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Coastal Geo-environmental Hazards and Its Management

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

This paper assessed and cartographically analysed the impact of recent coastal geo-environmental hazards upon coastal resources and also human life. Cyclonic storms, high wave action, tidal bore, coastal flood and also coastal erosion are the main geo-environmental hazards over the Bay of Bengal coastal area especially Kanthi coastal tract of west Bengal. Sea surface temperature over a period of 50 years was observed through this study to be changing up to the magnitude of about 0.019°C/year over the Bay of Bengal between the period from 1972-2005. As a result accelerated trend for the genesis and favourable condition for the sever cyclone of 1978, 1988, 1989, 1995, 2009, 2010, 2011, 2012 and 2013 and local sea level has risen, on average 15 cm/last 3 decades. High wave action and coastal flood due to cyclonic storms and also high rainfall during the monsoon seasons (In record and evidence of highest sea gauge during the last 30 years generally increasing which relatively 2 m to 3 m) have been affected to coastal environment. On the other hand, coastal erosion is another geomorphic hazard identified in this study to be due to high wave action during the cyclonic period and also monsoonal season. In result about 25 m to 50 m/year coastal land has been eroded at Digha-Shankarpur and adjoining coastal tract. For this reason, the popular and famous beach tourism spot Digha-Mandarmoni of West Bengal has been extremely affected and also destroyed the gentle sea beach in recent time. Agricultural crops mainly food grains, vegetables, cashew nut, betelvine and many commercial crops and horticulture have been affected by the geo-environmental hazards of this area. So, resource depletion and resource crisis

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are the main problems of this area in recent time. Other hand the numerous number of geo environmental hazards through the year have been attacked to the coastal inhabitant. For the reason coastal people of the Kanthi coastal area has been suffering continually during the last 50 years. As a result thousands of people are environmentally refugee. So, it is right for the planning of coastal zone management by the proper and cartographic techniques.

Keywords: Sea surface temperature; local sea level; environmental hazards.

1. INTRODUCTION

Coastal zone is the area of interaction between land and sea. It includes both terrestrial as well as marine resources, which may be renewable as well as non-renewable. In addition, interactions between various natural processes and human activities are important factors in the coastal area. Coastal communities are more vulnerable to climate change because in addition to metrological parameters they are also affected by changes in oceanic parameters, especially increases in sea level and wave heights that will in some cases represent physical social and economic impacts on community. The coastline of West Bengal along the Bay of Bengal is about around 350 km and is dominated by the Ganga delta, which covers around 60 percent of this coastline. The elevation of the coast in the southernmost region is <3 m above the sea level [1]. This coastal tract can be divided into two distinct zones based on the continuous erosion and accretion. When the resultant sediment transport entering a particular area is greater than the sediment going out from the area, accretion or beach development takes place. On the other hand, when there is a deficit of the incoming sediment supply into a particular area with reference to the sediment going out of the same area, beach erosion takes place. So, coastal erosion is the most important geomorphic hazard in recent time of this area. According to the researchers, the major cause of coastal erosion and shoreline change is sea level rise [2]. Sea level rise is one of the frequently effects of global warming which has a direct role in coastal erosion. It is a particularly ominous threat to the human community because a number of large cities and 10% of the world's population live in coastal areas within an elevation of 10 m from mean sea level [3]. According to Miller and Dougla (2004), the global sea level has risen, on average, by 1.5-2.0 mm/year in the last century and since 1993, the rate has increased to 3 mm/year [4]. The latest IPCC Report [5] predicts that the global sea level will rise by about 60 cm by 2100 AD. By field investigation and throughout variation of highest sea gauge 1977 to 2012, evidence indicate that a general sea level rise along this coastal tract. (In record and evidence of highest sea gauge during the last 30 years generally increasing which relatively 2 m to 3 m). Through the highest sea gauge data and field investigation it's have been detected that the local sea level has risen remarkable along this area over the last 30 years, the rise of sea gauge and also local sea level increasing about 15 cm/last 3 decades. Digha - Junput coastal tract over which this study has concentrated is a part of Kanthi coastal plain of Purba Medinipur, West Bengal (Fig. 1). The extents of the study area is between Latitude 21°36′50″N to 21°43′00″N and Longitude 87°29 ′40″E to 87°49′30″E. The length from Digha to Junput coastal tract is 45 km and it has 4 blocks are Ramnagar-I, Ramnagar-II, Contai-I, Contai-II. The elevation of the coast in the southernmost region is <3 m above the sea level [1].

