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Change detection analysis of the shoreline using Toposheet and Satellite Image: A case study of the coastal stretch of Mandarmani-Shankarpur, West Bengal, India

Santra Mitra S[1], Santra A[2], Mitra D[3]
1- School of Geography and Environment, University of Southampton, Hampshire, Southampton, PO: SO17 1BJ
2- BIT Mesra, Patna Extn Centre, P.O. Bihar Veterinary College, Patna 800014
3- Indian Institute of Remote Sensing, Kalidas Road, Dehradun- 248 001
shreyashi.mitra@gmail.com

ABSTRACT

Change detection helps in ascertaining shoreline trend analysis and its future prediction. In this study, the coastal tract of the part of West Bengal, which is sensitive to rapid shoreline change is chosen. Applying remote sensing and GIS techniques on the multi-temporal satellite image and topo-sheets, shoreline extraction using water index and subsequent change detection analysis have been carried out to assess the erosion-accretion pattern in the region at both regional and local scale. Depending on the erosional pattern, the entire study area was divided into four erosional-cells, and independent study was carried out in different cells. The results exhibit that this coastal region has been experiencing erosion. Excluding the contribution of inland water bodies, it has been estimated that between 1950 and 2005, a vast stretch of the land has been engulfed by the sea-water. This clearly signifies the necessity of coastal zone protection measures to be implemented in the area.

Keywords: Shoreline, change detection, erosion, accretion, water index.

1. Introduction

Being a transitional tract between land and water, coastal areas are considered to be one of the most complex, dynamic and sensitive geomorphic units that need to be under constant observation to follow and monitor the continuous changes, occurring there (Yanli, 2002, Alesheikh et al., 2007). Change detection in this regard, is extremely useful to assess the trend of the coastline shift depending on which future shoreline position could be ascertained or predicted under generating different scenario (Xuejie and Michiel, 2007). Even more, the historical and functional approaches to monitor shoreline changes help the geomorphologists in deciphering the coastal processes operating in the area (De Silva, 2005). The methods for change detection analyses vary across the countries and geographical characteristics (Di et al., 2004). In the past, when only conducting surveys was considered to be the most reliable means to carry out an Earth-Science related research, extensive field and measurements used to be carried out to measure ground position of coastline. However, manual error brings unsystematic errors that cannot be rectified easily (Wright and Coleman, 1973). Therefore, besides being cost-ineffective, laborious and time consuming, coastline detection error rectification was a voluminous and problematic task for the environmentalists at earlier days (Xuejie and Michiel, 2007). So this demanded substitution by the modern techniques. Remote Sensing has been a very efficient and capable tool for this purpose having the characteristic of taking instantaneous picture of the ground truth (Lillesand and Kiefer, 1997, Jensen, 1996). Modern scientific experiments rely on the remotely sensed data to obtain a physical diagnosis of the surface of the Earth. Taking advantage of this technology, major attempts have been observed in change detection studies. In this present study, an attempt has been made to use the remote sensing data and Survey of India topographical sheets for change detection assessment in a coastal tract of Mandarmani- Shankarpur area in India, which have been considered being experienced by the rapid coastal shift problem (Komar, 1976, Maiti and Bhattacharya, 2009, Santra et al., 2011). The objective of this study is to quantify the change of the coastal terrain over the time period between 1950 and 2005 using geo-spatial techniques, and present an explanatory account of the factors causing the erosion in the study area. This study expects to support the coastal planners through providing a statistical documentation of the geomorphological facts of the study area.

2. Materials and methods

2.1 Study area

2.1.1 Geographic location

India is blessed by a long shoreline enclosing the State from three sides, i.e. East, South and West. Compared to the western part, the eastern coast of the Indian subcontinent, experience lots of dynamism in terms of the coastal stability (Chatterjee, 1995). West Bengal has a substantially long coastline of almost 100 kilometres (including island) characterised by high floral and faunal biodiversity, diverse geomorphic features and anthropogenic intrusions (Bhattacharya, 2001, Bhattacharya et al., 2003). The area selected for this study is the part of this extensive shoreline of Bay of Bengal along the West Bengal coast (Figure1). The coastal stretch is about 22.40 Km long extending from the eastern part of the Shankarpur to the Pichhabani inlet, including Mandarmani coast. The latitudinal and longitudinal stretch of the coastline is about 21°38'13.126"N to 21°41'16.034"N and 87°35'7.718"E to 87°46'14.29"E respectively. The coastal tract under study is mainly comprised of the Mandarmani coast, which is also known as Dadanpatrabar Coast and Shankarpur coast. Mandarmani or Mandarbani is situated in the Ramnagar II Block of the Contai Sub-Division of the District of East-Medinipur in West Bengal, whereas Shankarpur is situated at Digha block. Tidal height experienced in the study area is between 3 to 5 metres. Usually in the study area, located at the East Coast of India, the horizontal shift due to the tidal difference between high tide and low tide of the sea is approximately 3 to 5 metres (approximately) compared to 9 to 11metres at Western coast of India (Chatterjee, 1995).

