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Morphological Change Study of Ghoramara Island, Eastern India Using Multi Temporal Satellite Data

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Abstract
Ghoramara island is situated at 18.36 nautical miles away from Haldia dock in Hooghly estuary, Eastern India. It is a rhombic shaped island covering an area of around 4.8 km² with a total shoreline length of 8.5 kms. This sparingly populated sensitive ecosystem is rapidly changing its morphology due to extensive coastal erosion on the northwestern coast and marginal accretion on the southeastern side. The degradation of the system due to natural and anthropogenic causes leads to the total areal reduction of the island. There is a major loss of agricultural land and fisheries. The two islands Lohachara and Supribhanga lying to the southwest of Ghoramara have already been submerged. The vulnerability and stability of the island is the major fear of the inhabitants. In the present study, multi-resolution and multi-temporal satellite images of Landsat have been utilized to understand the erosion accretion pattern of the island over past four decades (1972-2010). The rate of change in shoreline positions have been estimated using statistical linear regression, end-point rate and net shoreline movement method and cross-validated with regression coefficient (R²) method. Land use land cover map has been prepared for all these years to understand how the erosion-accretion affected the island. It has been shown that the island is constantly shrinking over time and lost almost 50% of its area.

Keywords*:* Hooghly estuary, Ghoramara Island, shoreline change rate, regression coefficient (R²), land use land cover.

Introduction

The coastal zone refers to a broad geographical area where the terrestrial and marine factors are mixed to produce dynamic/sensitive ecosystems[1]. The shoreline, interface between land and sea[2,3], is very dynamic feature of the coastal zone. It undergoes frequent changes, short term and long term, caused by hydrodynamic changes (river cycles, sea level rise), geomorphological changes (e.g. barrier island formation, spit development) and other factors (sudden and rapid seismic and storm events)[4,5]. The rate of shoreline changes is one of the common measurements used by coastal scientists, engineers and land planners to indicate the dynamics and the hazards of the coast[6-12].

The Hooghly estuary is a funnel shaped coastal plain estuary and is one of the largest estuary of the river Ganges. The morphometric setting of the estuary is the product of continuous fluvial sedimentation by a series of para-deltaic lobe progradation systems developed on the western shelf margin areas and eastern basinal troughs of the Bengal basin tectonic frame, over the entire Holocene period. The quaternary sediments are underlain by the tertiary sediments indicating an accumulation in a subsiding tectonic trough[13]. Looking at the geological setting, the estuary itself occupies the Eocene hinge zone. Sagar is the largest island of the Sundarban, positioned at the mouth of the Hooghly estuary and divides it into two channels, the western channel is retained as Hooghly and eastern is named as Muriganga. Ghoramara and Sagar were joined and formed a single island till 1903, when Ghoramara got separated from Sagar and stabilized as a separate island.

The study area Ghoramara Island is located 18.36 nautical miles southeast of Haldia dock. This island is extended between 21°53'56"N to 21°55'37"N latitude and 88°06'59"E to 88°08'35"E longitude (figure 1). The island covers an area of 4.8km². The major villages on this island include Khasimara, Hathkola, Baghpara, Raipara, Mandirtala, Chunpuri Lakshmi Narayanpur and Khasimara Char. Out of these the Kashimara Char, Lakshmi Narayanpur and Kashimara have already been lost. The major occupation of the people is agriculture and fishing. Main plant cover includes coconut, bamboos and casuarinas. The area experiences a tropical warm and humid climate. Rain occurs due to southwest monsoon from May to September, and the northeast monsoon from November to December. Maximum rainfall and comparatively lower temperatures are encountered with the onset of the monsoon period from June to September while the highest temperatures and minimum rainfall occur during pre-monsoon season from February to May with little or no rainfall. Minimum temperature occurs from November to January. As the Hooghly estuary experience semidiurnal tide with flood tide of short duration, 3 to 4 hours, and the ebb tide remains for 8 to 9 hours, so the island also experience the stronger flood tides for shorter duration. It is 6.5 m above mean sea level[14]. The rise in the sea level is caused by natural as well as anthropogenic activities like global warming. In the region, local sea level rise have been estimated as 2.6 mm per year[15,16]. The population of the island till 2001 is 5000[17] but due to the submergence of the inhabited Lohachara Island under water because of rising sea levels, the people from Ghoramara Island are relocated to other nearby islands like Sagar. The inhabitants are forced to leave the island due to degradation of the natural habitat. The term environmental refugees have been used for the inhabitants of this island[18]. The area is under severe threat of erosion. Where it has already lost around 50% of its area in last four decades and the two islands, Lohachara and Supribhanga, are already drowned under water. Thus the stability of the island is in question. Rapid and vast erosion is going on around the island.

Remote sensing techniques integrated with the geographical information system (GIS) has been used for many studies[19, 20]. The integrated method has been used in the shoreline changes studies due to repetitive and synoptic coverage, high resolution, multi-spectral data base and its cost effectiveness. Multi-temporal satellite images of Landsat have been used to understand erosion-accretion processes over past 38 years and to demarcate the shoreline position during different periods. In the present study, an investigation has been carried out in Ghoramara Island to delineate the shoreline and land use land cover changes.

