.74 square kilometres of land, 10.13 square kilometres of reserve forest, and 434.55 square kilometres of riverine area. The whole length is 50 kilometres (31 miles), while the width is 5 to 15 kilometres (3.1-9.3 mile). Sandwip has a population of roughly 450,000 people (Bangladesh Bureau of Statistics, 2011).

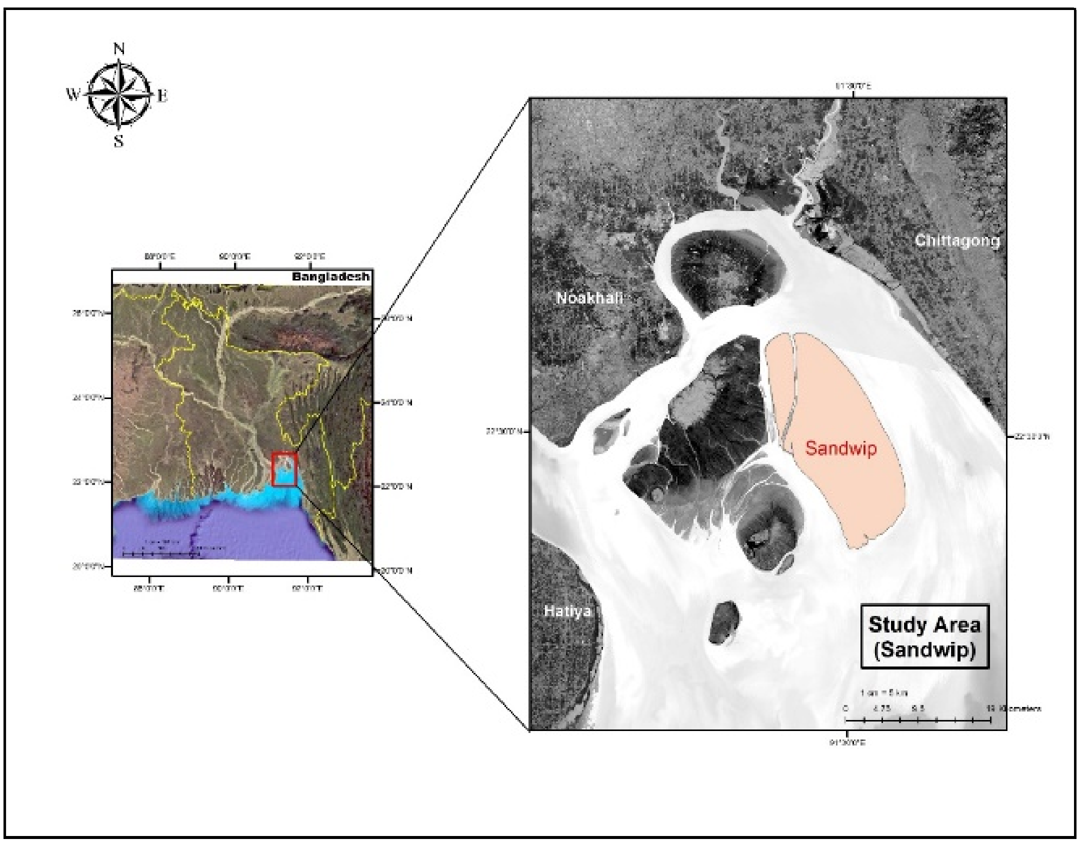

Figure 1: Study Area

3. MATERIALS AND METHODS

3.1 Study Approach

The Approach of the study is shown in the Figure 2

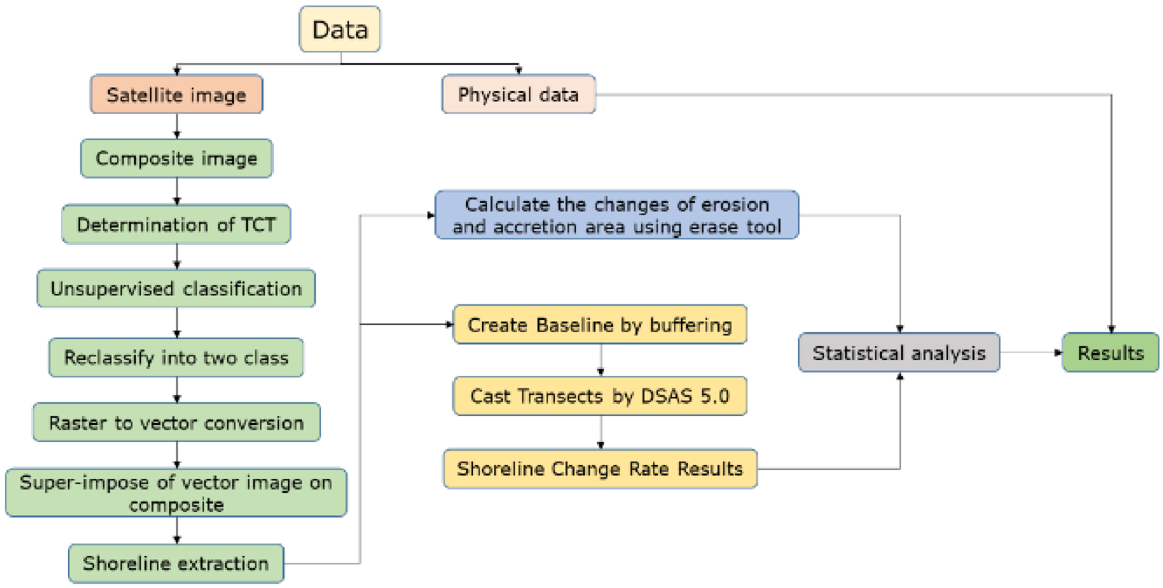

Figure 2: Study Approach

3.2 Data Source

Landsat 4-5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) is used in this study. These satellite image is collected from USGS website (USGS). Both of the images have 30m resolution. Landsat 7 ETM+ images have the problem of Scan Line Corrector Failure (SLC-off), resulting in black gaps. So, Landsat 4-5 TM imagery is chosen over Landsat ETM+ image. ETM+'s band resolution is same as in the TM, 30 meters (USGS). Digitizing shoreline is hard and will be inaccurate if there is cloud present in the study area. Therefore, to obtain a cloud-free image, all the photos were taken between November and February. Tide level has an impact on shoreline. It is one of the factor that cause shoreline changes regularly. Changes of shorelines means changes of area. Shoreline at the time of high tide has been considered in this