2.1.2 Geology and Geomorphology

The geological history of the coast is comparatively short and the coast is still in its formative state (Bhattacharya and Sarkar, 1996). Its present day situation is the consequence of fluvio-tidal and coastal processes that has resulted from the on-lapping sequence of Flandrian transgression, > 5900 yrs B.P. and off-lapping sequence of delta progradation untill the sea level gets stabilised at around 3000 years B.P. (Chakraborty, 1990). This coastal tract has varied geomorphologic features. The beach has a linear almost east-west extension of variable width. Morphodynamically the beach has a dissipative profile (Short, 1983) with high compaction of sediments and a gently sloping gradient towards the sea. The back-shore beach is featured by a number of dune trains with undulating surface. The southernmost dune-tail lies along the lower marine terrace. Dunes present on the coasts are covered with halophytic creepers and herbs. When the sea recedes, the dunes move forward and change their place. The foreshore beach is generally flat, slightly concave upward to gently undulating, often with upper and lower beach faces. Surface sedimentary structures include backwash ripples, rhomboid marks, crescentic, wave- and interference ripples of ladder-back types, current crescents, rill marks and swash marks (Komar, 1976).

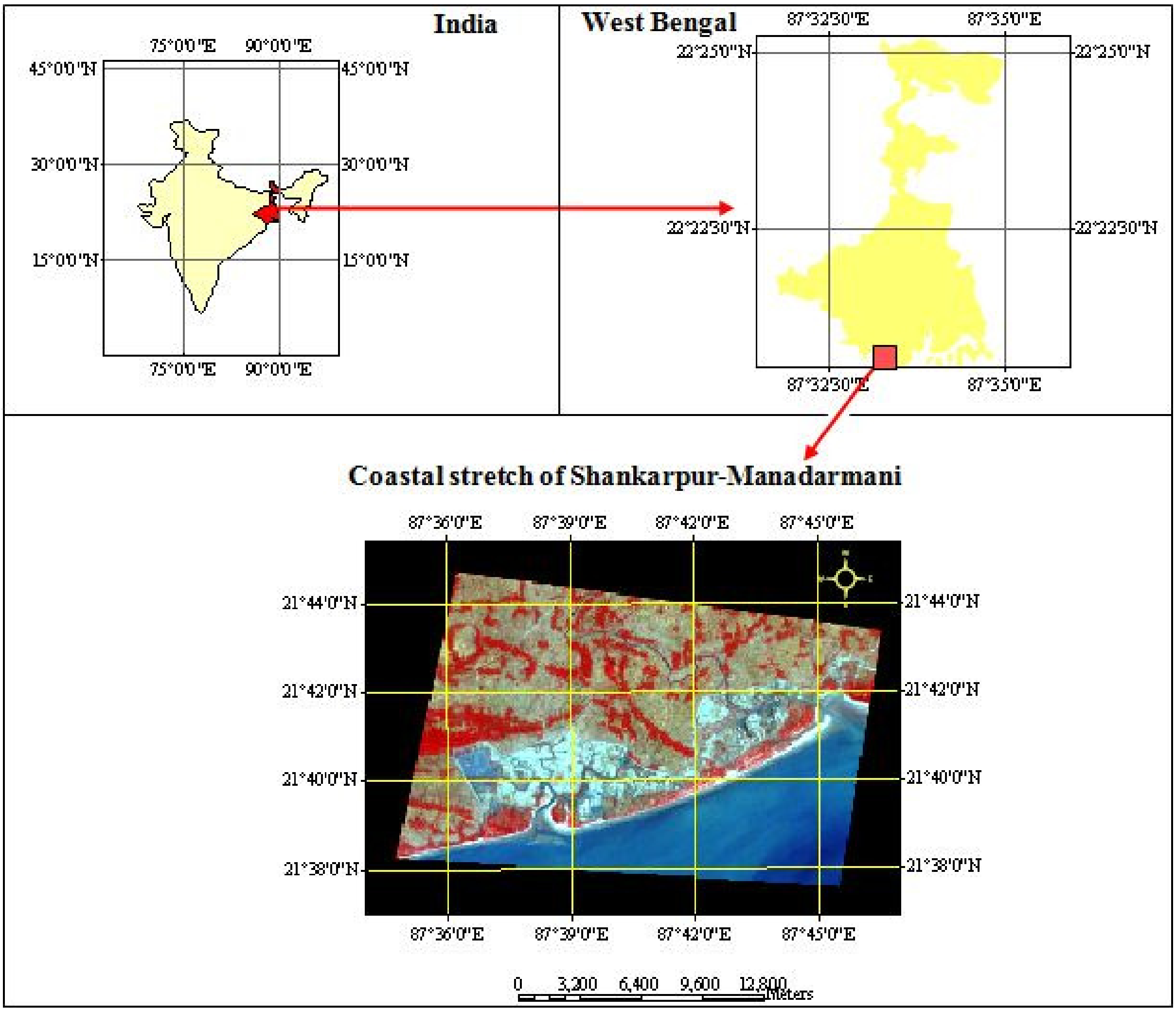

Figure 1: Geographical location of the study area

Cut-out trenches reveal alternation of seaward dipping cross-beds and parallel beds reflecting deposition from low tide and high tide respectively (Bhattacharya et al., 2003). The transition zone, in between and foreshore and backshore, changes its position in time and space depending on the fluctuation of high water spring and neap tides. This zone is characterised by a spectrum of surficial and internal, sedimentary and biogenic structures (Bhattacharya, 2001).

2.1.3 Tidal Influence

Tidal height experienced in the study area remains between 3 to 5 metres (approximately). Usually in the study area, situated at the East Coast of India, the horizontal shift due to the tidal difference between high tide and low tide of the sea remain 3 to 5 metres (approximately) compared to 9 to 11metres at Western coast of India.

2.2 Materials used

The biggest challenge, while making the database for change detection of shoreline is the difference in the position of the water due to the tidal height differences. If the image is acquired at the time of high tide then there is a possibility of misclassification of land into water and vice versa (Selvavinayagam, 2008). So to avoid the problem and also for accurate change detection analysis, those images were selected whose tidal situations were almost similar during image acquisition. The tidal information was acquired from the Indian nautical almanac. The multi-temporal data set prepared for the work is listed in table 1. Entire change detection analysis has been done using ERDAS 9.1 for digital image processing and ARC GIS 9.2 for geospatial analysis.