1.1 Objectives

Geo environmental study of any a coastal area in India appears to be a real challenge because of it's over changing conditions as well as the lack of availability of sufficient data. For the study of geo-environmental viz: coastal erosion, shifting of shoreline, change of geomorphology and land use is influenced by the micro level local change of sea level. Based on the forgoing scenario this investigation has been carried out the following objectives:

1. To study the changing climatic events through the last century (1917-2017).
2. To find out the changing nature of geomorphic hazards of this area.
3. To recommend a viable plan on the basis of geo-environmental study of the coastal area.

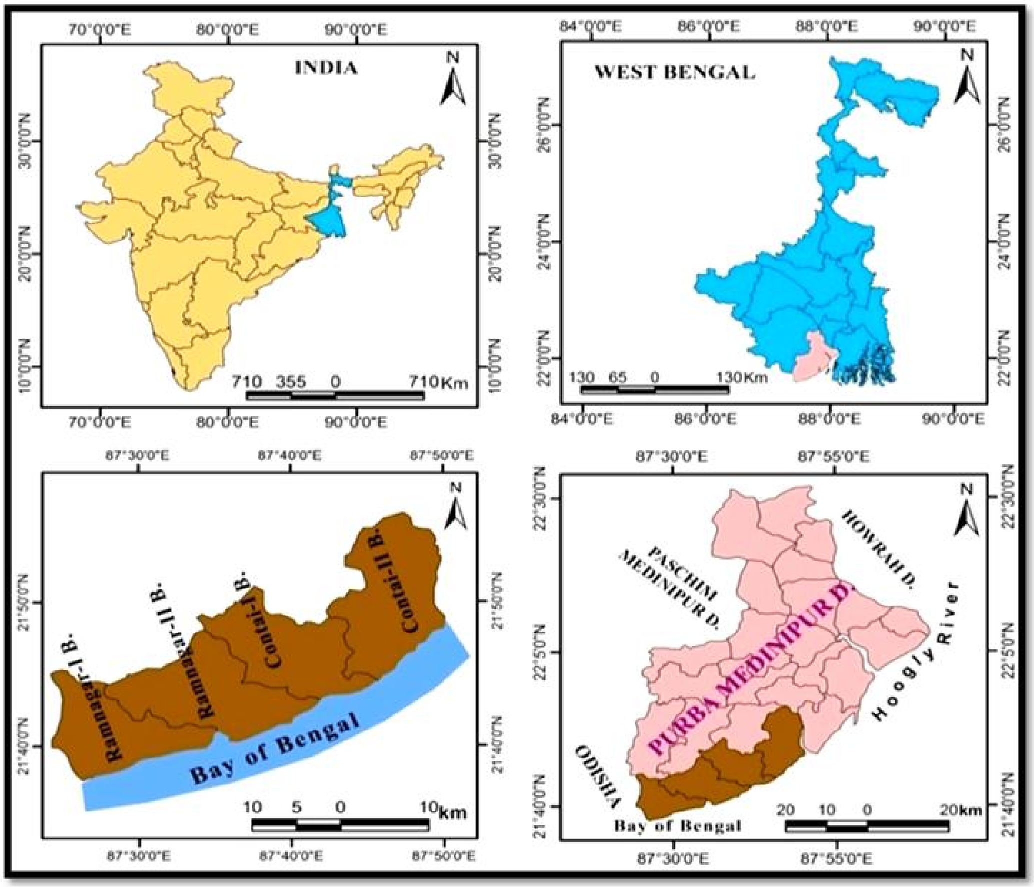

Fig. 1. Location map of the study area

1.2 Database

Data used for this study are –

1. Geological and Geomorphological Maps (1:50000) of GSOI (1995), Toposheet-73 O/6, 73 O/10, 73 O/14 (1931- ’32 & 1968- ’69) of SOI and Google map from 1936-2011
2. Local sea gauge data and cyclonic data.
3. Last 10 years (2007-2010) beach & dune erosion data of the study area.
4. Field observation and socio economic data.