study. Satellite images at the time of high tide is found by analyzing acquisition time of the image and tide chart. Seven bands such as Band 1, Band 2, Band 3, Band 4, Band 5, Band 6, and Band 7 is used in this study. So, considering all factors, 5 satellite images from 2000-2020 with 5-year interval (2000, 2005, 2010, 2015, and 2020) has been used in this study (Table 1).

Table 1: Landsat Data for Study Area

Satellite (Landsat)	Path-Row	Acquisition Date	Tide	Resolution
5	136-45	1999-11-25	High Tide	30 meter
5	136-45	2004-12-24	High Tide	
5	136-45	2010-01-15	High Tide	
8	136-45	2014-12-20	High Tide	
8	136-45	2020-02-04	High Tide	

3.3 Extraction of Shorelines

The study is about analysis of erosion accretion and rate of shoreline changes of Sandwip, a major coastal islands at Meghna estuary. Therefore, the first stage is to identify shoreline. There are some traditional methods to identify the shoreline but using those methods is hard when there is much sedimentation and tidal impact. So, in this study, Tasseled Cap Transformation Wetness index and color infrared composite image is jointly used to identify and extract shoreline (Figure 3, Figure 4). Extracted shoreline is overlaid in Google earth high resolution image and found Tasseled Cap Transformation Wetness index provides satisfactory result for extraction of shoreline for Sandwip Island at Meghna Estuary (Figure 5).