Table 1: Details of the data used for change detection

Data	Chronological order of Preparation/Acquisition	Scale/Spatial Resolution
Survey of India Toposheet	1950	(1:250,000)
Survey of India Toposheet	1963	(1:50,000)
LANDSAT 5 TM	1990	28.5m
IRS IC LISS-III	2000	23.5m
IRS P6 LISS-III	2005	23.5m

2.3 Methods

Atmospheric scattering caused by atmospheric particles often obscures the exactness of the reflectance values of the ground features by adding some values with the original reflectance (Jensen, 1986). If the analyses involve consideration of multi temporal data, then this process becomes even more important as the atmospheric condition is expected to change all the time. Thus it is unlikely to produce same scattered energy in two different times. In this study, three multi date satellite images were considered. Therefore, to overcome the atmospheric contributions, atmospheric correction of the images was necessary. For this, the images were rectified for path radiance using Dark Object Subtraction method (Chavez Jr, 1988). For the simplicity and rapidity, the method is chosen. While applying this method, the pixel having minimum brightness value in each band of each image was detected and that value was subtracted from the pixel values in the corresponding band. This resulted into the atmospherically corrected images.

Accurate geometric corrections and referencing are the indispensible prerequisites to perform change detection analyses. Without this, the results will lose its reliability, and analyses would fail to diagnose changes accurately (Saha et al., 2005). Geometrically corrected Landsat ETM+ image was retrieved for this study. No additional measure was applied to further rectify the image. However, IRS LISS-III images require geometric registration. For the purpose, those images were rectified geometrically using 65 well scattered and distinct GCPs selected from Toposheet and Landsat ETM+ image. It is worth mentioning here that the selection of GCPs was restricted only to the land surface. For obvious context, water mass could not be used for GCPs selection. Intersection of roads, sharp bending of canals, reservoirs, etc. was selected as the distinct, stable, prominent features to be treated as GCPs. In the absence of these features at some portions of image, river bends have been chosen for two sites. Considering the nature of the surface of the study area, geometric transformation was done using polynomial 1st order (affine) equation. The overall accuracy of the transformation in terms of Root Mean Square Error was restricted to be within 0.1 to 0.2 pixel, which corresponds to 1 to 7 metres on the ground. Finally, the transformed image was projected in Universal Transverse Mercator (UTM) projection (WGS 84, zone: 45 North) using Nearest Neighbour Interpolation technique.

