Shoreline shifting and its prediction using remote sensing and GIS techniques: a case study of Sagar Island, West Bengal (India)

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Abstract The shoreline position is difficult to predict but the trend of erosion or accretion can be determined by geospatial and statistical techniques which may help in reducing the loss of property. The study aims to assess the shoreline changes and prediction in Sagar Island, a delta of the Ganges, situated in West Bengal, India. Shorelines have been delineated by using Tasseled Cap Transformation techniques from the Landsat MSS (1975), Landsat TM (1989, 1991) and Landsat ETM+ (1999, 2002, 2005, 2008, and 2011) images. The uncertainty was calculated for every year for assessing the positional error related to shoreline extraction. Total shoreline change rate/year has also been calculated and the uncertainty of total shoreline change rate was found ±3.20 m/year. In the present study, End Point Rate (EPR) and Linear Regression (LR) methods have been used for shoreline change rate calculation and prediction of shoreline. Long term (1975–2002) and short term (2002–2011) erosion and accretion rates were calculated for the study area. Sagar is the biggest island of the Sundarban region; so, it was divided into three segments in order to analyze the change on a segment basis. It was observed that the most of erosion occurred in the Segment B (south Sagar). The rate of erosion was −7.91 and −7.01 m/year for the periods 1975–2002 and 2002–2011 respectively. The mean shoreline change rate was high in Segment B (South Sagar) with values of −6.46 m/year (1975–2002) but the rate was decreased into −5.25 m/year during the later period (2002–2011). The study reveals that most of the southern part of Sagar Island is vulnerable to high rate of shoreline erosion.

Keywords Shoreline change rate · Shoreline prediction · Tasseled cap · End point rate · Linear regression model · Sagar Island · India

Introduction

Shoreline change is perceived as a major problem mainly in the delta region all over the world. Shoreline or coastline generally defined as the line of contact between land and water body which is a dynamic in nature (Pajak and Leatherman 2002; Cui and Li 2011). The landform dynamics of coastal areas has been a major concern to the researchers (Van Zuidam et al. 1998; Mills et al. 2005; Marfai et al. 2008; Ryabchuk et al. 2012; Mujabar and Chandrasekar 2013). The dynamic nature of shoreline makes it difficult to delineate how much area is accredited or eroded by the time (Fenster et al. 2001). There are several factors which trigger the transformation of shoreline for example, sea level rise, storm surge, wind, wave tide etc., (Orford et al. 2002; Cooper et al. 2004; Forbes et al. 2004). According to Scott (2005), it undergoes short term and long term frequent changes causes by hydrodynamic changes (e.g., river cycles, sea level rise), geomorphological changes (e.g., barrier island formation, split development) and other factors (e.g., sudden and rapid seismic and storm events). Natural processes and human activities are also

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responsible for coastline changes (Sesli et al. 2008). Coastal regions are affected by various natural forces like wave, currents, wind, tide etc. and anthropogenic forces like human activity that cause shoreline change frequently. The backward movements of land due to these forces are called erosion and the forward movements of land are called accretion. According to Srivastava et al. (2005), loss of coastal land properties, structures and submergence of the beaches near the shorelines are directly related to these coastal erosion processes. Most of the coastal regions in Sundarban especially the delta regions are affected by erosion (Nandi 2013). Continuous erosion along the shoreline is responsible for losses of economic and natural resources which affects the livelihood of the local community.

In order to increase the possibility of overcoming the effect of the erosion process, attempts must be made to predict the future position of shoreline. Detailed and accurate information of past and present shoreline position are required for future prediction of shorelines. Shoreline prediction models can be executed in GIS environment. Several models have been evaluated for shoreline prediction with the help of historical data such as End Point Rate (EPR) model (Fenster et al. 1993), Average of Rates (AOR), Linear Regression (LR) and Jackknife model (JK) (Dolan et al. 1991) etc. End Point Rate model mainly predicts the future shoreline position by using the historical rate of change data whereas the Linear Regression model is mainly based on robust linear prediction method for predicting the short term changes by using long term shoreline data. Several studies were carried out by EPR, LR models for shoreline prediction and modeling (Fenster et al. 1993; Li et al. 2001; Srivastava et al. 2005; Maiti and Bhattacharya 2009; Santra et al. 2011; Chenthamil Selvan et al. 2014). Future prediction of shoreline by using these two techniques depend on some important factors like accuracy of shoreline detection, time duration of shoreline data acquisition etc. and a number of data point is taken into consideration during the measurement of shoreline position. Coastal management planners and policy makers usually use these two techniques to predict future shoreline changes. Several studies on quantitative assessment of shoreline change have been carried out by researchers in the past couple of decades (Chen et al. 1995; Paul 2002; Newsham et al. 2002; Hazra 2003; Burgess et al. 2004; Maiti and Bhattacharya 2009; Kuleli 2010; Chand and Acharya 2010; Addo et al. 2011; Mukhopadhyay et al. 2012; Nandi 2013; Santra Mitra et al. 2013; Mondal 2013; Mahapatra et al. 2015).

Multi-temporal shoreline mapping is considered as a valuable task for coastal monitoring and assessment. Now-a-days, satellite based remote sensing data with geographical information system (GIS) is being used for shoreline extraction mapping and analysis purpose. Recent advancements in remote sensing and GIS techniques have led to improve the coastal geomorphological studies, such as: Semi-automatic

determination of shorelines, identification of relative change among coastal units, extraction of topographic and bathymetric information, future shoreline prediction etc. In our study area (Sagar Island), several multidisciplinary studies using remote sensing and GIS techniques were conducted by various researchers. Ghosh et al. (2001) analyzed the trend of geomorphological changes of Sagar Island in response to natural and anthropogenic activities using satellite derived remote sensing techniques. Jayappa et al. (2006) demarcated various coastal geomorphological landforms regarding shoreline changes and also suggested remedial measures for erosion control in Sagar Island. In their study, Kumar et al. (2001, 2007) analyzed the geomorphological, land use, land cover and coastal vegetation changes using satellite data. The rapid erosion and critical coastal issues of Sagar Island were studied by several researchers using multi-temporal satellite images (Gopinath and Seralathan 2005; Purkait 2009; Gopinath 2010; Chakraborty 2013). The remote sensing, GIS and statistical techniques were also used for shoreline changes along the eastern coast of India (Jana et al. 2013). In another study, Kundu et al. (2014) carried out shoreline mapping of the Sagar Island during the period 1951–2011 using geospatial techniques. The present study focuses the shoreline change and its future prediction from satellite derived multi-temporal Landsat MSS, TM and ETM+ data using GIS. It also aims to estimate the rate of shoreline change in the Sagar Island by the End Point rate (EPR) and Linear regression (LR) models.

Study area

Sagar Island is located in the Indian Sundarban Delta which is a part of the famous delta of the Ganga-Brahmaputra-Meghna (GBM) basin. The Sundarban, shared between India and Bangladesh is one of the largest mangrove forest in the world. The Indian Sundarban is situated between 21° N to 22°30'N and 88° E to 88°29' E and spreads over the south-eastern part of both North 24 Parganas and South 24 Parganas of West Bengal covering an area about 9630 Km^2. Total 102 islands are situated in Indian Sundarban, among them 54 islands are having human habitat and the rest of 48 islands are covered by mangrove forest. Sagar is the largest Island of Indian Sundarban deltaic complex. It is surrounded by the Hooghly river in the North and West, Muriganga River in the East and Bay of Bengal in the South. Hooghly and Muriganga River mainly control the coastal changes of this island. The attitudinal and longitudinal extent of this island varies from 21°37'21"N to 21°52'28" N and 88°10'25"E to 88°12'17"E respectively. The length of the island is 30 Km to the North–south direction and has a maximum width of 12 Km (Fig. 1).

This island has been affected several times by various natural phenomena like cyclone, flood, earthquake, tidal fluctuation etc. The shoreline of the island is dynamic and has
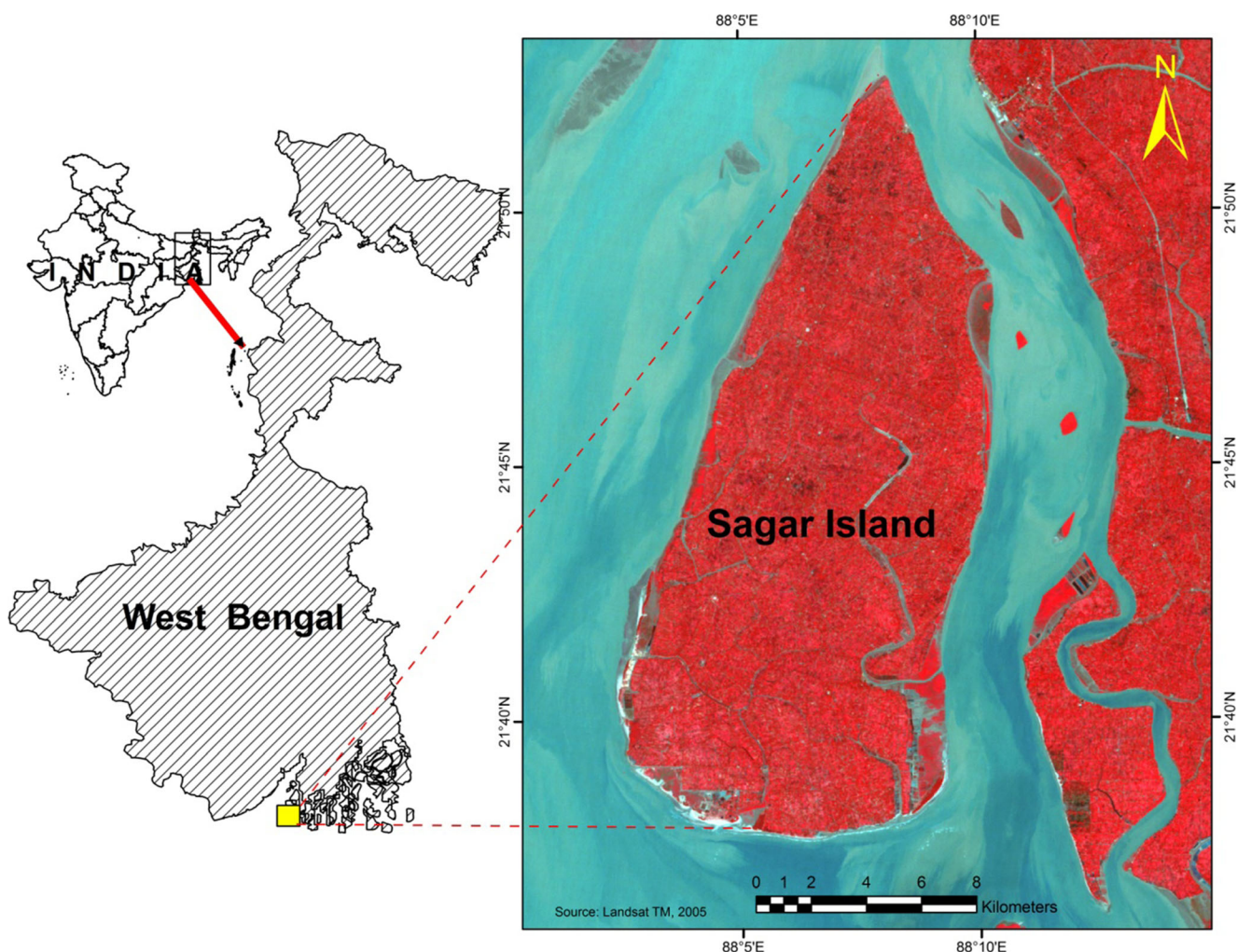
Fig. 1 Location map of the study area