Material and Methods

Data Sources: Multi-resolution satellite data over the study area, such as landsat MSS, TM and ETM+ of different dates have been acquired, as the same resolution data is not available over the chosen period (1972-2010). The archived Landsat images are freely available to the users so these are used. The orthorectified Landsat data was downloaded from USGS global visualization viewer. The area is covered by Survey of India (SOI) Toposheet No. 79C/1 at 1:50, 000 scales.

Landsat data is typically used for coastal zones because of the multi-spectral and multi-temporal capabilities of the data. However, only multi-temporal data has been utilized that allow us to keep track of the various changes in characteristics of the coastal zone. The details regarding satellites and their acquisition dates are listed in table 1.

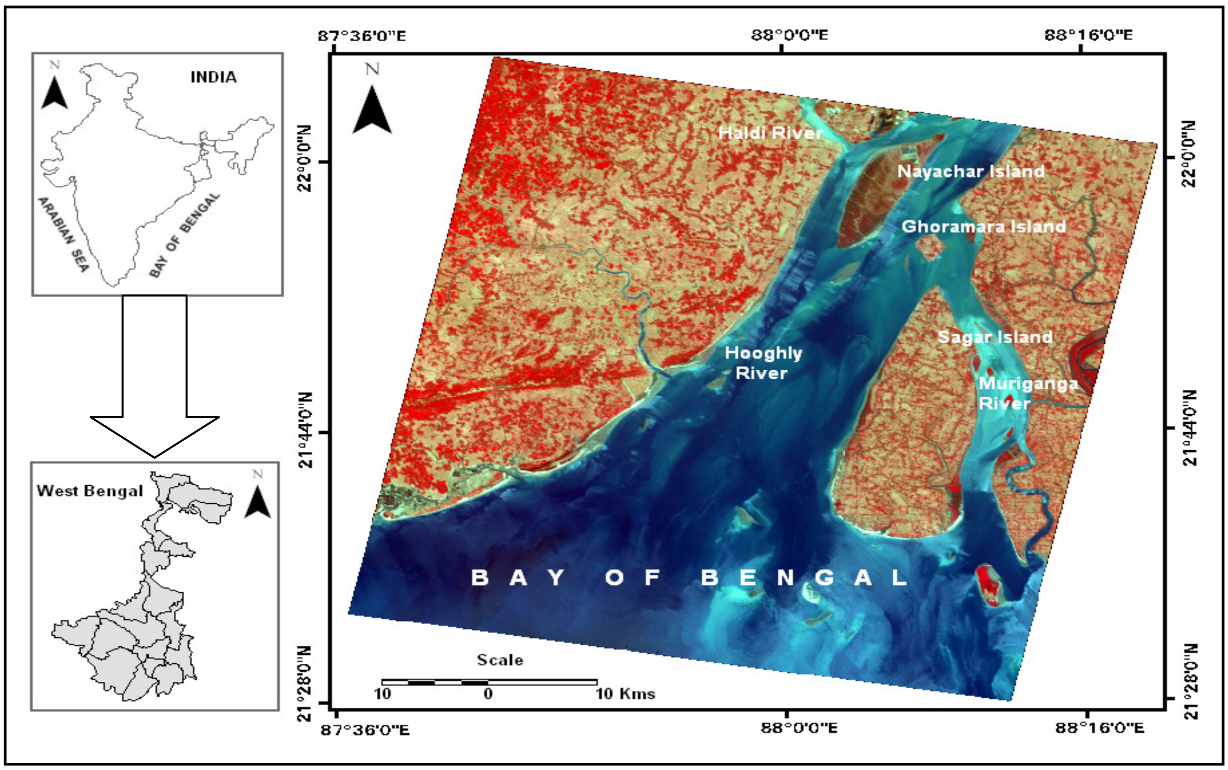

Figure-1
Location map of Ghoramara Island

Table-1
Characteristics of satellite data used with acquisition dates

Satellite/sensor	Date of acquisition	No. of bands	Spatial resolution (m)	Path/Row
Landsat -5, TM	February 6,2010	7	30	139/45
Landsat -5, ETM+	November 17,2000	8	30	139/45
Landsat-4, TM	January 19,1989	7	30	139/45
Landsat-3, MSS	February 9,1979	4	79	149/45
Landsat-1, MSS	December 12,1972	4	79	149/45

Shoreline Mapping: Shoreline is the line distinguishing land from water body. The precise definition of the shoreline is given by[21] as the line contacting between the mean high water line and the shore. Various methods of the shoreline extraction from the satellite imageries have been developed. Shoreline can be identified and delineated from a single band image by using the processed NIR bands of Landsat MSS, and TM, as the reflectance of water is nearly zero in reflective infrared band, and reflectance of majority of land cover is greater than water. The processing of the NIR bands included 'Histogram/gray level thresholding'[22]. Band 5 is best for distinguishing land from Water because it exhibits a strong contrast between the two where water shows high absorption in the middle infra-red energy and vegetation strongly reflect the middle infra-red energy.