All the optical images, after geometric and radiometric corrections, were then digitally processed using the Water Index method. The Water Index is one of the band ratios where the sum of visible bands are divided by the sum of the infra red bands (Braud and Feng, 1998). The procedure aims at obtaining the sharp edge between water and land as water reflectance is more pronounced in visible bands, while absorption is dominant in the infrared band. Using this characteristic, this technique was applied on the images and threshold level slicing was done to distinctly separate landmass from the water. The sharp edge between the two classes refers to the coastline. Then in the GIS environment the sharp shorelines were digitized and the layers of multi date shorelines were prepared for 1950, 1963, 1990, 2000 and 2005 in the line feature class. Using the overlaying operations and spatial analyst tools the analysis for spatial and temporal change detection had been done.

To study the spatial change pattern along the shoreline, 45 cross sections (Figure 2) were taken arbitrarily almost at the 90º angle across all the shorelines, digitised and amount of the shift of the shorelines in a certain time-interval were measured. It gives the spatial shift of the shoreline over the time. Then cells were generated over the total amount of shifts.

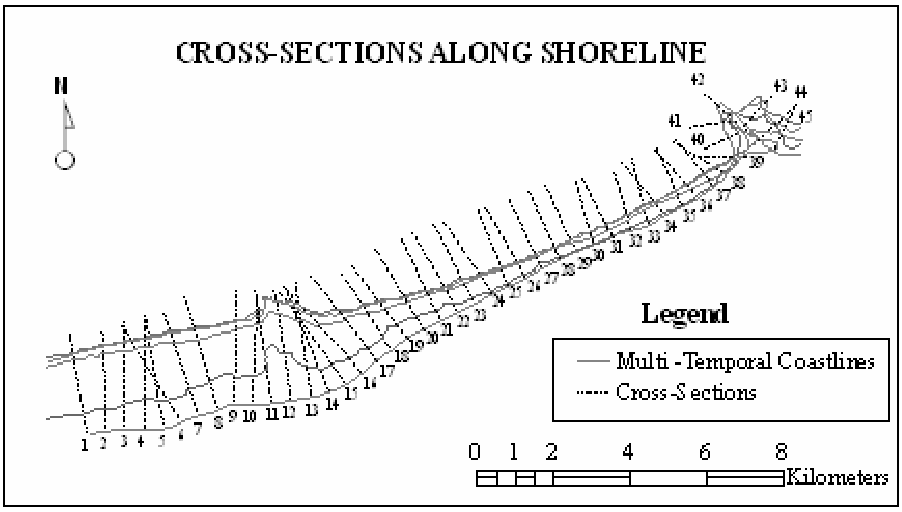

Figure 2: Cross-sections at right angle of the base shoreline of 1950

The change in land cover classes was done for the period of 1990 to 2005 because of the non-availability of the satellite images prior to 1990. The satellite images were classified along the coast into five classes namely tidal mudflat, sandy beach, vegetation, agriculture and Aqua culture. Then change of each land cover class over time was analysed to assess the impact of the coastal shift on the land cover system.

Extensive field study was done for the collection of the information of the present condition of the coastal status. The probable reasons for the rapid change of shoreline were tried to be conceptualised by the local interaction and field survey. The finding of the project was tested by the field survey as well for the confirmation of the facts.

3. Results and Discussions

3.1 Spatio-Temporal Change in Shoreline position

The shoreline in the study area has never been constant and shows a continuous changing pattern (Figure 3). Both the spatial and temporal variations in the deposition and accretion have been observed in the study area. The temporal intervals (being 1950 to 1963, 1963 to 1990, 1990 to 2000 and 200 to 2005) used in the study for assessing the changes have not been uniform. However, the erosion and accretion patterns clearly show a continuous geomorphic sculpturing over the coastal tract in each temporal gap. Erosion works as a constant factor for the coastline modification in the most of the areas, whereas a small segment near Pichhabani inlet shows deposition. In the western part of the study area erosion was prominent between 1950 and 1963. However, it gets more distinct between the time intervals of the next 27 years. In the following 15 years, the coastline shows a gradual shift towards adjacent land as a consequence mainly of wave erosion. Analysis shows that the proportion of land and water has been continuously changing in the study area (Table 2) along the coastline. Excluding the contribution of inland water bodies, it has been estimated that between 1950 and 2005, almost 10% of the land has been engulfed by the water.