undergone changes due to varying rate of erosion and accretion. High rate of shoreline change has been affecting the human settlement and coastal ecosystem along the coastal areas of the island. The coastline of West Bengal belongs to the Amero trailing edge coast whereas the opposite continental coast is a collision coast. All the important river system of Sunderban maintains a north to south trend. The accretion erosion behaviors of the rivers are primarily controlled by the regional geology of delta formation involving both fluvial and coastal processes. According to various geologists very insignificant delta formation has occurred during the last couple of decades. However, Roy Barman (1992) identified that the rate of sediment supply from the Himalayas and North Eastern Hills was more than the rate of subsidence of the Bengal basin. As a result, the basin of sedimentation filled up rapidly and the Bengal delta started prograding southward. The climate of the Sagar Island is tropical oceanic. Three seasons- winter (November – February), summer

(March – June) and Monsoon (July – October) can be recognized over there. Winter temperature ranges from 10 to 25 °C and summer temperature from 28 to 36 °C. The region receives annual rainfall ranging between 1500 and 2400 mm. The lower deltaic region of Bengal forms the seaward continuation of the Bengal basin which is bounded on three sides: west, north and north-east by the Pre-Cambrian crystalline rocks and on the eastern side by the Tertiary hill ranges of the Assam-Burma arc. Local name of Sunderban soil is 'nonamati'. Ganga alluvium and its salinized part are considered as parent material of Sunderban soils. Sodium chloride (NaCl), silt and clay are present in this soil. Sunderban region is well known for its thick mangrove forest. Mangroves of the intertidal zone are submerge twice daily during high tides through a complex network of tidal creeks. The dominant mangroves species of Sagar Island are – I) *A. alba* II) *A. marina* III) *Bruguieragymnorrhiza* IV) *S. griffthii* V) *Aegicerascorniculatum*etc (Das 2006).

Table 1   Details of satellite dataset

Satellite data	Path/Row	Date of acquisition	Resolution
Landsat MSS	148/45	12.05.1975	60 m
Landsat TM	138/45	11.19.1989	30 m
			15 m
Landsat TM	138/45	10.30.1991	30 m
			15 m
Landsat ETM+	138/45	11.03.1999	30 m
			15 m
Landsat ETM+	138/45	11.12.2002	30 m
			15 m
Landsat ETM+	138/45	11.17.2005	30 m
			15 m
Landsat ETM+	138/45	11.19.2008	30 m
			15 m
Landsat ETM+	138/45	12.02.2011	30 m
			15 m

Materials and methods

Data used

Multi-temporal satellite data of Landsat MSS, TM and ETM+ of different periods have been used in this study. However, the satellite images could not been collected in regular interval due to the unavailability of cloud free imagery during the chosen period. The details of the satellite data are given in the Table 1.

Software used

In this study, we used ERDAS IMAGINE 9.3 software of Leica Geosystems for optical image processing and ArcGIS 10.0 software of Environmental Systems Research Institute, for vector generation, analysis, editing and map composition
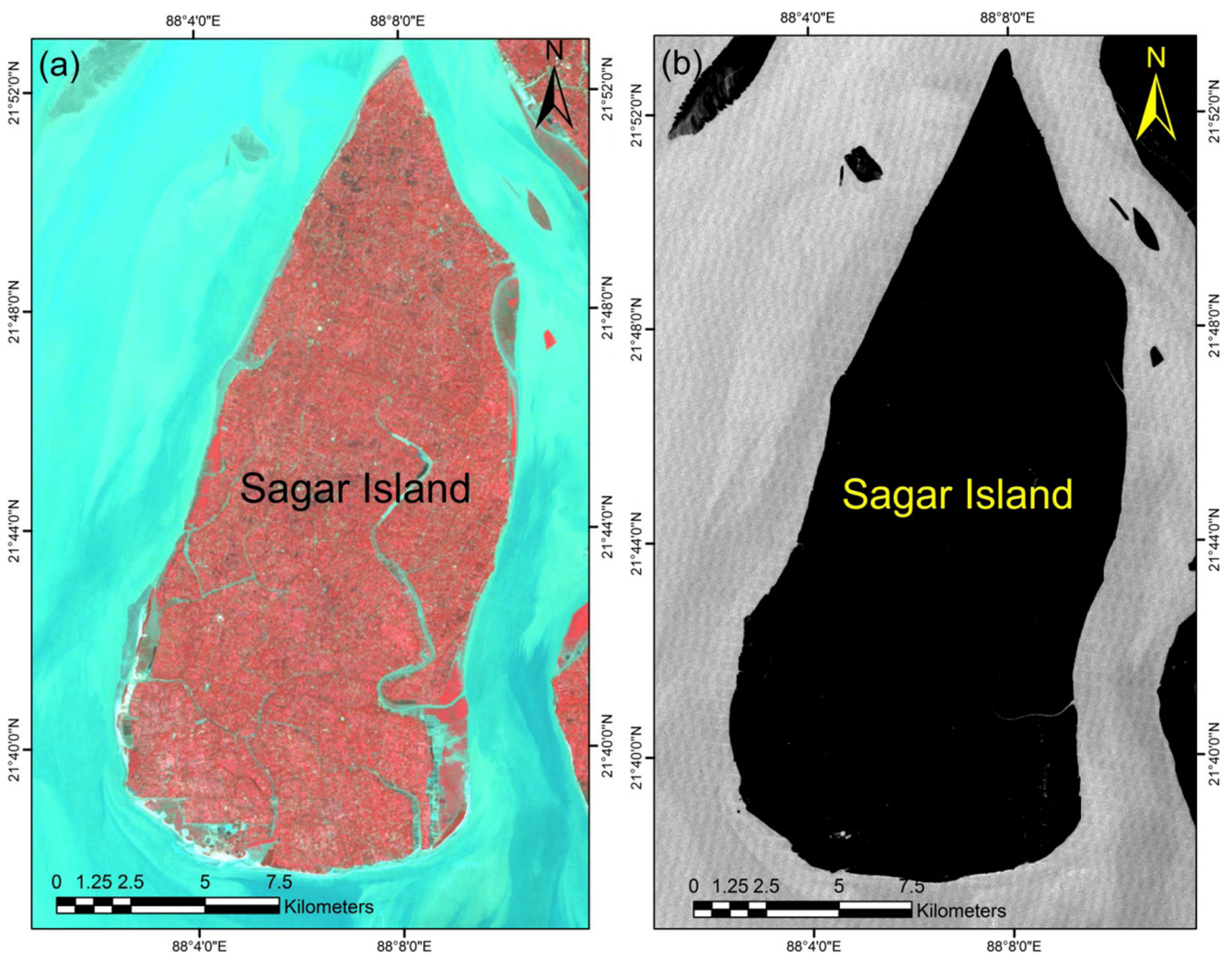

Fig. 2   Shoreline extraction based on tasseled cap transformation techniques: before image processing (**a**) and after image processing (**b**)

purpose. Except these, Digital Shoreline Analysis System (DSAS 4.2) software of United States Geological Survey, has been used for cast transects and shoreline change calculations.

Methodology

Data processing

Multi resolution and multi date satellite data of Landsat series over the study area (Path/Row- 138/45 for Landsat TM and ETM+ and Path/ Row- 148/45 for Landsat MSS) have been taken for shoreline mapping. At first, geometric correction was done for all three images. Then radiometric correction was carried out for each of the bands of satellite images. It includes two steps: first, converting the DN values into radiance values and then converting the radiance values into reflectance values. The Landsat MSS image of 1975 was considered as the base map for the entire study and it was resampled into 30 m to match the spatial resolution of Landsat TM and ETM+ images.