In this study band rationing method has been used where the ratio between band 4 and band 2 and other between band 5 and band 2 is used. The rationing between band 5 and 2 is done in the coastal zones to eradicate the vegetative cover, if any, occurs on the shoreline. Ratio b2/b5 is greater than 1 for water and less than 1 for land. The above method is good for soil covered coastal zones, but not for lands with vegetation cover as it mistakenly the assign some of the vegetative land to be water due to combined background reflectance. To overcome this problem, the two ratios are combined. This gives the final images that represent the shoreline. Thus, finally the continuous shoreline positions during different years (1972, 1979, 1989, 2000 and 2010) were drawn (figure 2).

Shoreline changes and change rate assessment: To measure the amount of shoreline shift, 1972 shoreline position (obtained from Landsat MSS) has been chosen as a base or zero (0) position. Each method used to calculate shoreline change rates is based on measured differences between shoreline positions through time. The procedure involves the selection of a base line in the general direction if a shoreline, establishing transects perpendicular to the base line and then finally calculating the distance between the shorelines along various transects. Several statistical methods are used to calculate the shoreline change rates with the most commonly used been are end-point rate (EPR), linear-regression (LR) and net shoreline movement (NSM)[23]. The end point rate calculations are done by dividing the distance of shoreline movement by the time gap between the oldest and youngest shoreline in the data set[24]. The major advantage of this method is ease of computation and calculations can be done on minimum two shorelines only. The EPR method is only good for short term shoreline change analysis as it only consider latest and oldest shoreline position and suppresses all in other in long term analysis. Uses of LR eliminate this difficulty. Here the shoreline shift is calculated by fitting a least square regression line to all shoreline points for a particular transects[25]. The net shoreline movement (NSM) reports distance not rate. It reports the distance between the oldest and youngest shoreline for each transect. To carry out shoreline changes study a Digital Shoreline Analysis System (DSAS), an extension of ARC GIS, has been employed that do all these calculations. The inputs required for this tool are shoreline in the vector format, date of each shoreline, and transect distance. In this case a baseline parallel to the general orientation of the shoreline is generated. 60 transect with a spacing of 200m each are drawn perpendicular to this general orientation and calculations are done along these. Various steps followed for shoreline mapping and change rate calculation are shown in figure 3.

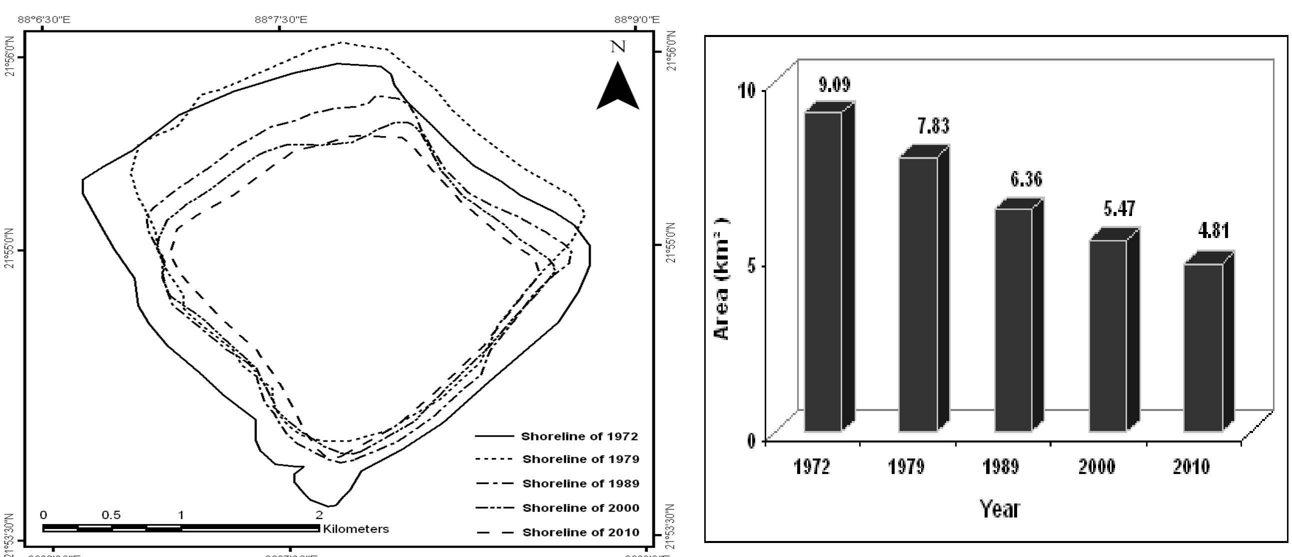

Figure-2
Shoreline positions in different years around Ghoramara Island. Bargraph shown areal changes of Ghoramara Island during different years

Net area/areal change calculations: In this process the zones of erosion and accretion has been demarcated and also the areal changes of the island has been estimated (figure 6). All the spatial analysis is carried out in ARC GIS software spatial analysis tool. For determining the area of the island during a particular year a polygon is constructed along the boundary on GIS platform yields area of the island during that year. For deciphering the net aerial changes and quantifying the erosion-accretion around the island the polygons for the two consecutive years (1972-79, 1979-89, 1989-00, 2000-10) are united by the Overlay method. The "union" operation allows the joining of two coastlines. Considering the segments located between the polygon, their length and erosion/accretion areas were calculated. For aerial change the vector data is converted to raster data with a grid size of 10meters.