2. METHODOLOGY

Intensive visits to the study area, extensive literature survey and experimental documentary analysis are three key measures to prepare this paper and for conducting this study. Reports of Geological Survey of India, Survey of India (SOI), Department of Tourism-Govt. of West Bengal, Department of Environment-Govt. of West Bengal, Digha Development Authority, Institute of Wetland Management and Ecological Design, Ministry of Forestry and Environment, etc. and recent research papers published in different regional, national and international journals and presented in different seminars, programmes, etc. are very essential and helping tools to complete this study. Basic cartographic materials like Geological and Geomorphological Maps (1:50000) of GSOI (1995), Toposheet-73 O/6, 73 O/10, 73 O/14 (1931- ’32 & 1968-’69) of SOI and Google map have been used. Besides these, different cartographic and GIS techniques have been applied as necessary as. Through field data generation and literature survey the author has attributed that this coastal tract is affected environmental hazards due to many natural and anthropogenic causes – mainly increasing sea surface temperature, sea level rise, high wave action, cyclone and unplanned construction etc.

3. RESULTS AND DISCUSSION

The key physical parameters that need to be understood to identify coastal erosion as a problem in the coastal zone are:

Table 1. Observed the various physical parameters of the study area

Parameters	Observed time
Air temperature	1965-2010
Sea surface temperature	2003-2009
Rainfall and Monsoonal pattern	1965-2015
Annul frequency cyclonic storms and depressions	1980-2015
Sea level rise	1977-2012

3.1 Air Temperature

The Kanthi coastal plain is extended extreme summer & short winter. There has been an observable rise in the surface air temperature that may affect the overall physical and socio-economic processes of this region. The air temperature observation in Digha for 35 years (1965-2010) reveals 0.6°C increased in the average daily minimum temperature and 0.1°C increase in the average daily temperature. After 1970, increasing trend is well marked and more marked after 2000 (Fig. 2). Another important observation is that the daily minimum temperature is rising faster than the daily maximum temperature resulting in a gradual decrease in diurnal range [6]. The researcher study; air temperature over the Bay of Bengal is rising at a rate of 0.019°C per year. If this trend continues, the air temperature in this area is expected to rise by 1°C by 2050 [7].

3.2 Surface Water Temperature

The surface water temperature in Kanthi coast (Northern and Southern sector) have shown significant rising trends for both pre-monsoon and monsoon periods. The researcher study, the annual composite sea surface temperature of Bay of Bengal near Haldia during the period 2003-2009 varied from 28.023°C in the year 2004 to 29.381°C in the year 2009. During the period the sea surface temperature showed rising trend at the rate of 0.0453°C per year [8]. This observed rate is found to be in conformity with the estimation done by Singh [9], which estimates a decadal rate of about 0.4°C to 0.5°C (Fig. 3). Rising sea surface temperature is directly related with the increased frequency and severity of cyclonic storms and depression in the Bay of Bengal. It is also reported that increasing trend in SST may result in changes to the chemical composition of sea water, leading to increased acidification & decreased dissolved oxygen level.