Shoreline extraction

Automatic shoreline delineation is a complex process due to the presence of water saturated zone at the land water boundary (Maiti and Bhattacharya 2009). In this study, Tasseled Cap Transformation technique was applied for shoreline extraction. The coefficients for Tasselled Cap Transformation of Landsat data were derived from the EROS data centre (Huang et al. 2002). The tasselled cap transformation recombines the spectral information of the six ETM+ bands into three principal view components through the coefficients derived by sampling known land cover spectral characteristics. Among the three principal view components, i.e., brightness, greenness, and wetness, the wetness component is used for differentiating the land from water. In this wetness index band, land and water interface is clearly visible and shoreline can be easily demarcated. Then shoreline pixels were extracted and the image was converted into binary image. Finally, the raster binary image was converted into vector image and the shoreline boundary was extracted (Fig. 2).
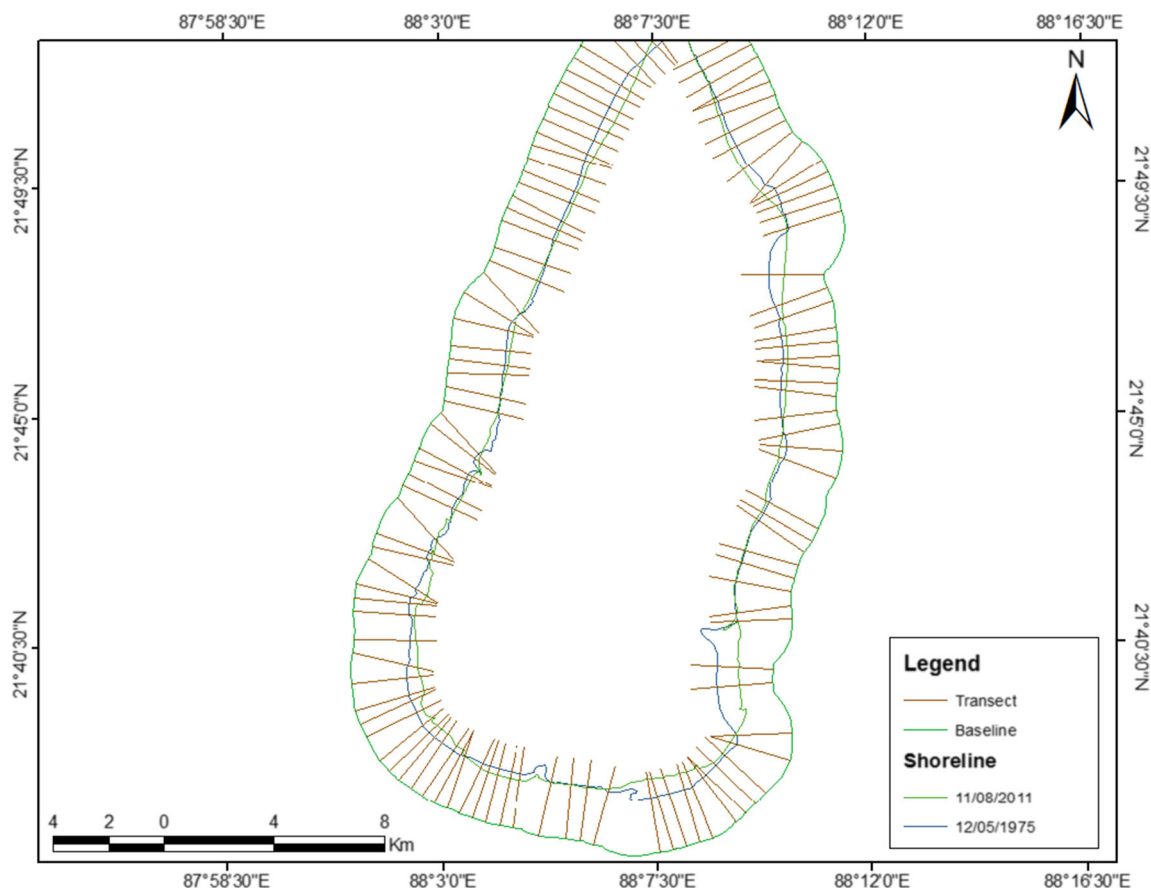

Fig. 3 Cast transects perpendicular to the baseline for Sagar Island

Cast transect from baseline method

The Federal Emergency Management Agency (FEMA) has utilized the transect from baseline approach and has considered it as a standard method for determining long term coastal change rates and coastal hazard zones that are prone to high amounts of erosion (Crowell et al. 1991). This method is mainly based on statistical approach. Before drawing the transect, a single baseline was generated from the shoreline. There are two methods for baseline demarcation: 1) creating baseline from a specific distance of the shoreline. 2) buffer method. The later method is the most reliable and accurate method for baseline demarcation; so, it was adopted for generating the baseline in the study. Some attribute fields i.e., OBJECTID, SHAPE, SHAPE Length, ID, Group, OFFshore and CastDir are necessary to implement the baseline calculation in the DSAS software. These attributes give necessary information to DSAS about the order of the Transect as well as the location of the baseline with respect to the shoreline (onshore or offshore). This all information is interlinked into the calculation process so that the rate-of-change statistics can be properly estimated and erosion is denoted as negative and accretion is denoted as positive. Some attributes are also necessary in the shoreline attribute table for casting transect and implementation of the calculation. These attributes are OBJECTID, SHAPE, SHAPE Length and DATE. After that transect has been cast in perpendicular to the baseline in an interval 500 m for Sagar Island. All transect has been cast orthogonally from the baseline across the shoreline of different years (Fig. 3).

Change rate calculation and future shoreline prediction using EPR and LR method

This is a most common and widely used method for shoreline change calculation and future shoreline prediction. Coastal land planners and managers are specially using this method to predict future shoreline change with the help of constant rate of shoreline change value. This method has become popular mainly due to its simplicity and robustness. No prior knowledge regarding the sediment transport or wave interference is required because the cumulative effect of all the underlined processes is assumed to be captured in the position history (Li et al. 2001).

Shoreline change rate calculation and prediction using EPR model

The future shoreline position is estimated using resulting slope (rate) and y-intercept.

$$\text{Shoreline position} = \text{Slope} * \text{Date interval} + \text{Intercept}$$

The EPR model is mainly calculated using two endpoints, the historical position (P_1) and the latest position (P_2). If we use P to denote future shoreline position, T for date/time interval, B_{EPR} for model intercepts and m_{EPR} for the rate of shoreline change, then this equation can be written as

$$P = m_{EPR}*T + B_{EPR} \tag{1}$$

The rate of shoreline is change for a given set of samples, m_{EPR} has been calculated as

$$m_{EPR} = (P_1 - P_2)/(T_2 - T_1) \tag{2}$$

EPR intercept can be calculated as

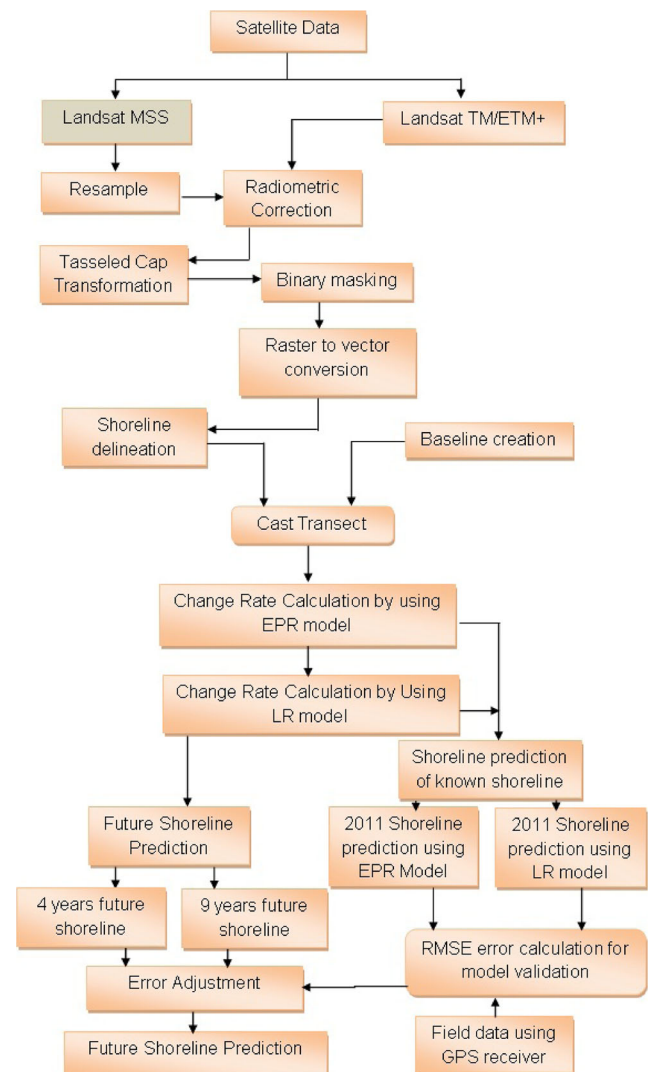$$B_{EPR} = P_1 - (m_{EPR}*T_1) = P_2 - (m_{EPR}*T_2) \tag{3}$$

Fig. 4 Framework of methodology

Since the end point line can extend beyond the most recent point (n) can be rewritten to use that position (P_2) and the elapsed time ($Tn-T_2$)

$$P_n = m_{EPR}*(Tn-T_2) + P_2 \qquad (4)$$

The major advantage of this method is that any type of information related to the shoreline like, sea wave data, sea current data, tidal information, sediment supply etc. are not required for the analysis. It is based on the historical shoreline map and the most recent shoreline map.

Shoreline change rate calculation and prediction using LR model

Linear regression method is a statistically robust quantitative method. It is a popular statistical technique for estimating the shoreline movement and rates of change (Crowell et al. 1997). In this method a rate of change statistics is determined by fitting the least of the regression line to all shoreline points for a particular transect. It shows the relation between year/ time and amount of shoreline shifting in transect. The "residual sum of square", i.e., Regression coefficient (R^2) is calculated for assessing the accuracy of the line fit to the scatter plot and identifying the relationship between these two axes (X, Y). It gives the value ranging from 0 to 1 to measure the accuracy. If all of the values are found exactly matched

with the estimated trend, then R^2 will be equal to 1 otherwise R^2 will be equal to 0.

Model validation

In order to validate the model, a known shoreline was predicted using the previous data. Then, Root Mean Square Error (RMSE) error was calculated between the actual shoreline positions and predicted shoreline positions. For validation purpose, the shoreline position data from the field was also collected by using a GPS receiver. The Root Mean Square Error (RMSE) was calculated for validation, compare and estimating the error of the model output using the following equation.

$$RMSE = \sqrt{\left\{ \left(X_{mod} - X_{org} \right)^2 + \left(Y_{mod} - Y_{org} \right)^2 \right\}} \qquad (5)$$

Where X_{mod} and Y_{mod} are the model generated X and Y coordinates of the shoreline and X_{org} and Y_{org} are the actual X and Y coordinates of shoreline.