Land use and land cover map: The multi-temporal satellite images have been classified (supervised) into five land use land cover classes taking maximum likelihood algorithm[26] using ERDAS IMAGINE 8.5 software. These five classes include water, wetland, fisheries, land vegetation and paddy field. Area covered under these different classes is also estimated. The classification is done on the basis of ground truth observations.

Results and Discussion

The analytical techniques that are used here are EPR (end point rate), LRR (linear regression method), R^2 (regression coefficient), NSC (net shoreline change). EPR for the entire shoreline shows that 33%, 48%, 5% and 12% transects, records the advancing shoreline during the time span of 1972-1979, 1979-1989, 1989-2000 and 2000-2010 respectively. Whereas rest of the transect lines experience retreating shoreline during the same time span. On the other hand, the entire shoreline during the time span of 1972-2010 is affected by the shore zone erosion. Table 2 summaries the statistical data about shoreline change and change rate in EPR and NSM method for each period.

In LR method, the shoreline shift rate can be predicted by fitting a least square regression line with the observed shoreline position along a transect line. Transect-wise shoreline change rate has been calculated and plotted in figure 4. The distribution of R^2 value for all the transect lines throughout the shoreline shows some distinctive distribution pattern. Transect 1 to 9, 27 to 28 and 59 to 60 have the R^2 value > 0.90 and shows a linear pattern, rest of the transects shows R^2 value < 0.90 (figure 5). The R^2 value fit well with shoreline category i.e. advancing and retreating shoreline classified based on the yearly change rate. Transect 7 to 27, 30 to 58, 31 to 32, 11 to 16 fall in the category of advancing shoreline and rest of transects come under retreating shoreline during the period of 1972-1979, 1979-1989, 1989-2000 and 2000-2010 respectively. The average shoreline movement within the period 1972 – 2010 is -528.10 m. The net shoreline movement over the span of 38 years from 1972-2010 for all transects is given in table 2.

The morphological changes observed at the Ghoramara Island are shown in figure 2. Mud flats occur all along the island during 1972 with total area of around 9 Km^2. A creek development in southeastern mud flat leads to an extensive erosion of this part. Erosion in the southern part and deposition in the northern part is observed during the interval; 1972-1979 but erosion is more pronounced than deposition so total area is reduced to 7.83Km^2. During 1979-89 interval the total area get further reduced and erosion occur along the NW and NE side where as deposition on SE and SW side. In 1989-2000 interval marginal deposition occur in the SE side (figure 6), whereas in 2000-2010 deposition only along the southern side. The bar graph of areal changes in the various years shows a decreasing trend that indicates reduction of area every year. Figure 6 and table 3 represents that the erosion rates are much higher than the accretion rates that cause the shrinking of the total area.

Table-2
Statistics of shoreline changes in EPR and NSM method during different time interval of Ghoramara Island

	Year (mt/y)	**1972-1979**	**1979-1989**	**1989-2000**	**2000-2010**	**1972-2010**
EPR	Mean	-17.77	-18.86	-12.32	-9.52	-13.90
	S.D.	35.46	28.97	11.88	9.48	6.85
	Max	36.32	18.67	0.95	11.49	-5.51
	Min	-91.11	-85.14	-60.03	-53.88	-33.20
NSM	Year (mt)	1972-1979	1979-1989	1989-2000	2000-2010	1972-2010
	Mean	-124.36	-188.59	-135.47	-92.51	-528.10
	S.D.	248.24	289.68	130.73	94.78	260.23
	Max	254.24	186.70	10.45	114.90	-209.38
	Min	-637.77	-851.40	-660.33	-538.80	-1261.60