3.3 Rainfall and Monsoonal Pattern

The present analysis shows that there is a marginal increase in the monsoon and post monsoon rainfall over the last 10 years. The annual average rainfall of the Kanthi coast is 1625 mm. However in high rainfall years it goes up to 2000 mm and falls to 1300 mm during the low periods [8]. The analysis of rainfall data it's shows that intensive rainfall occurs during the monsoon season. Decadal

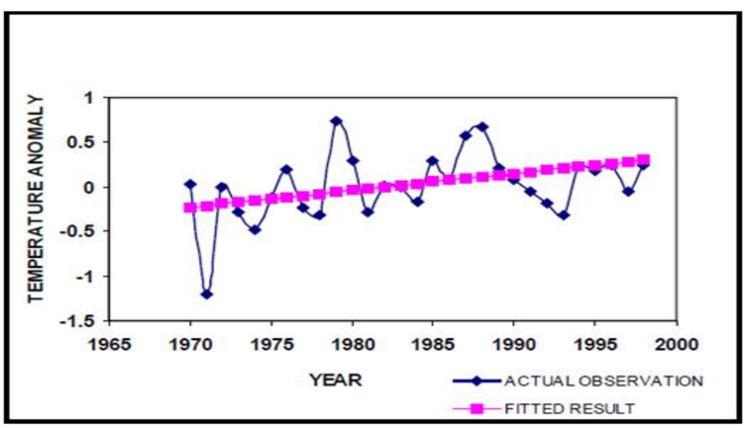

Fig. 2. An overall trend of atmospheric warming is evident over the land
(Source: Hazra, 2010)

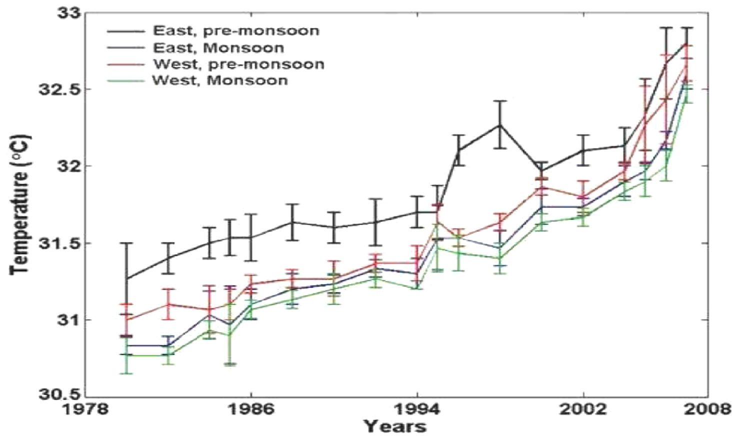

Fig. 3. Warming trend of surface water temperature during pre-monsoon and monsoon season
(Source: Mitra et al., 2009)

variation of rainfall pattern over Digha has been studied using the data from Indian meteorological department within the time window of 1990-2000; both the higher and lower rainfall values are more than the yearly average. A trend of marginal increase in total rainfall can be noticed within this time frame. The post monsoon rainfall however has increased significantly during the time window of 1971-2015 (Fig. 4).

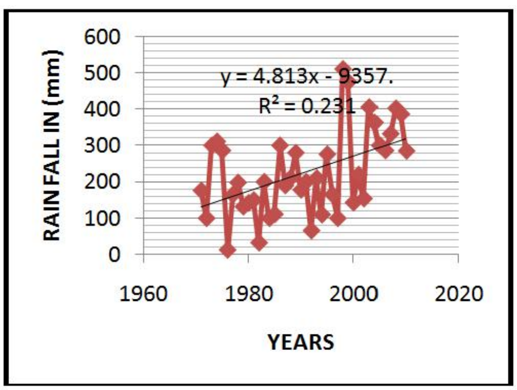

Fig. 4. Post monsoonal trend (1965-2015) in Digha
(Source: IMD, Kolkata)

3.4 Annul Frequency Cyclonic Storms and Depressions

Frequency of storms and depressions having direct bearing upon the distribution of rainfall in Sundarban and the adjoining coastal areas have been studied [10] for the period of 80 years (1891-1970). According to Singh [11] the severe cyclonic storms over Bay of Bengal registered 26% increase over the last 120 years, intensifying in post monsoon. During the last part of decade (2006-2009) the northern part of Bay of Bengal registered many cyclones *viz. Sidr, Nargis, Bijli* and *Aila Hudhud, Layla* etc. From the analysis of cyclone and surge data of the Bay of Bengal, a rise in the high intensity events like severe cyclonic storms has been observed and consequent damage and flooding can be inferred**.** This phenomenon has to be analyzed and explained further to see whether an increase in sea surface temperature is linked to the increase in cyclone intensity over the Bay of Bengal. During the last 35 years (1980-2015) although the total number of disturbances has reduced but the frequency of severe storms increased remarkable (Fig. 5). The cyclones bring high wind, heavy rain and storm surge causing embankment failure and devastation through saline water inundation. The cyclonic floods damage the houses, cultivable lands, ponds and washed away domestic animals.