Error adjustment

After RMSE calculation the error was adjusted in the models for generating the shoreline and finally the future shoreline

Fig. 5 Shoreline evolution along northern **a**, western **b**, south western **c**, eastern **d**, south-eastern **e** and south **f** parts of Sagar Island for the period 1975–2011
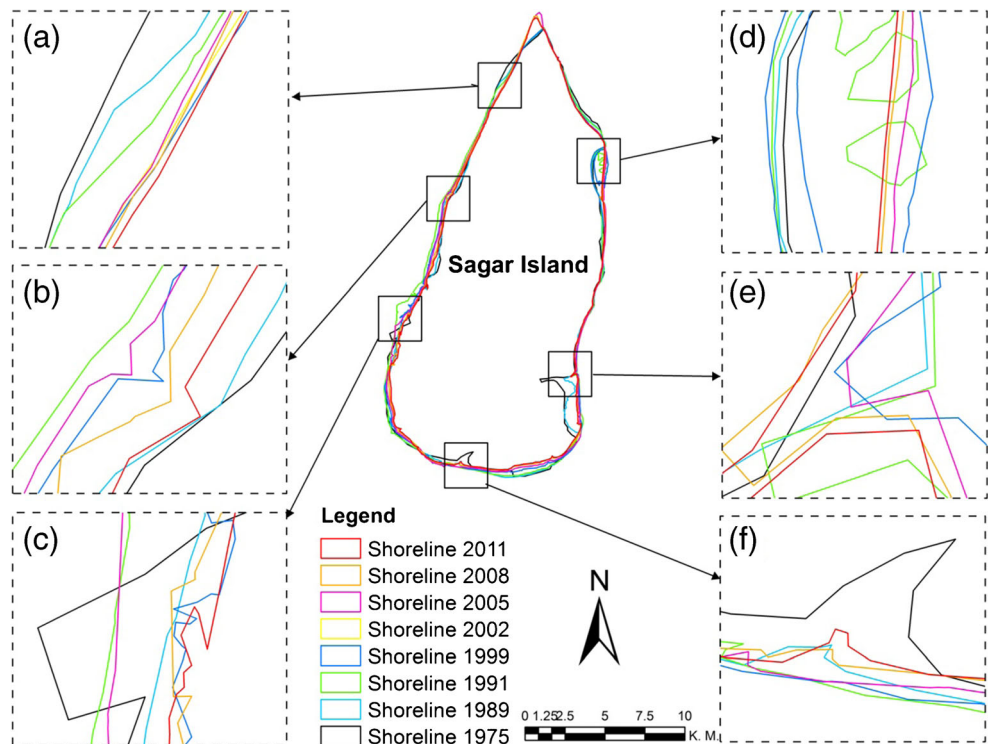
Table 2 Year-wise changes (area) in Sagar Island

	Year							
	1975	1989	1991	1999	2002	2005	2008	2011
Area (Sq. Km.)	240.89	241.45	248.28	245.02	241.82	243.65	240.92	237.89

was predicted by adjusting the errors. The brief methodology has been shown in the Fig. 4.

Results and discussion

Shoreline changes in Sagar Island during the period 1975–2011

Shoreline of the Sagar Island has been delineated from multi-temporal satellite imageries of different years (1975, 1989, 1991, 1999, 2002, 2005, 2008, and 2011). Band 3 (wetness index) of tasseled cap transformation has been used for shoreline extraction of Sagar Island.

The coastal erosion and accretion both was found in the northern part of the Sagar Island. After 1975 the process of erosion was happened in the northwestern part of the Island. Here the island has continuously eroded due to the meander shape of River Ganges. In the extreme northern part of the island the process of accretion was seen and since 2002, some mangrove patches were grown up in this muddy coastal area. During 1975 to 1991 the western part of the area has been continuously eroded. But recently, these mangrove patches are degrading due to various factors. The sediment of those land masses has been flown by the fluvial action of river Ganges and has deposited in the west, north-west part of this island due to the meander shape of the river in this part. Those small land masses acted as a natural barrier and protected the Island from erosion. During 1975 to 2011 the erosion activity has

been going on continuously and the shoreline of the southern part has changed negatively (erosion) in a very fast rate. This portion of the island has a connection with the sea (Bay of Bengal). So, here the sea mainly affects the erosion processes rather than the river. These coasts have been affected by sea waves, winds, sea currents, tidal activities etc. For this reason erosion activity of this part is very high. Muddy beaches have developed along the eastern part of the island. Actually muddy beaches have low erosional characteristics than any other beaches. But in this part some of the muddy beaches along Muri Ganga estuary are eroding severely. It can be attributed to the deposition of sediment in the estuary by the form of shoals and a tidal flat which in turn causes the more intensity of water flow towards the island. Erosion also occurs due to meander shape of the river in this part. In the year 1991 there was some small land mass developing in the northeastern part of the island. In the recent time this part is also eroding due to various causes (Fig. 5 and Table 2).

Land mass area of the Island has been changing respectively over the year. The shoreline of this Island is modifying time to time due to the various natural and anthropogenic causes. In this study it has observed that the area of the island increased. This increasing trend continued till 1991. In the year 1991 the area of this island reached the maximum. The year 1991's area (248.28 Sq. km.) was 103.06 % of the year 1975's area (240.89 Sq. km.). It has been observed that the area has been decreasing since 1991 in this island which means that the erosion was constantly going on in Sagar Island. In the year 2011 the area was 237.89 Sq. km (Fig. 6).

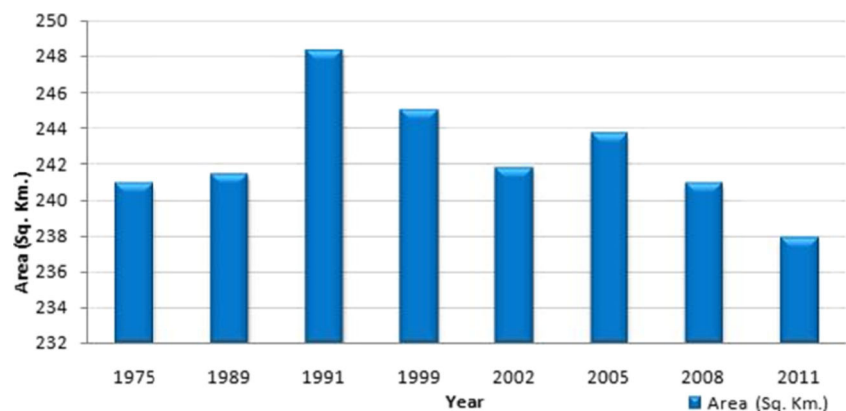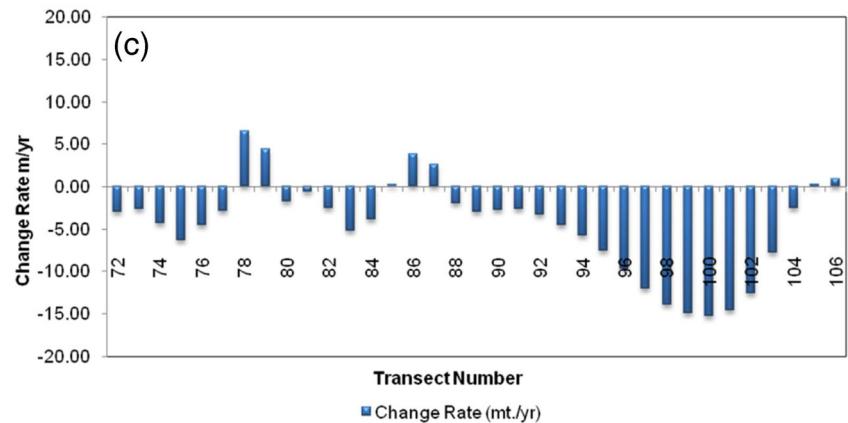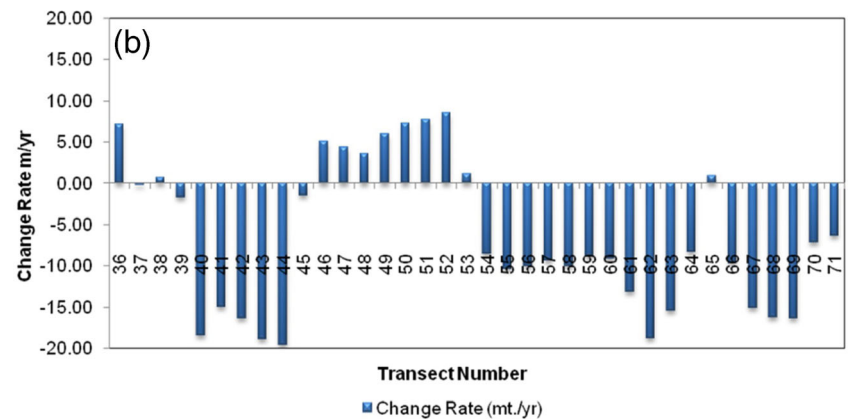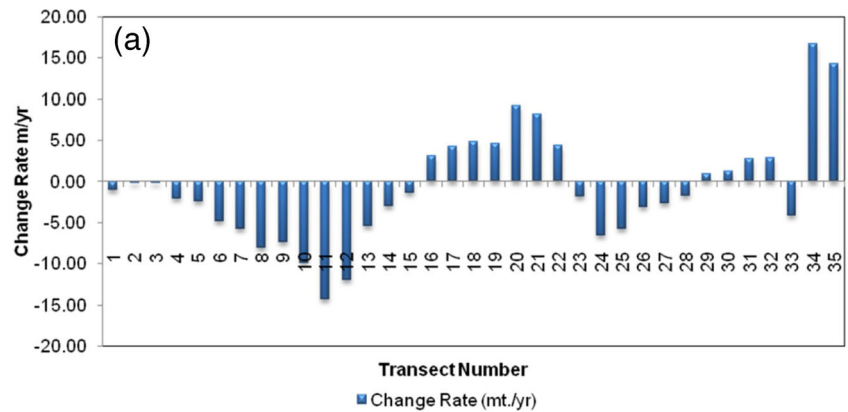**Fig. 6** Changes in area of Sagar Island for the period 1975–2011

Fig. 7 River bank erosion in Muriganga estuary (eastern part of the Sagar Island)

Fig. 8 **a** Shoreline changes (m/yr) for the period of 1975–2002 in segment A. **b** Shoreline changes (m/yr) for the period of 1975–2002 in segment B. **c** Shoreline changes (m/yr) for the period of 1975–2002 in segment C

The major causes of coastal erosion in Sagar Island

a. A number of river bank erosion has been observed on eastern and southeastern part of the island. This is due to high flood velocity and the meandering shape of the Muriganga River (Fig. 7).
b. The sea level rise has been estimated as 2.6 mm per year. Due to this sea level rise erosion has been increasing over the year.
c. Cyclones are one of the most destructive natural disasters affecting the Sagar Island. Cyclone affects the island with strong wind, heavy rainfall, and flooding, so beach erosion takes place and the shoreline is changing dramatically. In the year 2009 cyclone Aila affected the island. Almost Every year some of cyclones affect the island and change the land mass of the island.
d. Sandy beach is found in the southern, south-eastern and south western part of the island. These are highly eroded by natural activities like, sea waves, wind and tidal activity etc.
e. Mangroves protect the island from severe erosion. Now a day the rate of erosion is increasing in different parts of the island due to deforestation of mangrove forest. Mangrove afforestation should be taken up in cyclone-prone areas to protect the life and property in coastal region.