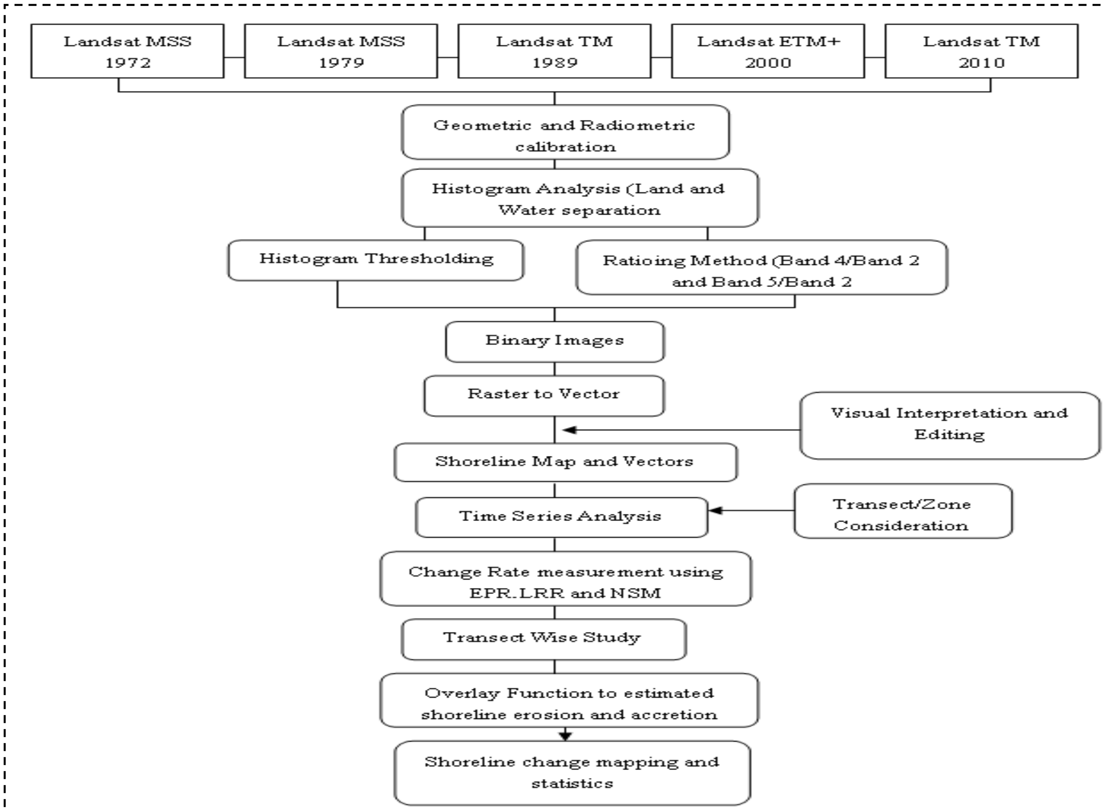

Figure-3
Flow chart of various stages of methodology used for the present study

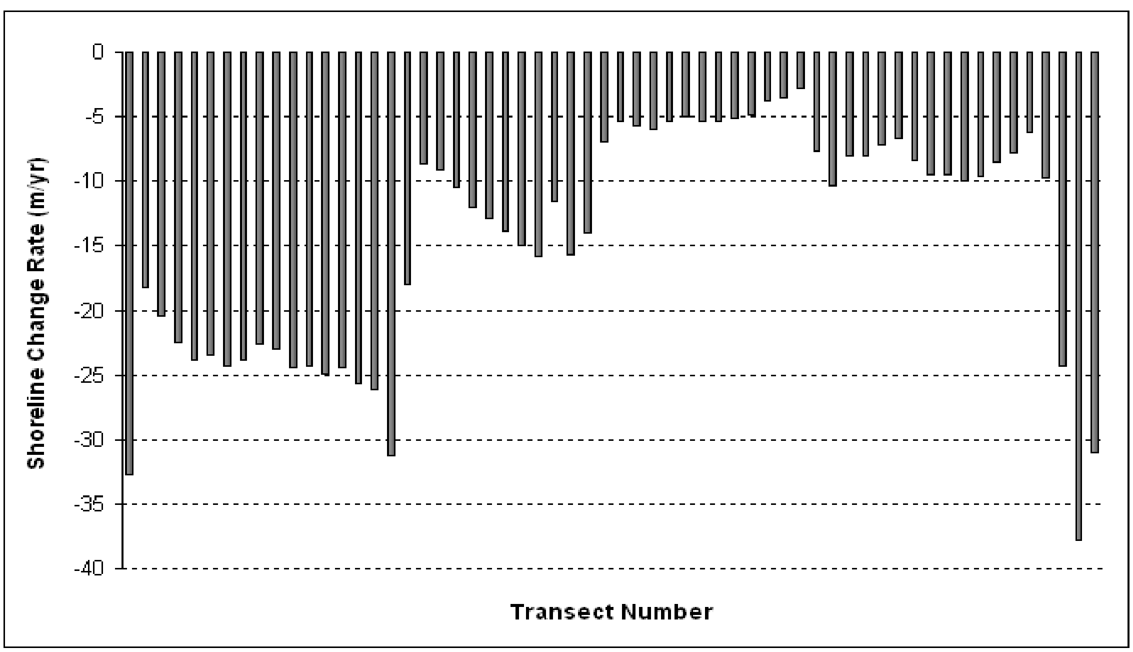

Figure-4
Shoreline change rate distribution graph of transects

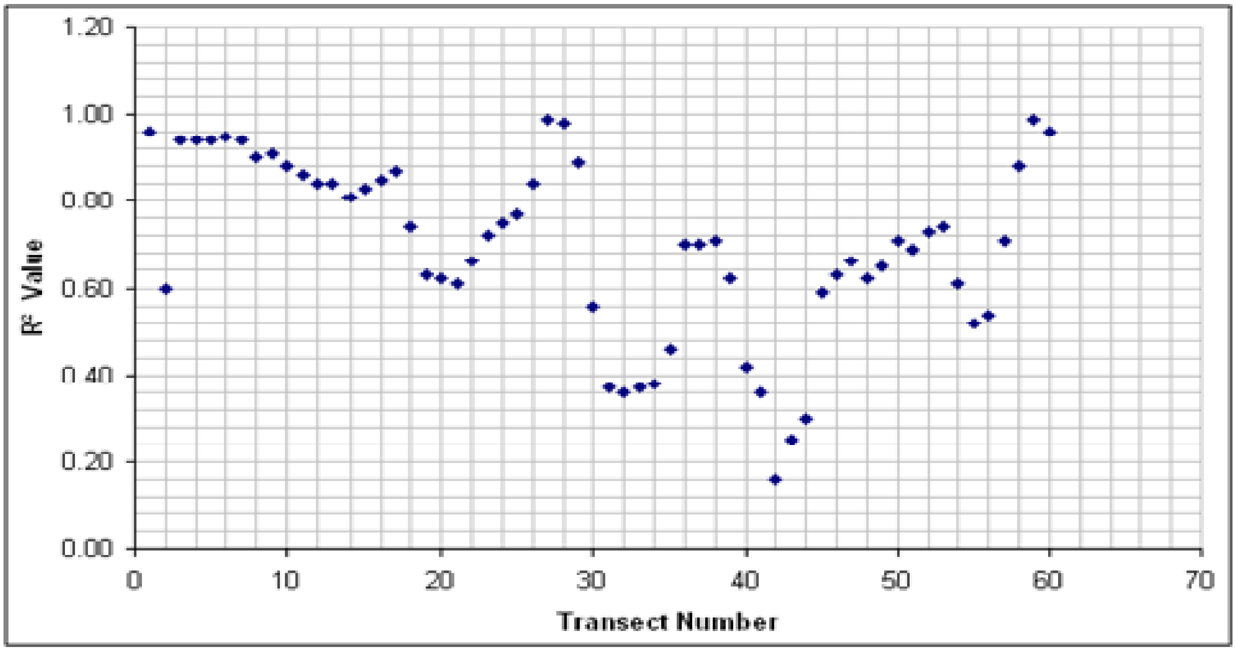

Figure-5
Distribution of R^2 values

Table-3
Erosion – accretion and net areal changes of Ghoramara Island during different intervals

	Area (km²)				
	1972-1979	**1979-1989**	**1989-2000**	**2000-2010**	**1972-2010**
Erosion	1.884	1.852	0.890	0.685	4.286
Accretion	0.625	0.374	0.003	0.024	0.000
Net change	-1.259	-1.478	-0.887	-0.661	-4.286

From 1979 onwards the apparent lateral shift of the island is observed towards the south eastern side. Continuous erosion on northwestern side and marginal accretion on the southern side is one of the major causes of shift of the island. The direct ebb tidal flow of river Hooghly hits the northwestern face of Ghoramara Island that causes the rapid erosion of this part. Moreover, the Hooghly River has a gentle slope towards the east so the main flow is in the eastern part. As the main flow touches the Northwestern part so this also increases the erosion in this part. Being an island of lying in the inland section of Hooghly estuary, the island is lying beyond the influence of wind generated waves. The tidal force does not hit the southern part of the island as it lies in the shadow zone of sagar island. This accounts for deposition in this part. This results in erosion in Northwestern part and marginal accretion in the southern part. The geomorphologic changes observed at Ghoramara are the result of changes in estuarine hydrodynamics. Lohachara and Supribhanga lying to