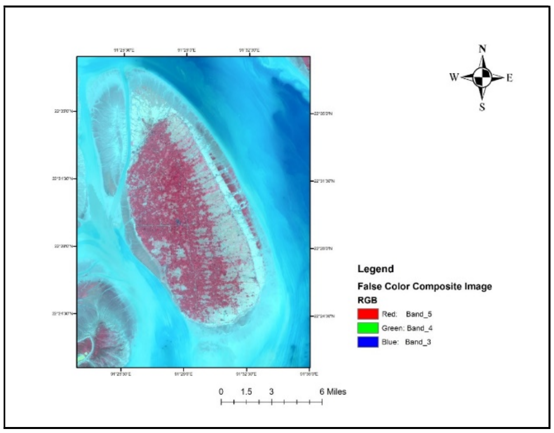

Figure 3: Color infrared composite images

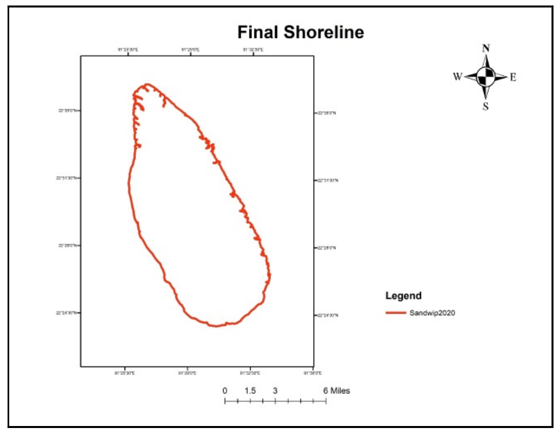

Figure 4: Shoreline of Sandwip (Year 2020)

Figure 5: Shoreline Overlay in Google Earth High Resolution Image

3.4 Erosion-accretion

ArcMap 10.5 is used to calculate the amount of erosion and accretion. Erase tool from 'Overlay' under 'Analysis tool' is used to separate the eroded and accreted area from total area for each temporal interval (2000 to 2005, 2005 to 2010, 2010 to 2015, 2015 to 2020 and 2000 to 2020). To separate the accreted area, Latest year is given as 'input feature' and previous year as 'erase feature' and to separate the eroded area, previous year is given as 'input feature' and latest year as 'erase feature'. Then using Calculate Geometry option, the amount of erosion and accretion is found.

3.5 Rate of shoreline change

The Digital Shoreline Analysis System (DSAS) version 5.0 is used to calculate the rate of change. DSAS is an extension of ArcGIS desktop that allows users to compute rate-of-change information from multiple historical shoreline positions (Himmelstoss et al., 2018). In this study, for Sandwip, shoreline of 2000, 2005, 2010, 2015, 2020 and a baseline is given as input in DSAS tool. Baseline is taken as a buffer 2000m of shoreline of year 2000 and 33 transact is created each having a 1200m spacing. For each transect, the Net Shoreline Movement (NSM) measures the distance between the oldest and newest shorelines. The end point rate (EPR) is computed by dividing the distance of shoreline movement by the time interval between the earliest and latest shorelines. From the analysis in DSAS, Net Shoreline Movement (NSM) and End Point Rate (EPR) is found.

NSM = distances (m) between oldest and youngest shorelines

$$\text{EPR} = \frac{\text{NSM}}{\text{time between oldest and most recent shorelines}}$$

4. RESULTS AND DISCUSSIONS

Following the shoreline extraction method as described, the shorelines of Sandwip island for the years 2000, 2005, 2010, 2015 and 2020 have been extracted and the amount of eroded and accreted area for the duration of 2000-2005, 2005-2010, 2010-2015, 2015-2020 and 2000-2020 have been calculated. Accreted area is shown with green color and eroded area shown with red color (Figure 6, Figure 7).