Uncertainty and error

The shoreline position is highly dynamic and it is changing time to time over the years due to sea wave, high tide, heavy storms, ocean current, climatic hazards etc. These natural processes are modifying the shoreline continuously. Mapping the historical shoreline introduces additional uncertainty. In this study, uncertainty has been calculated using estimates based on studies of Hapke et al. (2010). Additional uncertainty which was associated with the satellite imagery has been used for this study. Four main sources of error have been considered for uncertainty calculation. These errors are - georeferencing error (E_g), digitizing error (E_d), pixel error (E_p), and sea level fluctuation error (E_{sl}). In this study, sea level fluctuation error was negligible due to the higher short term variability of sea level along the coast of the Sagar Islands. Georeferencing error (E_g) is calculated from the georeferencing and rectifying processes. In this study georeferencing errors provided in the metadata of Satellite image have been used. Digitizing error (E_d) is a mean of the difference between repeated digitalization of the same image. In this present study shoreline has been automatically extracted from the satellite images. So, there was no digitize error to use in uncertainty calculation. Pixel error (E_p) characterizes the pixel size of the image. For Landsat TM (1989, 1991) and ETM+ images (1999, 2002, 2005, 2008, and 2011) it is 30 m which means any feature is smaller than 30 m cannot be resolved.

Shoreline positions are extracted from the satellite images for the period 1975 to 2011, the total uncertainty (UT) can be calculated via the individual errors (Hapke et al. 2010).

$$U_T = \pm \sqrt{E_g{}^2 + E_d{}^2 + E_p{}^2} \qquad (6)$$

Where E_g is the georeferencing error, E_d is the digitization error, and E_p is the pixel error.

The uncertainty of shoreline change rate (U_R) is an addition of the uncertainty of each year shoreline position, divided the number of years gap between the shoreline surveys (Hapke et al. 2010).

$$U_R = \pm \sqrt{(U_{T1}{}^2 + U_{T2}{}^2 + U_{T3}{}^2 + U_{T4}{}^2 + U_{T5}{}^2 + U_{T6}{}^2 + U_{T7}{}^2 + U_{T8}{}^2)/Y} \qquad (7)$$

Where $U_{T1}{}^2$, $U_{T2}{}^2$.....$U_{T8}{}^2$ are the total shoreline position uncertainty of each year and Y is the total time span of analysis.

The uncertainty of shoreline change rate is ±3.20 mt. /year for the each Island (period of 1975 to 2011).

Table 3 Shoreline change rate (m/yr) for the period of 1975–2002 in Sagar Island

	Segment A	Segment B	Segment C
Mean shoreline change rate (m/yr)	−0.75	−6.46	−4.4
Erosion (m/yr)	−2.96	−7.91	−4.94
Accretion (m/yr)	+2.15	+1.45	+0.55
Maximum rate of erosion (m/yr)	−14.25	−19.6	−15.25
Minimum rate of erosion (m/yr)	−0.19	−0.25	−0.59
Maximum rate of accretion (m/yr)	+16.66	+8.53	+6.49
Minimum rate of accretion (m/yr)	+0.97	+0.68	+0.23
No. of transects	35	36	35
Erosion transect	22	26	28
Accretion transect	13	10	7

Fig. 9 a Shoreline changes (m/yr) for the period of 2002–2011 in segment A. **b** Shoreline changes (m/yr) for the period of 2002–2011 in segment B. **c** Shoreline changes (m/yr) for the period of 2002–2011 in segment C
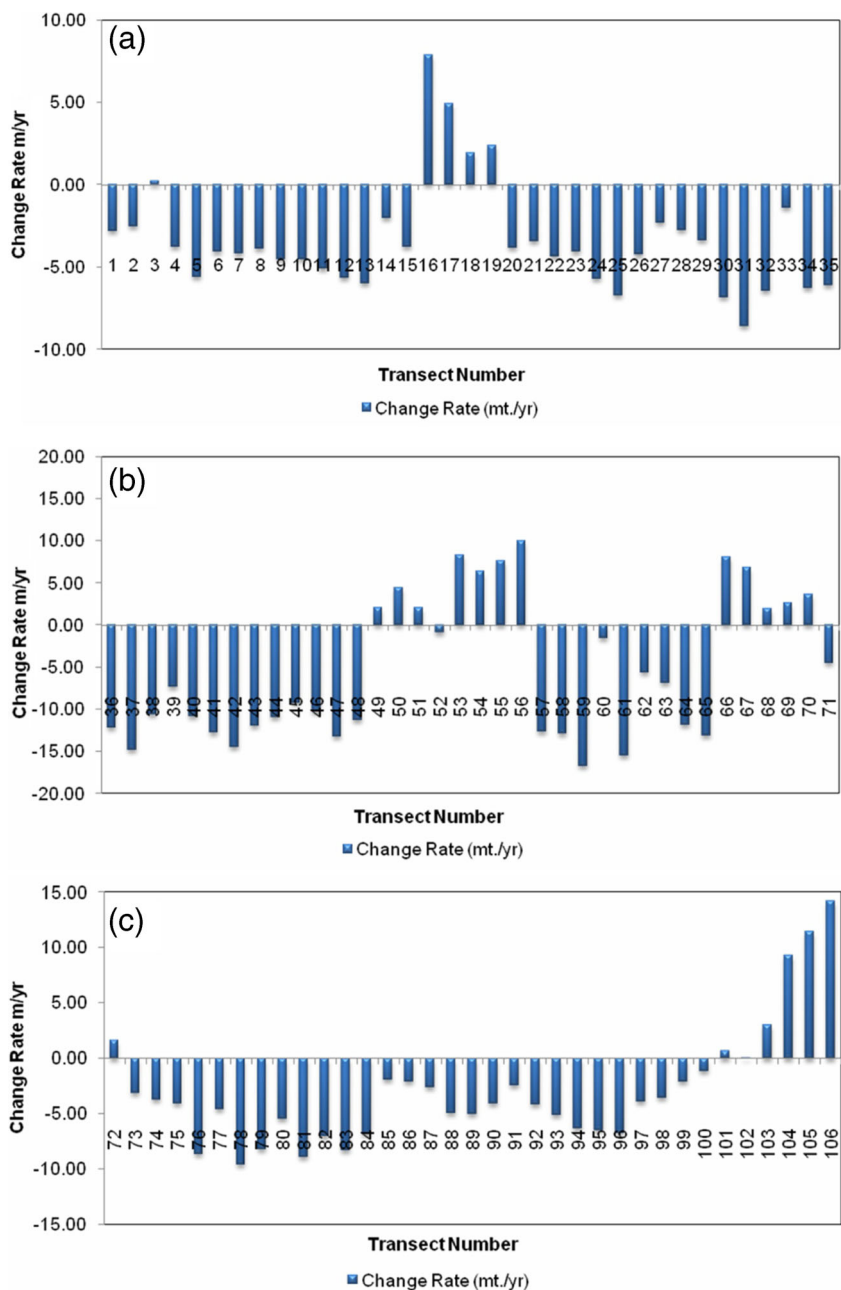

Table 4 Shoreline change rate (m/yr) for the period of 2002–2011 in Sagar Island

	Segment A	Segment B	Segment C
Mean shoreline change rate (m/yr)	−3.36	−5.25	−2.91
Erosion (m/yr)	−3.85	−7.01	−4.05
Accretion (m/yr)	+0.5	+1.76	+1.15
Maximum rate of erosion (m/yr)	−8.57	−16.77	−9.63
Minimum rate of erosion (m/yr)	−1.39	−0.87	−1.17
Maximum rate of accretion (m/yr)	+7.87	+9.92	+14.23
Minimum rate of accretion (m/yr)	+0.23	+1.98	+0.03
No of transects	35	36	35
Erosion transect	30	24	28
Accretion transect	5	12	7

Fig. 10 RMSE error in actual
and predicted shoreline at each
sample points of the year 2011
(EPR model)

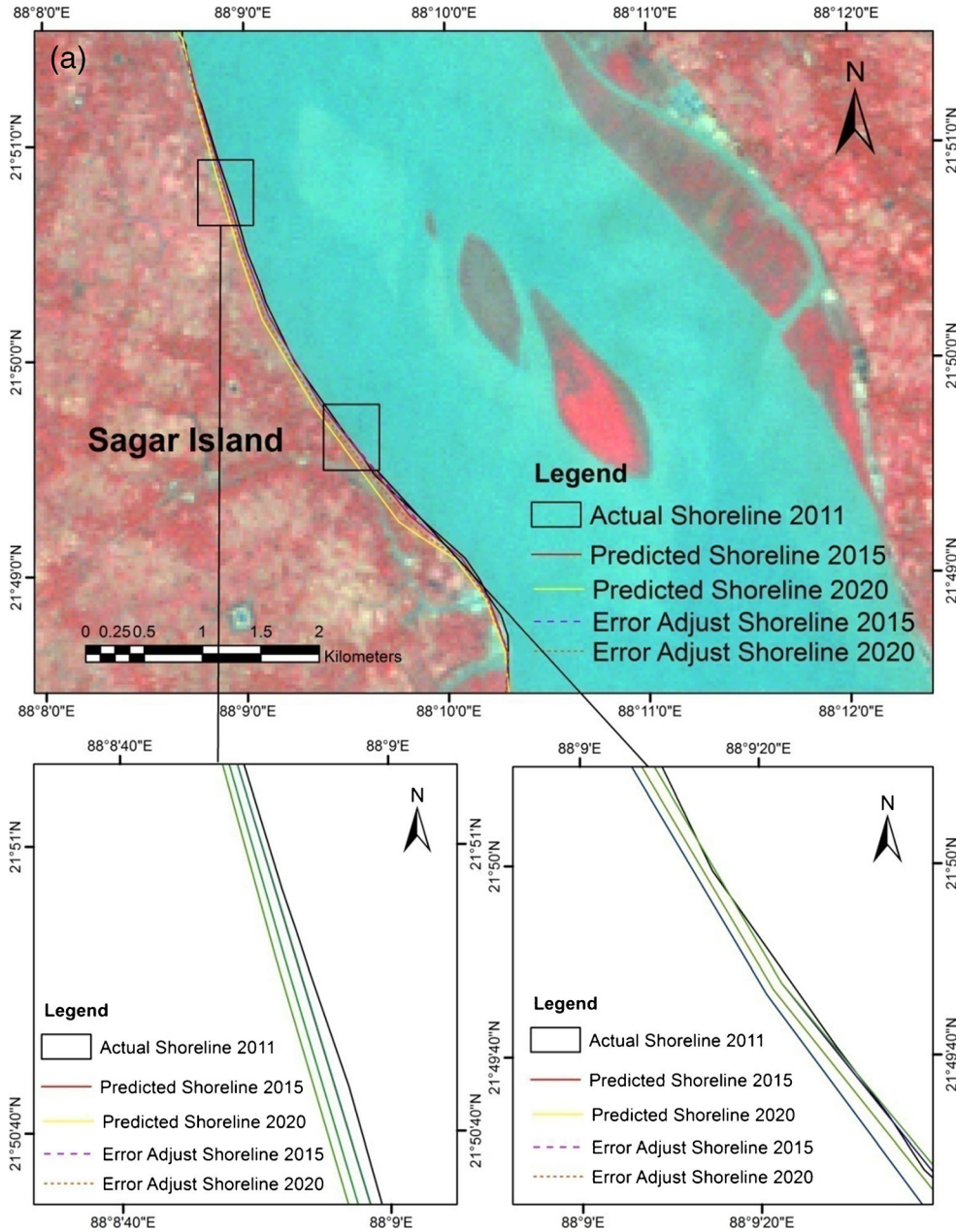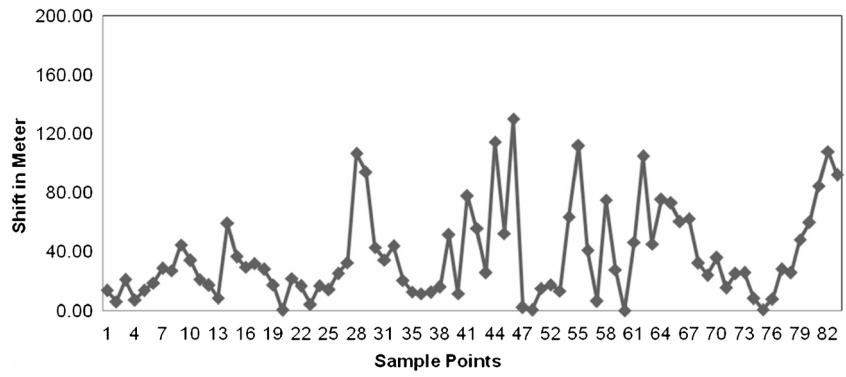**Fig. 11** **a** Error adjusted future shoreline of 2015 and 2020 in north
eastern part of Sagar Island using EPR model. **b** Error adjusted future
shoreline of 2015 and 2020 in southern part of Sagar Island using EPR