the southwest of Ghoramara are already drowned under water where as a new island balari bar has been grown in northern part of the estuary. All these changes affect the hydrodynamics of the estuary. A continuous sea level rise is also reported in this region where as due to shift of the Hooghly river course due to tectonic uplift decrease the fresh water influx. The island system is stable under high fresh Water influx. The farakka barrage was constructed by Kolkata Port Trust in 1975 to overcome the problem, but this has only improved the situation marginally but does not fully solve the problem. Due to low fresh water influx the siltation along the navigational channels is a major issue. The study shows the net area lost over past 38 years is around 50%. Figure 7 also shows that island has shrunk over time.

The areal reduction affected the land use and land cover of the island also. There is major loss in cultivated paddy field area from 292.72 hectares in 1972 to 113.49 hectares in 2010. The uncultivated land area also decreases from 272.52 hectares in 1972 to 129.33 hectares. Fisheries also decrease from 4.68 hectares in 1972 to 1.71 hectares in 2010. The only remedial measure for counter balancing the erosion is to increase the vegetative cover of the island. So the land plantation that includes the plantation of mangroves, caesarians and bamboos is increased. Around 29% of the area is covered by land vegetation. The net area is reduced from 941.76 hectares to 488.3 hectares in 1972-2010. Table 4 shows the change of land use and land cover area in different years. Figure 7 and Table 4 represents change of land use land covers area of Ghoramara island from 1972-2010.