3.5 Sea Level Rise

Digha - Shankarpur coast is a mesotidal coast, (where tidal amplitude varies between 2-3 meters). The tide, semidiurnal (i.e. high tide occurs twice a day) in nature, has some diurnal (once a day) influence also regarding height of the daily two high tide levels and low tide levels. We observed highest tidal position is obtained in the month of August creating maximum impact on the coast (Fig. 6). The relative mean sea level computed from the tide data of Digha - Shankarpur, supplied by the department of

Irrigation, Government of West Bengal while formulating the Integrated Coastal Zone Management Plan (unpublished) for the area, shows a definitely rising trend over the last 20 years. The rate of relative sea level rise is found to be over 3 mm/year and this makes some contribution to the coastal erosion over a longer time span [7]. Considering the present rate of temperature rise thermal expansion of sea water and higher rainfall there is a strong probability that the sea level rise will be 50 cm by 2050. This implies higher coastal erosion and inundation and a higher surge height during cyclones.

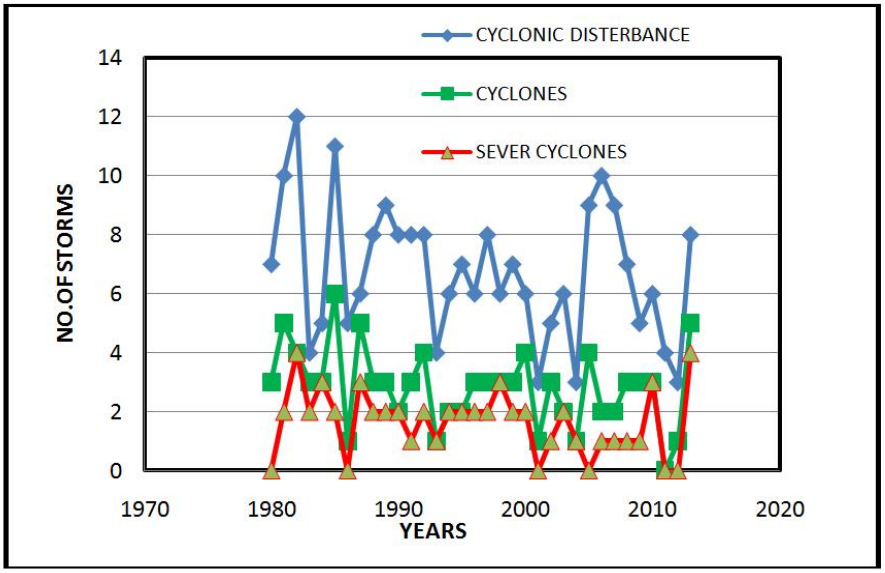

Fig. 5. Rising frequency of cyclonic storms over Bay of Bengal
(Source: IMD, Kolkata)