model. **c** Error adjusted future shoreline of 2015 and 2020 in north-
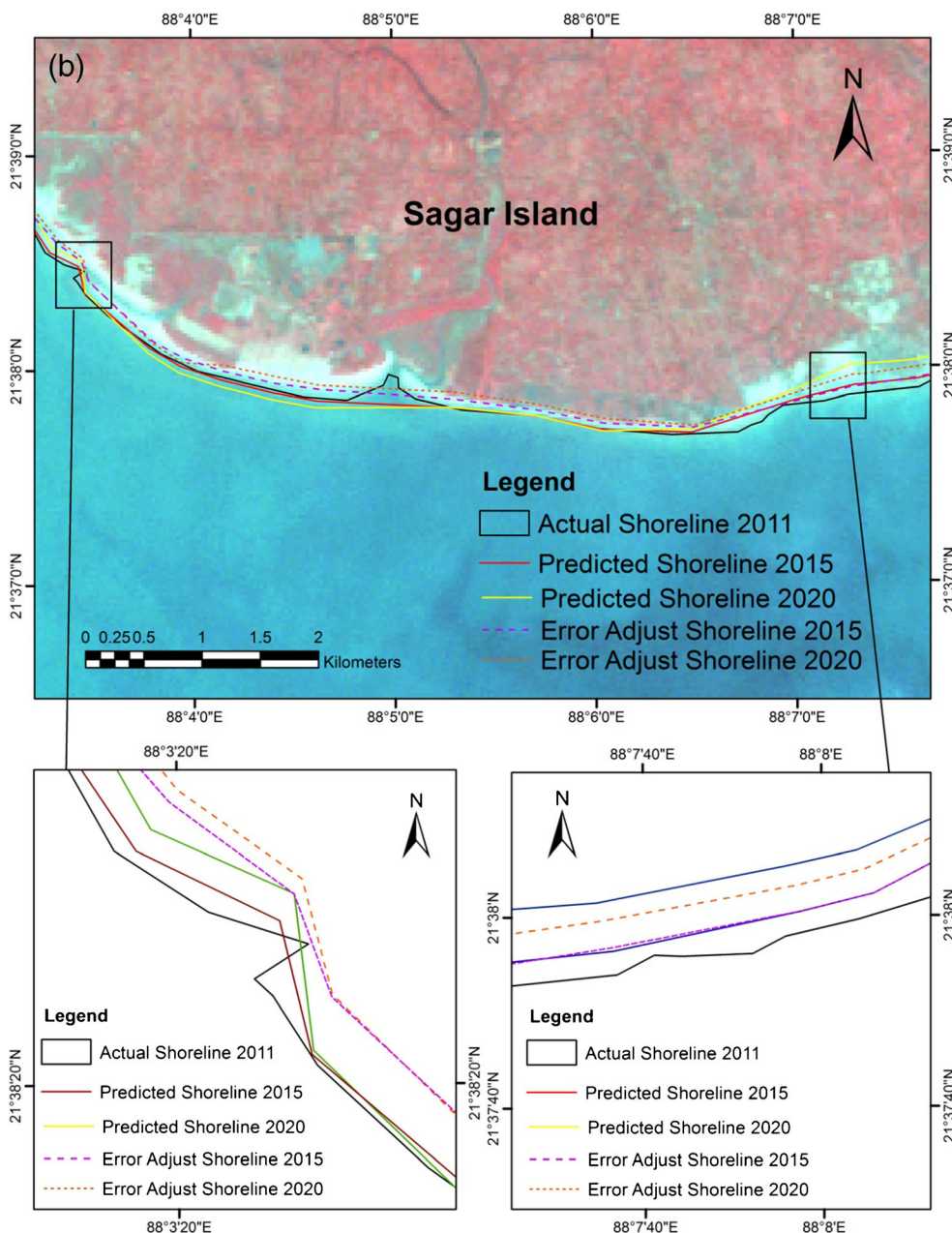western part of Sagar Island using EPR model

Fig. 11 (continued)

Quantitative assessment of shoreline change in Sagar Island

Since the Sagar Island is the largest island of the Indian Sundarban delta it has been divided into three hypothetical segments A, B and C for a detailed study. Segment A covers the northeast, east and southeast part of the island. Total 35 transects (Transect Number 1 to 35) have been cast in this segment for calculation. There are total 36 transecting (Transect Number 36 to 71) in segment B and it covers south and south-west part of the island. Segment C covers 35 transect (Transect Number 72 to 106) in west and north-west part of the Island.

In order to understand the dynamic changes and change rate for each period of observation, these two variables were calculated using End Point Rate (EPR) and analyzed. The shoreline change rate was different in long-term and short-term period. So, the long-term period (1975–2002) and short-term period shoreline changes (2002–2011) were calculated separately.

Long-term shoreline changes

The period from 1975 to 2002 have been used for long-term shoreline changes, where shoreline of 1975 was considered as a historical shoreline and 2002 as a recent shoreline.
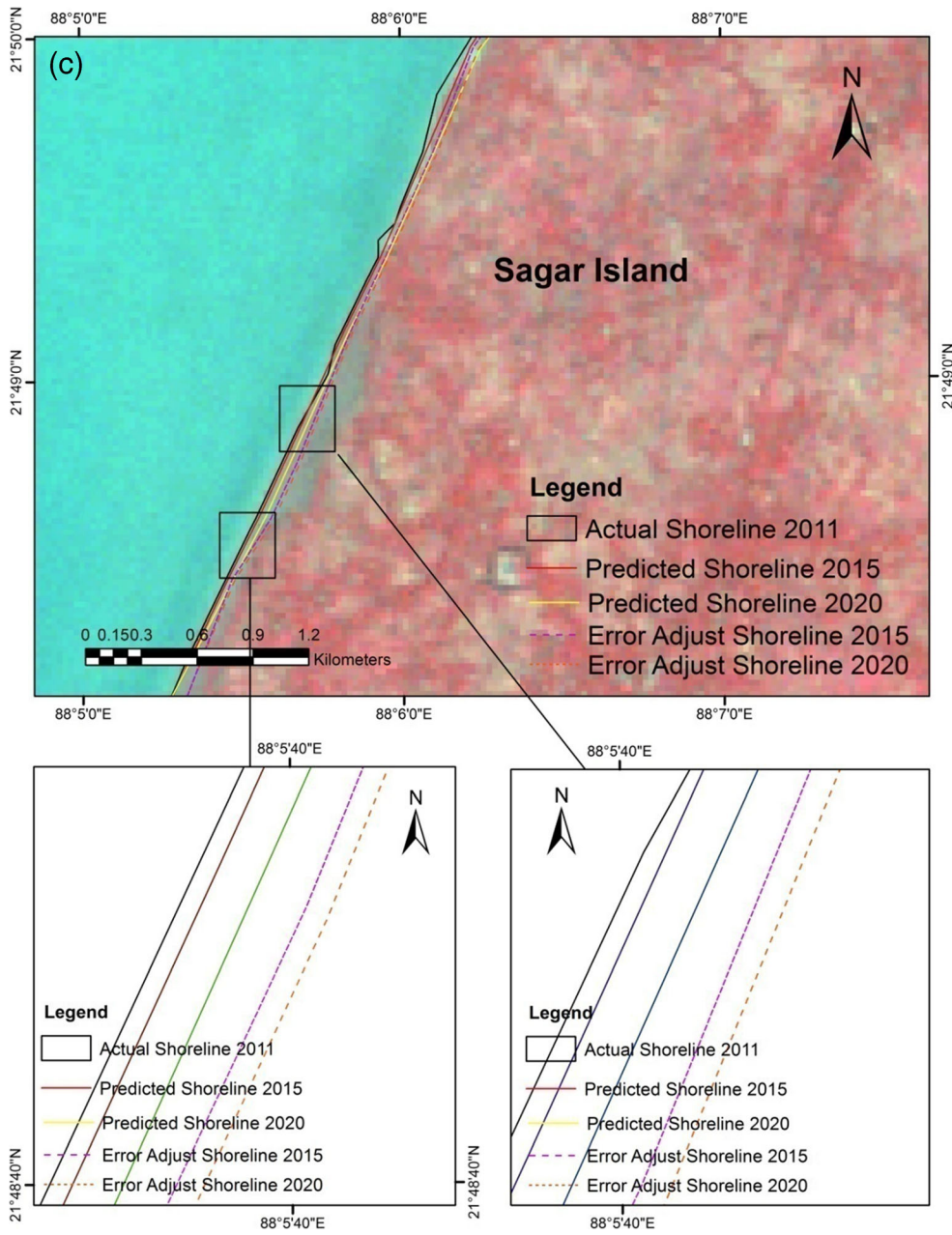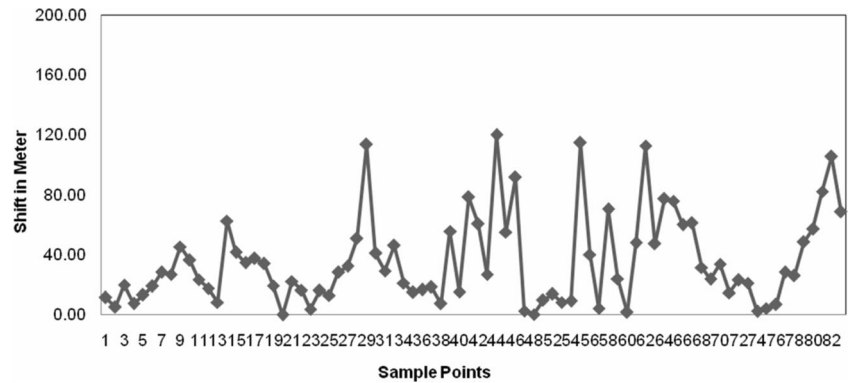
Fig. 11 (continued)