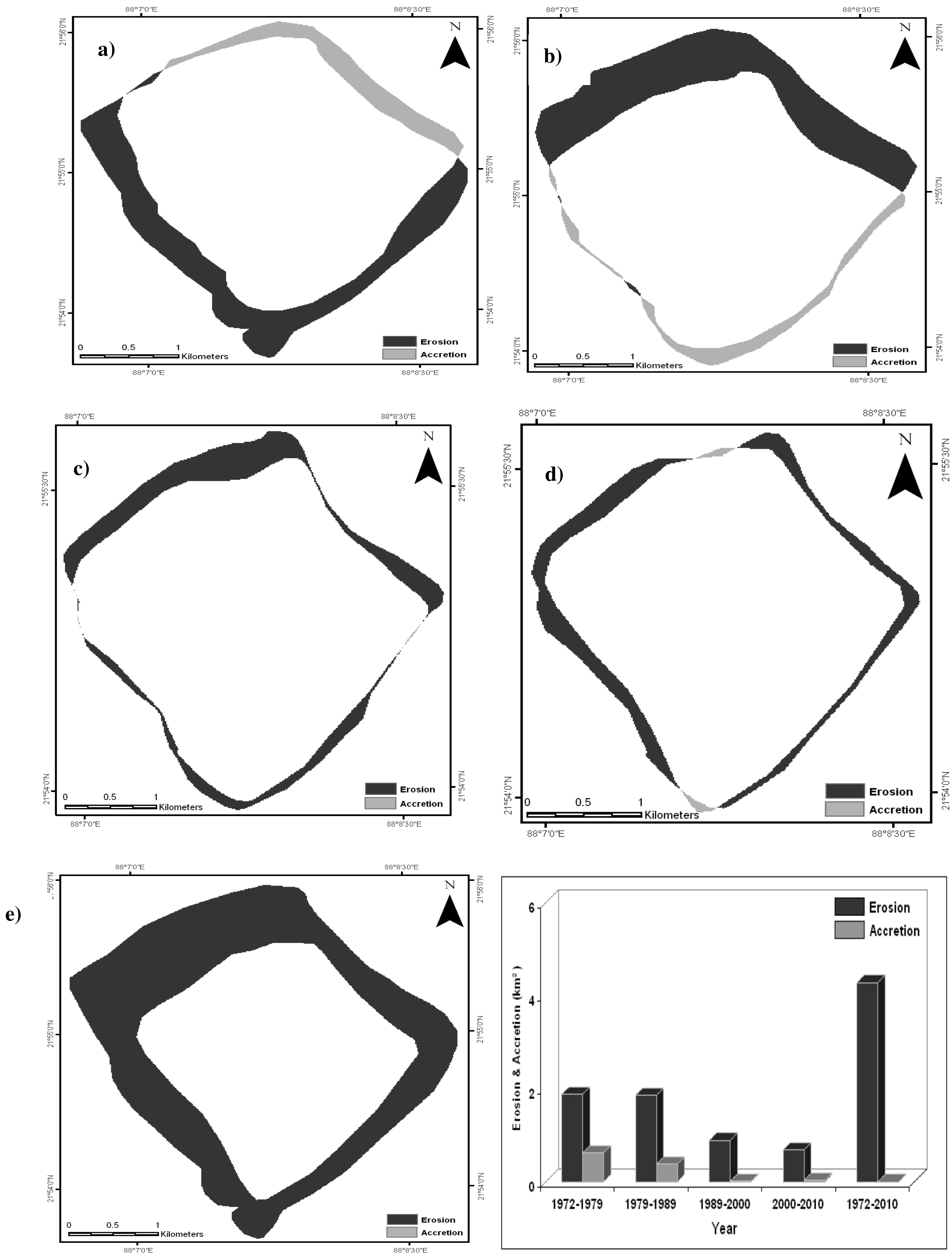

Figure-6
Bank erosion and accretion around Ghoramara Island and shifting of shorelines in different years: a) 1972-1979; b) 1979-1989; c) 1989-2000; d) 2000-2010; e) 1972-2010. Bargraph shows the erosion-accretion between successive years