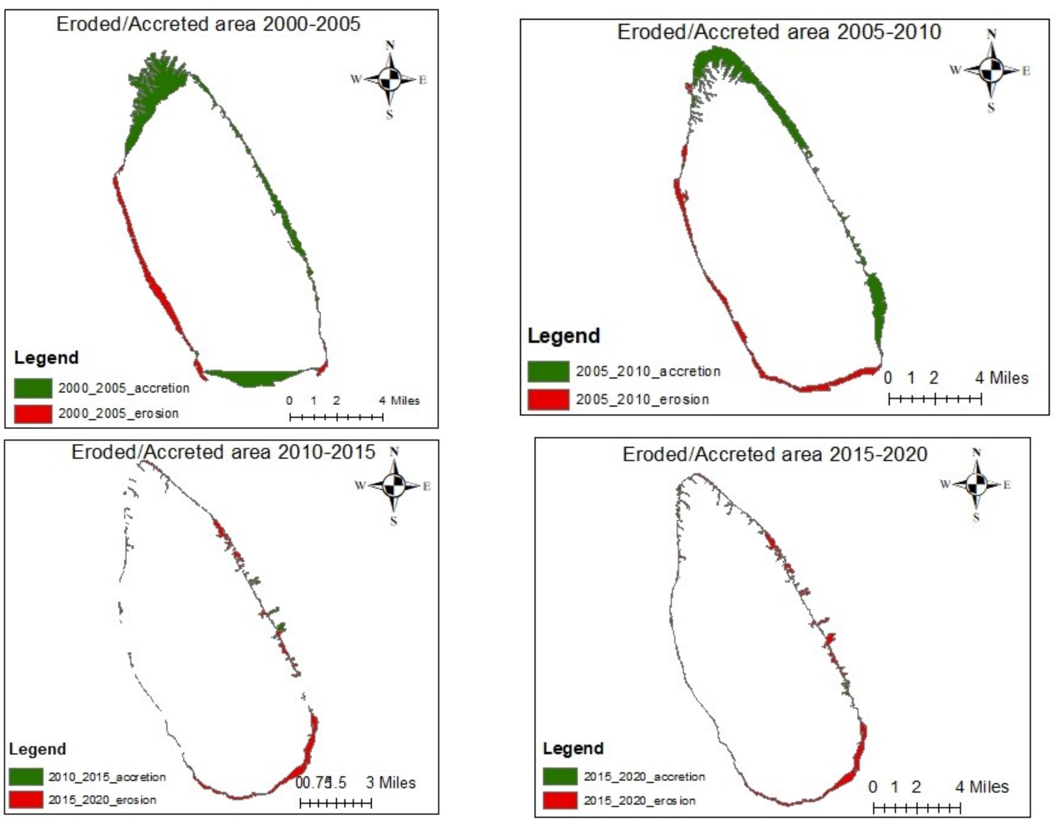

Figure 6: Erosion-accretion area at Sandwip Island during the period 2000 to 2020

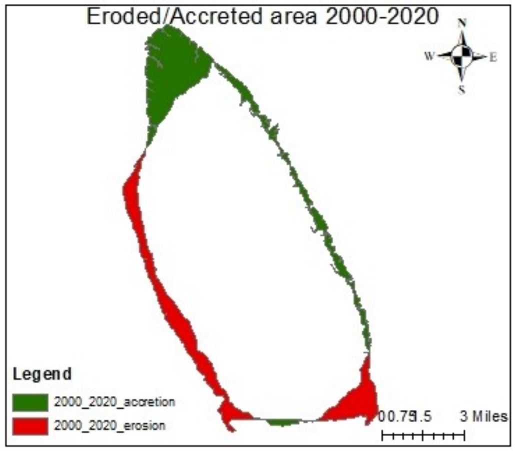

Figure 7: Net erosion-accretion area at Sandwip Island during the period 2000 to 2020

The amount of eroded and accreted area for the above-mentioned period has been presented in Table 2. There is an inconsistent pattern of erosion and accretion along the coastline of Sandwip Island. It is observed that accretion process is dominant during the period of 2000 to 2005 (14.96 km^2) and during the period 2005-2010 (8.01 km^2). A significant accretion has been placed during the period of 2000-2010 at the northern tip of the island. On the other hand, erosion process is dominant during the period of 2010-2015 (13.71 km^2) and during the period 2015-2020 (5.59 km^2). However, the morphological changes along the periphery of the Sandwip Island for the period of 2000-2020 have been found as 16.55 km2 erosion, 20.23 km^2 accretion resulting net change of accreted area as 3.68 km^2. During the period of 20 years (2000-2020), significant accretion has been taken place at the northern tip of the island and also accretion has been taken place along the eastern belt of the island. On the other hand, significant erosion has taken place at the southern tip of the island and also erosion has been taken place along the western belt of the island for the same period. With respect to the area of the island in the year 2000, which is 183 km^2, 9.04% area has been eroded, 11.05% area has been accreted and the net change of the island is 2.01% accretion during the period of 20 years (2000-2020).