Fig. 12 RMSE error in actual and predicted shoreline at each sample points of the year 2011 (LR model)

The mean shoreline change rate was found high in Segment B with values −6.46 m/year. This is the most dynamic segment of Sagar Island covering mainly the southern and southwestern part of the Island. The mean shoreline change rate was −4.4 m/year in segment C. During 1975–2002 the shoreline was highly eroded at the rate of −7.91 m/year in segment B whereas the erosion rate was much slower in the segment A at the rate of −2.96 m/year (Fig. 8a, b and c). Accretion activity was high in segment A (+2.15 m/year) whereas accretion rate was slower in Segment C (+0.55 m/

year). The maximum rate of erosion has been observed in the transect number 44 (−19.60 m/year) in Segment B. This transect is located in the southern part of the island. Transect number 2 is located in the northern part of the island (Segment A) shows a minimum rate of erosion −0.19 m/year. Maximum rate of accretion has been observed in the southeastern part of the island; transect number 34 located in Segment A, with an accretion rate of 16.66 m/year. Segment B was found most dynamic part of the Island. This part of the island is directly connected to the sea. So, sea activities like
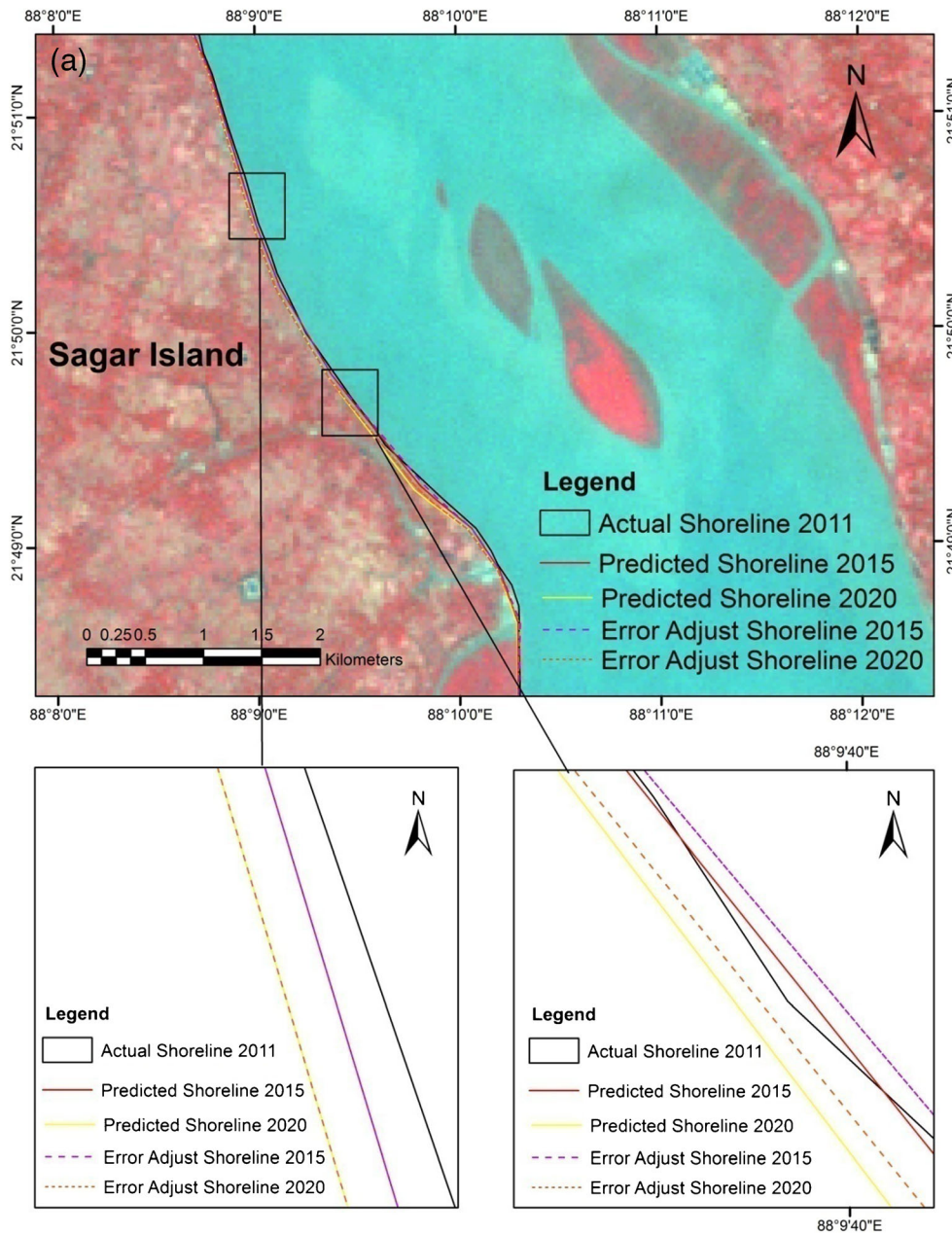

Fig. 13 a Error adjusted future shoreline of 2015 and 2020 in north eastern part of Sagar Island using LR model. **b** Error adjusted future shoreline of 2015 and 2020 in south eastern part of Sagar Island using LR model. **c** Error adjusted future shoreline of 2015 and 2020 in southern part of Sagar Island using LR model
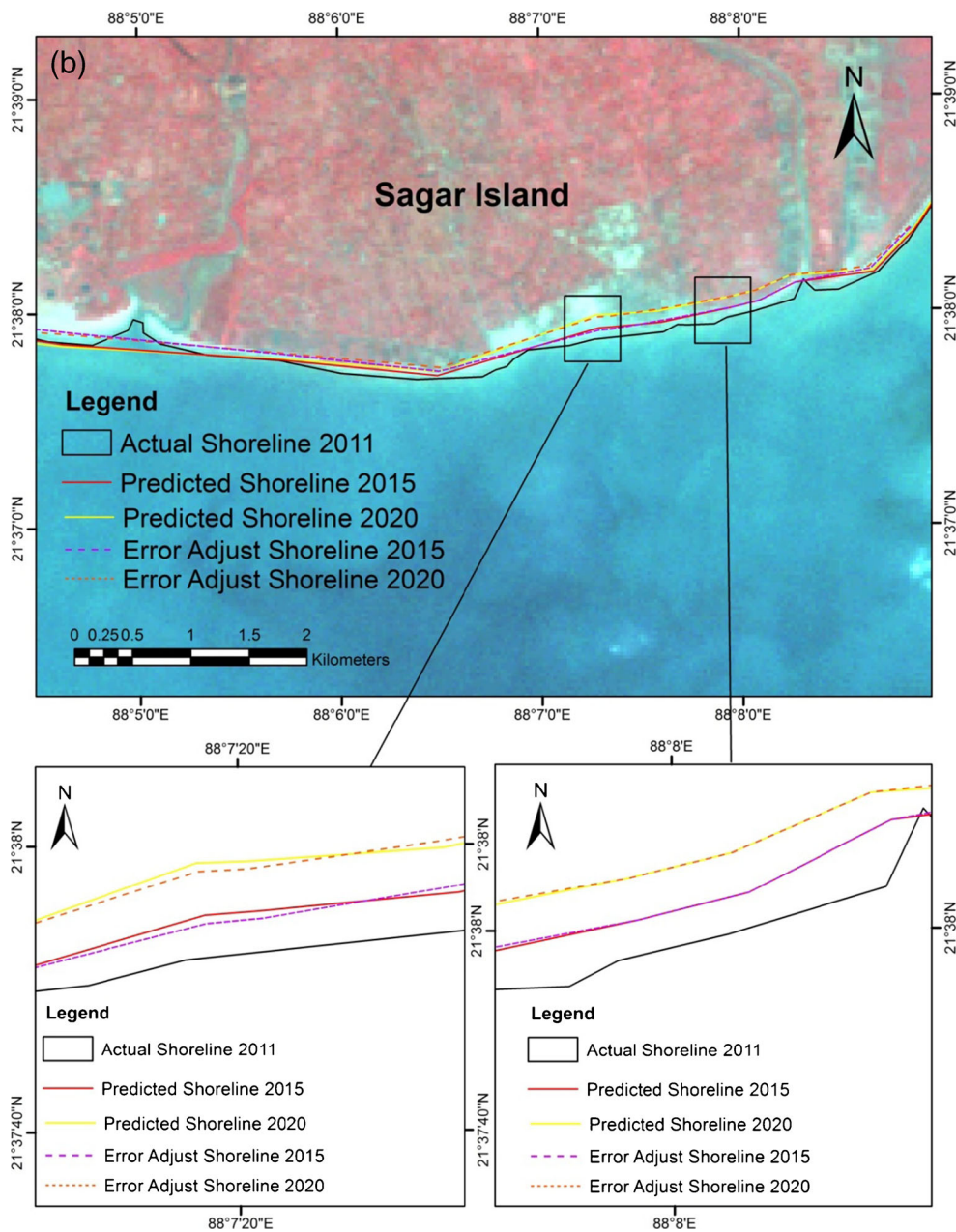
Fig. 13 (continued)

sea wave, current, tidal directly affect the shoreline. The Beach morphology of this part is responsible for shoreline change. Beach of the southern and southwestern part of the island consists of 80 % sand material. Sandy beaches are eroded higher than the other beaches (Table 3).