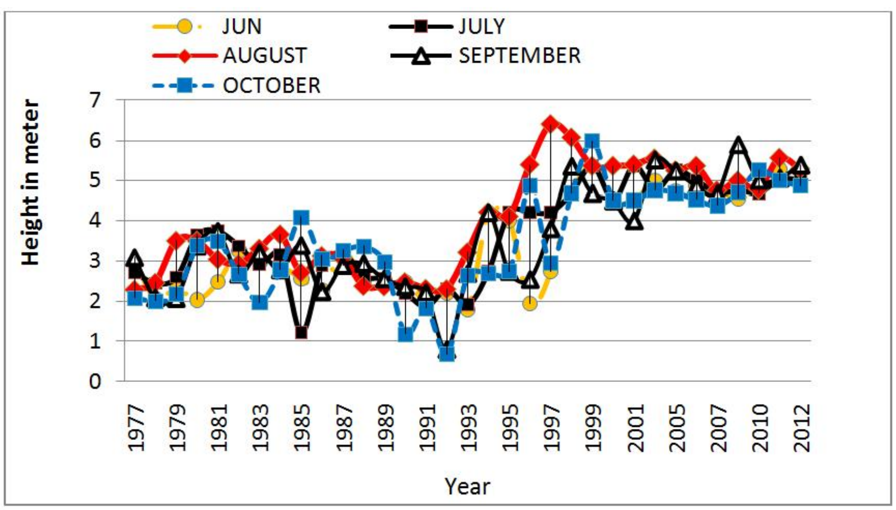

Fig. 6. Highest tidal positions is obtained in the month of August creating maximum impact on the coast

3.6 Anthropogenic Activity

Sand dunes are topographical height in the low-lying coastal plain of west Bengal. At present, of the entire coastal ecosystem, sand dunes have suffered greatest degree of human processes. Many dune systems have been irreversible altered through the activities of man, both by accident and design. Ecosystem components of the sand dunes are affected by the intensive use of dunes in the coast. Artificial structures like houses, hotels, fishery etc are disturbing the normal growth of the dunes and removal of sand by road cutting; grazing on the dune of Shankarpur - Mandarmani areas (Fig. 7). The level of grazing pressure is instrumental in determining species composition and dune plants are destroyed by growth of urbanisation, agriculture and costal defence programme. On the coast over the last 20^{th} years the large scale of tourism-related development rapidly increased the dune in Digha, Shankarpur, Tajpur and Mandarmani areas.

3.7 Type of Coastal Geomorphic Hazards

The type of coastal geomorphic hazards on the basis of present study in Kanthi coastal tract in the following ways-

- Beach erosion
- Dune erosion and shifting of sand dunes
- Shifting of shoreline
- Coastal flood

3.7.1 Beach erosion

The high energy coastal fringe sandy tract is well marked by wide beach plain and associated shoreline dune ridge around Shankarpur - Dadanpatrabar coastal plain. The beach fringed dune sector is under treat of rapid erosion in many parts of the sandy tract. Steep storm waves attacking a sand beach are usually destructive in their effect, moving sand to deeper water off shore [12]. Shankarpur and Chandpur beach are sinking at the rate of 15-20 cm per beach lowering during the month September, 1965 was even by 30-50 cm around Shankarpur due to storm of extreme intensity [13]. Digha beach is sinking at the rate of 15 – 20 cm per year [14]. Beach lowering during the month of September, 1965 was even by 30 – 50 cm around Digha due to a storm of extreme intensity [13]. The cyclone associated tidal waves of 1995 (May) caused a significant lowering of the beach surface around Old Digha [14]. At the same time the extreme high wave and storms to transport beach sediments of Shankarpur and Jaldah beach area. Thickness of soil removed from the foreshore of Shankarpur and Chandpur coastal tract by tidal waves and storm surges (Table 2 & Fig. 8). The stiff clay bank is getting eroded by high energy foreshore waves and being flattened from the initial seaward slanting surface of Shankarpur to Chandpur coastal tract. We observed the average beach width was 263.25 m in 2006; it was reduced by 15.875 m in 2012 and the extension of beach is decreasing from 250 m to 150 m and beach elevation is 3 m to 4 m on an average (Fig. 9). Beach gradient has increase from 0.03 m to 0.04 m; beach lowering also found indicating some erosional process is going on. Towards Old Digha, beach width is reduced from 120 m to 90 m on an average indicate increasing rate of erosion (Fig. 9 profile B). Beach gradient is 0.08 m indicate very steep slope and sudden break of slope clearly noticed where beach lowering is important due to reflective nature of wave cause of toe erosion and removing material. So the some important beach erosion factors are given bellow:

- ➢ Effects of human impact, such as construction of artificial structures, mining of beach sand, offshore dredging or building of dams or rivers;
- ➢ Reduction in sediment supply due to deceleration cliff erosion;
- ➢ Increased storminess in coastal areas or changes in angle of wave approach; etc.