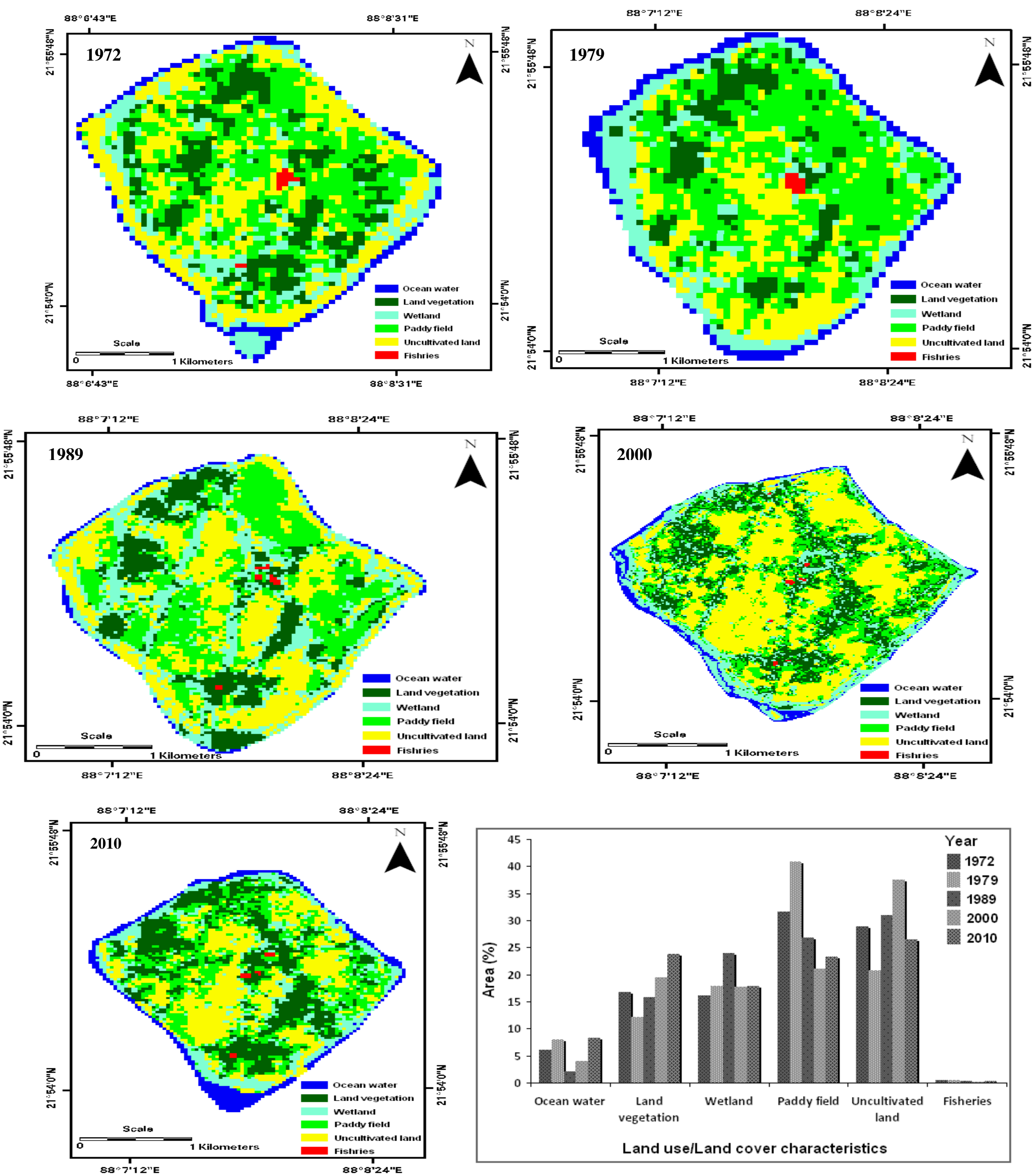

Figure-7
Spatial changes of land use land cover in Ghoramara Island over different years. Bargraph shows the area by percentage of landuse/landcover in different years

Table-4
Area coverage by hectares and percentage of each land use/land cover class for different years in Ghoramara Island

Class name	1972		1979		1989		2000		2010	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Ocean water	57.6	6.12	64.75	7.93	13.68	2.11	22.55	4.05	40.32	8.26
Land vegetation	157.68	16.74	99.35	12.16	102.96	15.85	108.50	19.48	116.37	23.83
Wetland	151.56	16.09	145.86	17.86	155.52	23.94	98.75	17.73	87.21	17.86
Paddy field	297.72	31.61	333.03	40.77	174.24	26.82	117.09	21.03	113.49	23.24
Uncultivated land	272.52	28.94	170.05	20.82	201.33	30.99	208.76	37.49	129.33	26.48
Fisheries	4.68	0.50	3.72	0.46	1.89	0.29	1.22	0.22	1.71	0.35
Total area	941.76	100	816.76	100	649.62	100	556.85	100	488.43	100

Conclusion

Using multi-resolution satellite data along with the statistical techniques shorelines during different years around Ghoramara Island have been extracted. Results show a very dynamic shoreline behavior. The island is undergoing rigorous erosion and it has been calculated that the island has lost almost 50% of its area over four decades due to severe erosion around all sides. The decrease of fresh water influx in the Hooghly River due to natural and anthropogenic causes is major cause of the instability of the island system. Transect wise study decipher erosion in almost all directions. The maximum erosion occurs on the northwestern side and a marginal accretion occurs in south as this part lies in the shadow Zone of Sagar Island. The rate of erosion is much higher than accretion rates that cause the island to shrink over time. Land use land cover map also show a drastic reduction in the area of agricultural land and fisheries. Land use land cover calculations also showed that the island total area has been reduced drastically from 9.09km² to 4.8 km². All the calculations have been done using remote sensing and GIS techniques that fit with the empirical observations on the island.

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