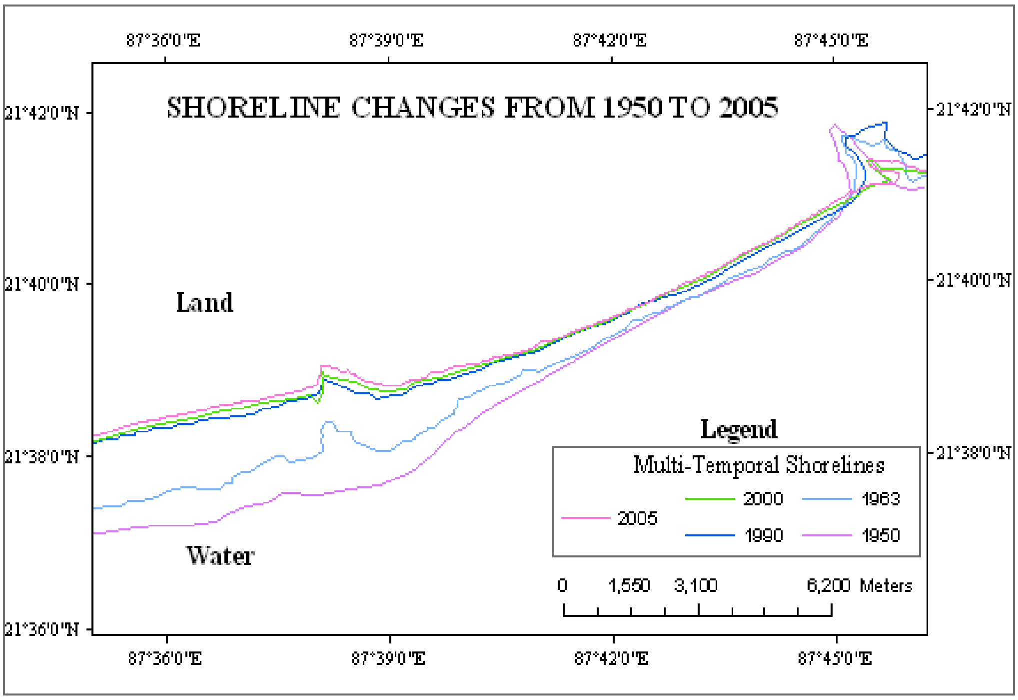

Figure 3: Changes of shoreline over time from 1950 to 2005

Table 2: Water and land proportion change over time

Years	Water (Area)		Land (Area)	
	Ha	**% to total**	**Ha**	**% to total**
1950	8195.87	31.15	18113.34	68.85
1963	8999.13	34.20	17310.08	65.79
1990	10334.66	39.28	15974.55	60.72
2000	10379.68	39.45	15829.53	60.55
2005	10638.02	40.43	15671.19	59.56

Total accretion is considerably less with respect to erosion (Table 3 and Figure 4). Whereas between 1950 and 2005, 837.03 ha were eroded from the coastal surface, only 33.77 ha accretion has occurred. This pattern of erosion and accretion indicates that the equilibrium between erosional and accretional processes in this spatial unit is towards negative, which is rather indicative of relative isostatic instability in near future.

Table 3: Erosion-accretion rate

Time gap	Erosion (Area)		Accretion (Area)	
	Ha	**% to total**	**Ha**	**% to total**
1950 to 1963	837.03	3.18	33.77	0.001
1963 to 1990	1356.43	5.16	20.90	0.001
1990 to 2000	158.59	0.01	13.57	0.001
2000 to 2005	167.26	0.01	8.92	0.0001

[N.B. In this table gross accretion and erosion along coast is shown. For eg. though from 1950 to 1963 total net land lost is 803.03 ha, it is inclusive of accretional effect of 33.77 ha increase. So total erosion is 837.03ha but net land eroded is (erosion-accretion)=nit erosion ha]= (837.03-33.77)=803.26 ha]