Table 2: Erosion and accretion of Sandwip Island during the period of 2000-2020

Period	Area (km^2)		
	Erosion (km^2)	Accretion (km^2)	Net Change (km^2)
2000-2005	-5.31	+20.27	+14.96
2005-2010	-6.93	+14.94	+8.01
2010-2015	-14.41	+0.70	-13.71
2015-2020	-6.61	+1.03	-5.59
2000-2020	-16.55	+20.23	+3.68
Rate of change (Per year)	-0.82	+1.01	+0.19
% of change of land area as compared to the area in the year 2000	-9.04 %	+11.05 %	+2.01 %

The rate of shoreline change is computed using the DSAS software with net shoreline movement (NSM) and end point rate (EPR). Transects along the accreted and eroded area have been shown with green and red colors respectively (Figure 8). The north, west, south and east boundary of the Sandwip island covers transects number 28-1 (16.8 km), 1-10 (12.4 km), 10-16 (17.3 km) and 16-28 (21.5 km) respectively (Table 3). Out of these four portions, East and South part is erosion dominant and west and north part is accretion dominant. Total peripheral length of Sandwip Island in the year 2000 was 68 km. During the period of 20 years (2000-2020), erosion has been occurred along 33 km reach and accretion has been occurred along 35 km reach, which are 48.5% and 51.5% respectively with respect to the peripheral length of the island in the year 2000. During last 20 years (2000-2020), accretion has been taken place along the North part with an average rate of 30 m/year and maximum rate of 146.7 m/year. Less accretion has been taken place along East part with an average rate of 18.8 m/year. West part experienced the highest erosion with an average rate of 31.4 m/year and maximum rate of 47.8 m/year. But South part have less erosion than East part with 11.4 m/year rate (Table 3). During last 20 years, Eastern part of the island has been accreted with a width of 379 m and Western part has been eroded with a width of 644 m. Northern part of the island accreted with a width of 605 m and Southern part of the island eroded with a width of 230 m. From the results, it prevails that the Sandwip Island has been moved towards northeast direction.