Short-term shoreline changes

The mean shoreline change rate was high in Segment B at −5.25 m/year and low in Segment C (−2.91 m/year). During 2002–2011 shoreline was highly eroded in the magnitude of −7.01 m/year in Segment B whereas the erosion rate was

slower in Segment A with a magnitude of −3.85 m/year (Fig. 9a, b and c).

Accretion activity was high in segment C in the magnitude of +14.23 m/year and accretion rate was slow in segment C in the magnitude of +0.03 m/year. The maximum rate of erosion has been observed in the transect number 59 at −16.77 m/year in segment B. This transect is located in the southwestern part of the island. Transect number 52 is located in the southern part of the island (segment B) shows a minimum rate of erosion −0.87 m/year. Maximum rate of accretion has been observed in the northern part of the island; transect number 106 located in segment A, with an accretion rate of +14.23 m/year. Segment B was
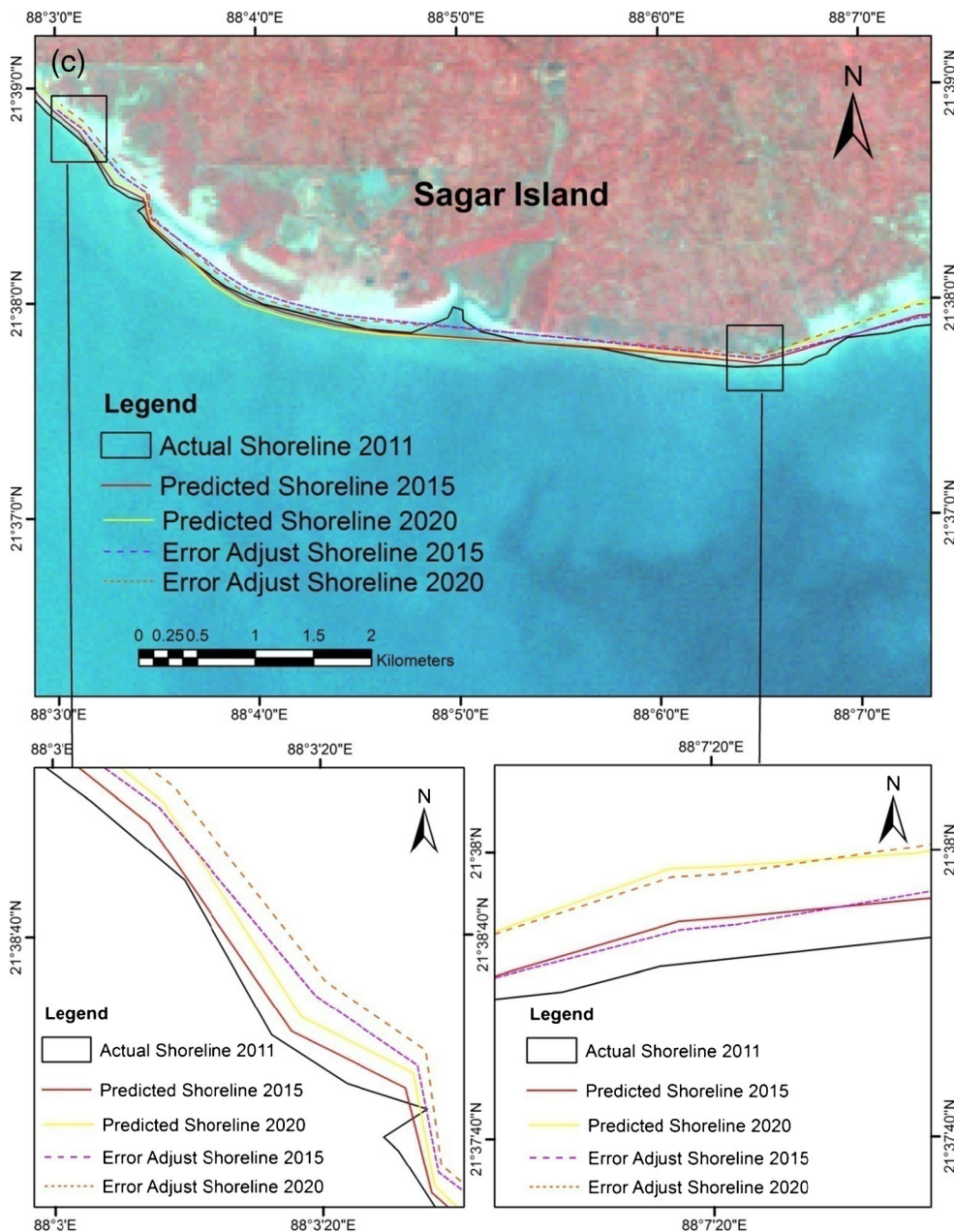
Fig. 13 (continued)

also found most dynamic segment in short-term period (Table 4).

Future shoreline prediction using EPR & LR model

The shoreline of the study area has been predicted by using EPR and LR models in the year 2011. In this prediction EPR model has been used only for the shorelines of 1975 and 2008. The first one was considered as the historical shoreline and the second was used as the most recent shoreline for predicting the 2011 shoreline. In this

study shoreline position of 2011 has been predicted for model validation and observed how much the model generated shoreline fits to the actual shoreline of 2011. In the case of LR model all shorelines of the study area (1975. 1989, 1991, 1999, 2002, 2005, and 2008) have been used for predicting the 2011 shoreline. After that the shoreline of the study area was predicted for short term period (2015 and 2020) with the help of End Point Rate method and Linear Regression method. In both methods shoreline change rate has been calculated from the historical shoreline data. Any natural impacts like sea wave, sea current,

tide etc. and any disaster impacts like a cyclone, tsunami etc. have not been considered.

EPR model validation

In this study, End Point Rate model has been used for future shoreline prediction. Before shoreline prediction End Point Rate model has been validated with the present shoreline position. Firstly, rate of shoreline shifting has been calculated from the shoreline position of 1975 and 2008 and on this basis of this value 2011 shoreline is predicted. The predicted shoreline of 2011 was analyzed with the actual shoreline delineated from satellite imagery of 2011 and calculated the RMSE error of each sample point. Positional shift between the actual and predict shoreline of each sample point has shown in the Fig. 10.

The RMSE error obtained from EPR model varies from ±0.08 to ±130.06 m. It has been observed that model prediction error is higher in the western part of the south Sagar, south-western part and north-eastern part of the Island. The average RMSE error of overall sample points are found to be ±37.09 m.

Future shoreline prediction using EPR model and error adjustment

The shoreline of the study area has been predicted for short term period (2015 and 2020) with the help of the End Point Rate and Linear Regression methods. An error adjustment process has been used in future shoreline prediction. At first, the Root Mean Square error was calculated for all transect then this RMSE error value was adjusted in future shoreline position (Fig. 11a, b and c).

LR model validation

Before shoreline prediction the Linear Regression model was validated with the present shoreline position. At first, rate of shoreline shifting was calculated from the shoreline position of 1975 to 2008 and on this basis of this value 2011 shoreline is predicted. The predict shoreline of 2011 was analyzed with the actual shoreline delineated from satellite imagery of 2011 and calculated the RMSE error of each sample point. Positional shift between the actual and predict shoreline of each sample point is shown in the Fig. 12.

The RMSE error obtained from LR model varies from ±0.11 to±119.88 m. It has been observed that the model prediction error is higher in the western part of the south Sagar, southwestern part and north-eastern part of the Island. The average RMSE error of overall sample points is found to be ±35. 61 m.

Future shoreline prediction using LR model and error adjustment

The shoreline of the study area has been predicted for short term period (2015 and 2020) with the help of End Point Rate method. An error adjustment process has been used in future shoreline prediction. At first, the Root Mean Square error was calculated for all transects then the RMSE error was adjusted in future shoreline position.

The predicted shoreline from LR model indicates that the maximum erosion will take place in the southern and southeastern part of the island and overall erosion will occur in most of the part of the study area. The erosion trend has found mainly in the eastern part of the south Sagar. The same shoreline change was observed in the shifting of shoreline from 1975 to 2011, which means that the prediction is almost following the same erosion and accretion activity. After future shoreline prediction an error adjustment procedure has been applied in the future shoreline position. The positional shifts in x and y direction of every sample points are calculated by RMSE error and show the direction of shifting. The calculated shift is adjusted to predict the future shoreline of 2015 and 2020. Applying the error adjusted method it is observed that the erosion rate increased than normal prediction. So, if this rate of erosion continuously goes on the dwellers of the island may face some serious problem in future. So, immediate actions are needed to decrease the erosion rate in this area (Fig. 13a, b and c).

Conclusions

The study showed the massive erosion process occurred in the Sagar Island. Mainly southern, southwestern and eastern parts of the area are undergone high rate of erosion. Accretion has been seen in only a small portion of southwestern part and in the northern peak of the Sagar Island. Various reasons are responsible for the erosion of Sagar Island. Mainly bank erosion in Muriganga estuary is responsible for the erosion of the eastern part of the island while the Southern part of the island is mainly eroded due to ocean activity. Future shoreline is difficult to predict because it is the most dynamic geomorphic feature of the earth's surface. But the trend of shoreline change based on the future shoreline prediction can be done using multi-temporal satellite data which may help to reduce the loss of property. The future shoreline of Sagar Island has been predicted using EPR and LR model for the year 2015 and 2020 in which LR method was found more accurate than EPR.

Future scope and recommendations

Shoreline is very dynamic. So, shoreline delineation from high resolution satellite data will be more accurate as compared to medium resolution satellite data. EPR and LR model has been used in this study for shoreline prediction but models like Average of Rates (AOR), Jacknife (JK), and Weighted Linear Regression etc. can be tested for shoreline prediction. Establishment of coastal structures and afforestation of mangrove forest are required to protect the mainland from high rate of coastal erosion.

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