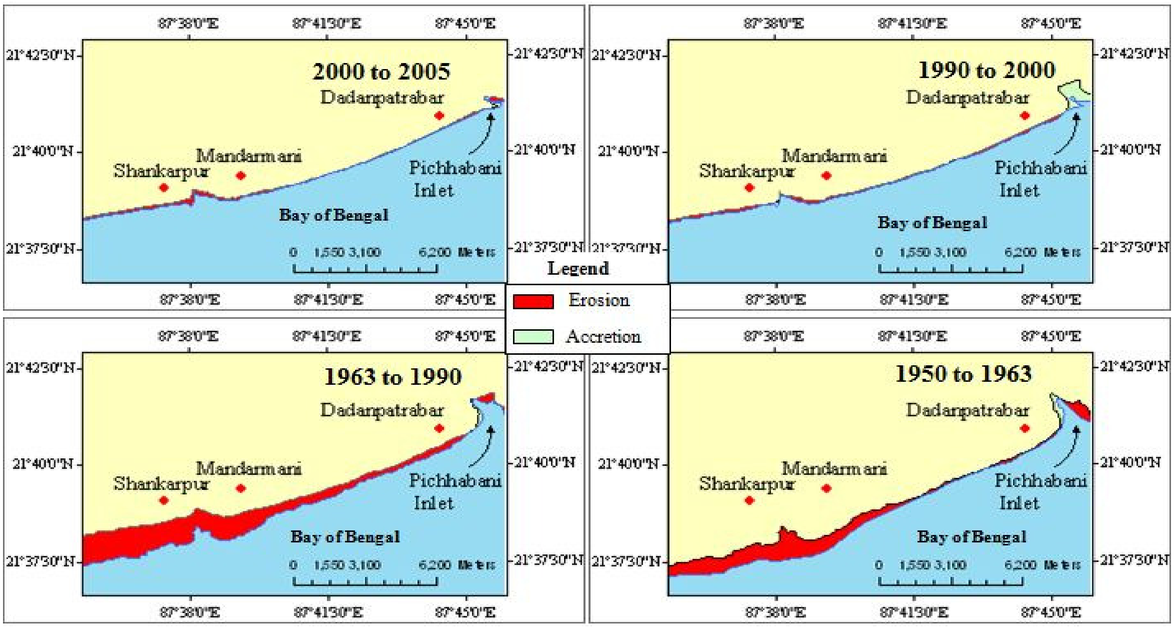

Figure 4: Spatio-temporal occurrence of erosion and accretion from 1950 to 2005

Relation of erosion and accretion with time has not been linear at all the places. The localized trend of the variation in degree of erosion has to be estimated to divide the coastal stretch in several erosion-prone regimes. For this the linear shift of the shoreline from 1950 to 2005 has been tried to be estimated with the help of some cross sections (Table 4). The results evidently support the fact that the shoreline shift over the time has not been constant. Dynamism of the coastal tract has been prominent all along the coastal stretch of the study area. This result may be seen as a supportive documentation of the findings of Maiti and Bhattacharya, 2008. Their conclusions evidently show the erratic expansion and contraction of the shoreline towards the sea floor of Bay of Bengal.

According to the total landward-shift of the coastline from 1950 to 2005 along the cross sections, the entire stretch has been divided into four cells having different degree of erosion induced coastal shift. These cells are nothing but a zone based on the prevalent dominance of erosion, and has been designated as erosional cell in the study. The cell 1 corresponds to the shift above 1500m, cell 2 between 1000 and 1500, Cell 3 to 500 to 1000 and cell 4 to below 500m (Figure 5).

Table 4: Linear shifts of the shoreline across the cross-sections

Cross Section id	Linear perpendicular Shift in m			
	1950 to 1963	1963 to 1990	1990 to 2000	2000 to 2005
1	-707.81	**-1644.88**	-222.22	**-296.19**
2	-544.81	-1469.85	-58.92	-131.10
3	-680.97	-1408.76	-98.50	-131.72
4	-733.04	-1302.33	-124.26	-130.85
5	-811.07	-1392.20	-86.31	-106.82
6	-738.42	1439.55	-108.17	-110.86
7	-671.11	-1567.65	-125.19	-130.64
8	-781.68	-1140.42	-184.50	-129.96
9	-724.43	-1260.11	-49.03	-134.69
10	-760.74	-1353.34	-8.31	-189.50
11	-925.06	-1211.60	-87.52	-270.95
12	**-1267.85**	-1028.74	-108.35	-223.28
13	-853.35	-1183.59	-193.93	-129.14
14	-679.55	-1362.78	-247.62	-209.45
15	-625.06	-1452.83	**-279.20**	-277.45
16	-523.27	-1176.35	-237.04	-194.89
17	-402.90	-984.53	-76.75	-117.53
18	-393.98	-798.90	-87.18	-137.88
19	-477.28	-532.77	-99.22	-118.89
20	-404.17	-425.41	-92.77	-51.92
21	-290.87	-482.60	-36.69	-61.98
22	-274.33	-389.62	-43.74	-36.55
23	-147.12	-440.57	-47.36	-78.68
24	-79.78	-450.40	-45.33	-21.29
25	-48.96	-410.72	-31.30	-25.62
26	-86.64	-319.34	-27.40	-26.86
27	-124.56	-216.84	-40.80	-15.90
28	-83.41	-263.87	-27.92	-12.18
29	-22.14	-229.56	-52.13	-26.34
30	--0.48	-202.85	-98.18	-42.01
31	-14.00	-230.78	-91.59	-43.98
32	-68.24	-211.70	-107.74	-26.42
33	-135.26	-278.87	-75.62	-32.67
34	-70.85	-275.83	-77.81	-33.02
35	-74.33	-269.29	-96.70	-38.59
36	-65.66	-275.89	-115.23	-41.64
37	-52.50	-152.75	122.27	-67.16
38	-102.36	+29.26	+144.38	+111.10
39	+85.52	+139.66	+52.20	+146.32
40	+262.55	+127.54	+152.12	+91.11
41	+221.67	-64.96	+121.94	+280.07