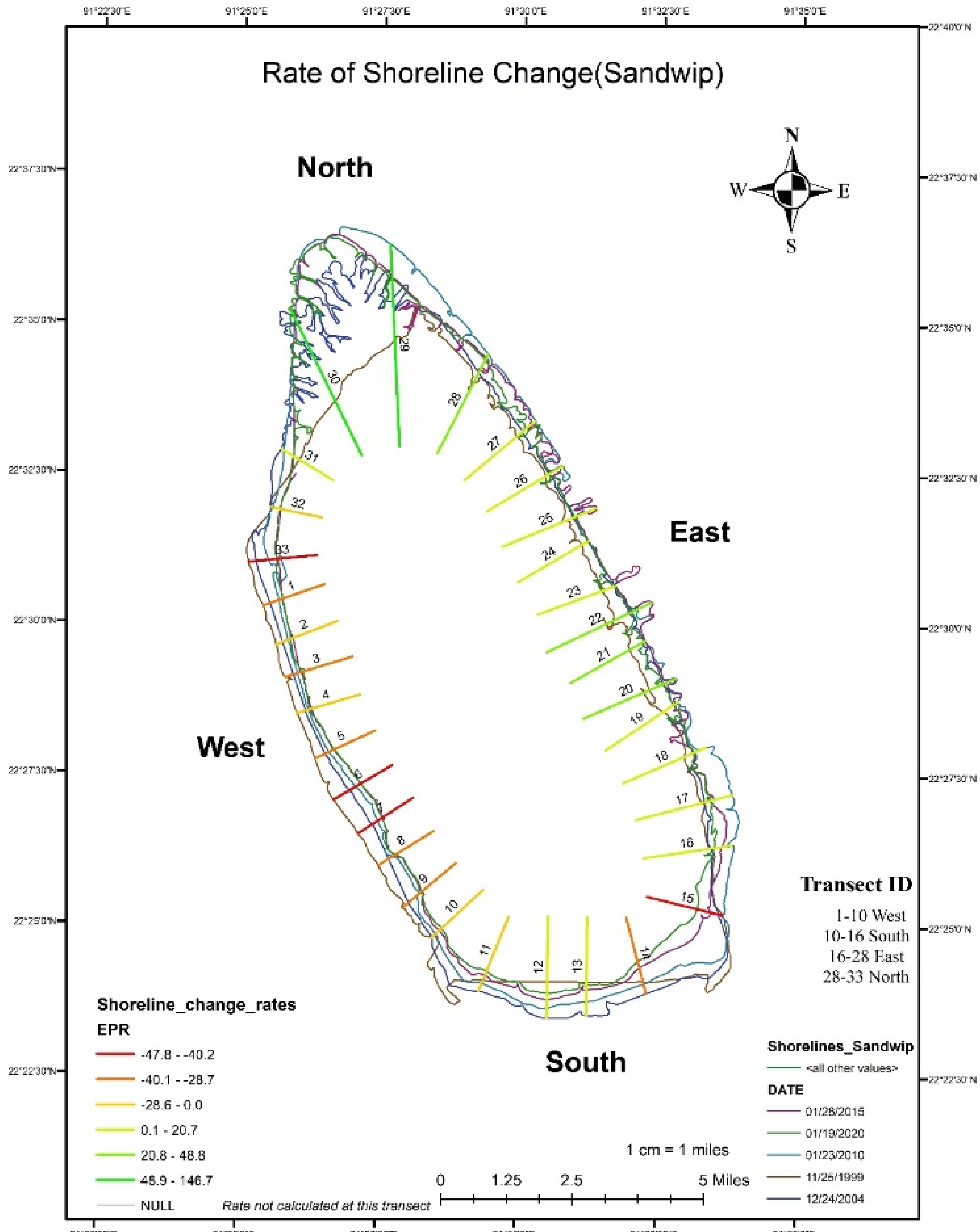

Figure 8: Shoreline change rate determination for Sandwip Island using DSAS

Table 3: Shoreline change rate of Sandwip Island

Zone	Length km	Transect ID (Figure 13)	NSM m	NSM average m	EPR m/year	EPR average m/year	Evaluation
West	12.4	1	-621.8	**-644**	-30.86	**-31.4**	Erosion
		2	-476.81		-23.66		
		3	-579.01		-28.73		
		4	-414.61		-20.57		
		5	-657.82		-32.64		
		6	**-962.74**		**-47.78**		
		7	-893.53		-44.34		
		8	-627.43		-31.14		
		9	-751.65		-37.3		
		10	-355.01		-17.62		
South	17.3	10	-355.01	-230	-17.62	-11.4	Erosion
		11	-311.53		-15.46		
		12	346.58		17.2		
		13	66.3		3.29		
		14	-645.1		-32.01		
		15	-809.71		-40.18		
		16	98.79		4.9		
East	21.5	16	98.79	379	4.9	18.8	Accretion
		17	202.8		10.06		
		18	338.66		16.81		
		19	393.11		19.51		
		20	481.98		23.92		
		21	502.71		24.95		
		22	619.26		30.73		
		23	416.28		20.66		
		24	221.1		10.97		
		25	292.11		14.5		
		26	147.26		7.31		
		27	230.74		11.45		
		28	983.93		48.83		
North	16.8	28	983.93	**605**	48.83	**30**	Accretion
		29	1841.17		91.37		
		30	**2956.57**		**146.72**		
		31	193.92		9.62		
		32	-260.03		-12.9		
		33	-857.72		-42.56		
		1	-621.8		-30.86		

NSM= Net Shoreline Movement, EPR= End Point Rate, '+'= Accretion, '-'= Erosion
Maximum value is **bold** for NSM and EPR for each zone

5. CONCLUSIONS

ArcGIS 10.5 has been used to determine the eroded-accreted area and DSAS 5.0 has been used to calculated rate of shoreline change. The study has been conducted at a major island in the Meghna estuary which is Sandwip Island. An analysis of erosion-accretion and rates of shoreline change over the past 20 years has revealed that the island is morphologically active. The island's area has increased approximately 2.01% in 2020 compared to 2000 and accretion has occurred along 51.5% of the island's peripheral length. The detailed reason behind this erosion-accretion is not conducted in this study. But the estuary is very dynamic. Sediment load, fresh water flow from upstream, wave, tide and storm surge are the main driving force for that dynamic change.

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