42	+356.96	+122.67	+187.48	+374.87
43	+205.84	**+848.86**	**+598.68**	**+646.96**
44	-53.90	-147.67	-54.33	-20.89
45	**+489.27**	+184.67	+329.19	+240.60

Highest negative shift   Highest positive shift

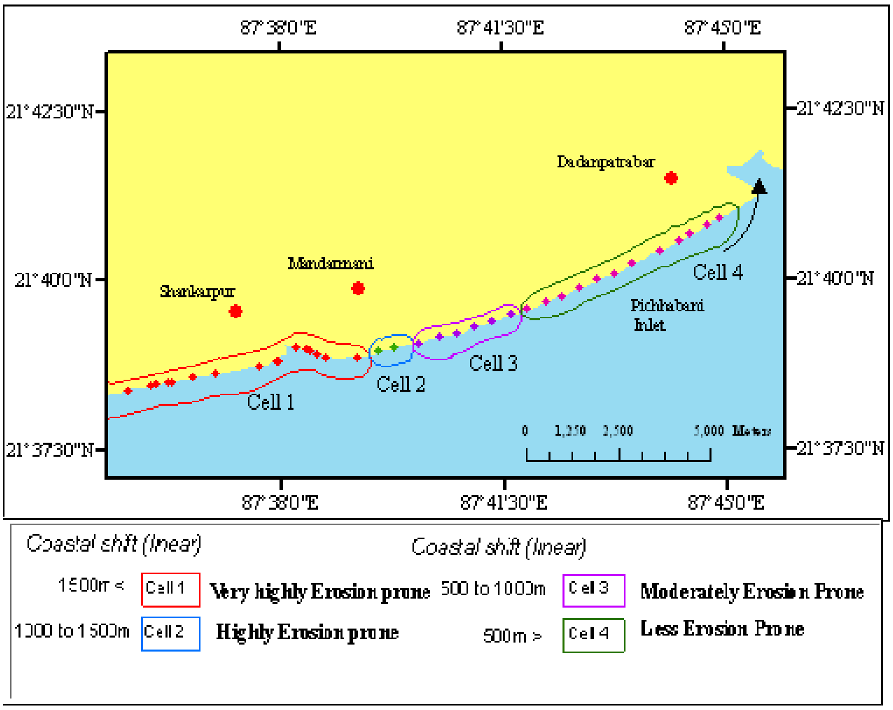

Figure 5: Erosional cell along the coastal tract depending on the total coastal shift from 1950 to 2005

The Eastern part of Dadanpatrabar has not been taken into consideration as there depositional activities are much stronger than erosion.

The entire analysis of the change detection comes to the conclusion that the entire study area can be divided into two regimes depending on the spatio-temporal coastal change pattern -

1. Shankarpur to the western portion of the Dadanpatrabar sector chiefly under an erosional regime and
2. Eastern portion of Dadanpatrabar to rest of the study are belonging chiefly to accretional regime.

This sort of dual manifestation is caused by the interaction of several factors. Previous studies, researches and field observation of the authors could provide some probable causal explanation to this nature of increased coastal erosion. Extensive geological evidence gathered by Bhattacharya et al. (2003) confirms that this coastal stretch belongs to a mesotidal (tidal amplitude 2-4 m) regime having semidiurnal tides with slight diurnal inequality. On the other hand, the impact of macrotidal (tidal amplitude >4m) Hugli (river) estuary is more pronounced towards the eastern part of the study area (Chakraborty, 1990). The moderate to high tidal amplitude creates tidal currents which act as an effective means for reworking the tidal and estuarine sediments (Bhattacharya et al., 2003). The coastal zone is, on the other hand, characterized by sea facing sand dunes (Chatterjee, 1995, Bhattacharya et al., 2003). When slightly high amplitude waves attack the base of the sea facing sand dunes, it leads to freefalling of loosened sand particles from dune tops. The sands so avalanched are heaped up as fan deposits at the base of the dunes and later mixes with foreshore beach materials. . Rip currents and alongshore currents mixed with this foreshore sands hit the coast at mutually right angle directions in most of the places along this coast (Bhattacharya, 2001). This geomorphic process leads to landward retreat of the beach, lowering of beach profile and loss of dune vegetation. Nevertheless, the trend changes towards the eastern sides of the study area where waves are observed to hit the beach at 30 to 40 degree angle. Besides, some riverine deposition of river Hooghly is observed here (Kuehl et al., 1997). These two factors substantially reduce the erosion in that part of the coastal zone. Apart from this gradual process, as a part of Bay of Bengal coast, the study area usually gets struck by the severe cyclonic storms (Kalboishakhi) atleast 2 to 3 times per year (Rana et al., 2010). The wave height in this storm sometimes crosses 8m. This aggravates the erosion process along the coasts toppling all natural and man-made barriers behind the backshore. Researches of Unnikrishnan and Shankar (2007) also highlighted a sea level rise as another probable cause of a coastal breach in this section of the Coast. The sea-level rise estimated near Digha Shankarpur (near Vishakapatnam coast) area1.06– 1.75 mm yr−1, with an average of 1.29 mm yr−1. It has also accelerated the coastal erosion in the study area. Besides these natural forcings of the shoreline modification, the authors have also identified anthropogenic activities as one of the major causes of the shoreline breach specifically near the Shankarpur coastal stretch. In addition to the Government endeavour, every year, some hundred thousand rupees are spent in building parallel- to -shore dykes made of sand-filled bags in this region. All these constructions have strong detrimental effects on the coast as these accelerate the erosive power of the waves. Each time, when the sea waves dash against the protective devises, (which also hit equally hard against the beach) they erode the embankments much faster, lowering the beach profile and retreat of coastal terrain.

3.2 Limitations of the study

The methodology of the study though has been tried to be framed as scientifically as possible, due to some data constraints there has been a trade off between the accuracy and approach of the research. As the study is supported by a database with irregular intervals, a definitive erosion rate was difficult to portray. The purpose of the study was to point out the geo-morphological facts, which is causing a instability in the study area along with some quantitative explanations. The major prospect of this study is to carry out an extensive modelling upon the shoreline prediction for the future using some scientifically approved approaches (Santra et al., 2011)

4. Conclusion

From the study, it has been observed that the entire terrain extending between Shankarpur-Mandarmani and Dadanpatrabar is under the threat of rapid erosion except the extreme Western parts where riverine accretion is taking place. About 2519.31 ha land has been eroded due to the coastal erosion in this part in 55 years. However, this serious problem has not been able to raise adequate human awareness. It has been observed that tourism activities have continuously been vandalizing coastal tract for the sake of earning economic profit (Dishaearth, 2006). According to the Coastal Regulation Zone Notification (referred to as CRZ) dated 19 February 1991, under the Environment Protection Act 1986, no construction should be done in the area falling between the Low Tide Line (LTL) and the Highest High Tide Line (HTL) and even in the area falling within 500 meters of the landward side of the

Highest High Tide Line (Ministry of Environment & Forests, 1991). Ignoring this Act, within the reach of high tidal water (High Tidal Line = HTL) hotels have been set up violating the rules and regulations of CRZ, especially in Mandarmani and surrounding tracts. However in Shankarpur, a better scenario persists. The past record of the enormous loss and damage caused by the coastal breech, all the establishments are now shifted from 1 km (approximately) from the beach in Shankarpur. The government is undertaking several coastline protection measures to reduce coastal erosion. Evidently, this effort is confined to a small coastal stretch. Nevertheless, this sort of scattered effort is not conducive enough to protect the vast coastal tract of Mandarmani-Shankarpur area of West Bengal. In order to maintain the overall balance of the coastal morphology as well as the environment, care and awareness are required from every section, starting from the grass-root to government level. Otherwise, the coastal erosion may cause the loss of valuable treasures like Mandarmani and its immediate surroundings in the future, and they would only remain in history.

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