In New Digha comparatively low rate of erosion is characteristic due to gentle slope of beach, low energy spilling breaker and wider beach. The swash can't reach up to the coastal embankment with high energy. In Shankarpur east upto Jalda, the condition is between that of Old and New Digha and due to impact of wave at a high angle here, the erosion is more. Due to moderate wider beach with gentle slope the spring tide reaches the unprotected coastal cliff as a result high rate of erosion occurs.

3.7.2 Dune erosion and shifting of sand dunes

Dune erosion is most significant event in the recent decades of Kanthi coastal plain. Erosion in the upper shores by high energy wave and tidal environment, flatting of the beach plain, formation of micro cliffs over the intertidal deposits, toe scour and associated crestal slumps of frontal dunes, removal of dune barrier by shoreline recession, reduction of dune height by wind and high wave action, cliffing at the seaward side of dune barrier and flattening of dune field by northward marching are important morphological changes of dune topography of Kanthi coastal plain at present.

Fig. 7. Recently sand dunes are suffered greatest degree of various human processes

Table 2. Thickness of sands are removed from the foreshore by tidal waves and storm surges

Sample nos.	Shankarpur (m)	Chandpur (m)	Mandarmani (m)
1	1.5	.5	.3
2	1.4	.45	.2
3	.96	.6	.4
4	.88	.5	.3
5	1.2	.5	.15
6	.7	.35	.2
7	.8	1.2	.3
8	.65	1	.24
9	.9	.85	.32
References	Casuarina trees, Gurd wall, Clay bank	Embankment, Casuarina trees	Plam trees

Source: Field investigation (2012-2015)

Fig. 8. Thickness of sands are removed from the foreshore by tidal waves and storm surges

During storms the high tide line over the raised water level goes right up to the base of the dune cliff. The storm sea level touched the base of the high dune cliff and the entire cliff retreating rate was triggered off due to wave scours and creastal slumps. Thus the loose and unconsolidated materials of the sand dunes are easily eroded in a single storm [14].

The landward and seaward movements of dunes are due to high wind speed of pre-monsoon season. It has been observed that the front dune of this area also shifted landward at the rate of 6 m to 12 m/year. Erosion by overwash might have been dominant between Shankarpur to Chandpur coastal tract, because deposition was made by the landward movement of eroded sand from the dunes.

Many dune systems around the world are in advanced stages of despoliation as a result of man's activities. In some cases the dunes have been completely removed by greatest degree of various human processes. Man's impact on coastal dunes has caused extensive ecological and geomorphologic changes. Increasing pressures place the dune communities under immense physiological stress, both from direct damage (trampling, grazing) and indirect damage through alterations in climate, soil and moisture regimes. Major threats to the sand dunes include mining levelling for construction, industries, road and other infrastructure development.

So, we observed the dune erosion along the study area is shown the average dune height was 12.44 m in 2005, it was reduced by 8 m to 10 m in 2012 by high wave action, cyclone and tidal surges etc.

3.7.3 Coastal erosion and shifting of shoreline

The geological survey of India (1995) has detected that shoreline positioned 5-15 km inland from the present shoreline around 6000 years BP. Around 3000 years BP the shoreline position was 2-3 km inland from the present shoreline. Further the public works, department constructed and inspection banglo ½ of km inland from the place with mouza Digha and Talgachari-I but with transgression of the sea this entire area has gone under the sea. Recently the Digha - Mandarmoni coastal area is landward shifting of shoreline due to local micro level rise of sae level and subsequent coastal erosion. Evidence also suggests that over the last 30 years the problems of erosion and shifting of shoreline have aggravated along this coastal tract (Fig. 11).

The rate of landward shifting of shoreline has been estimated by studying beach profiles and by interpretation of survey of India (SOI) toposheet, satellite images. From the recorded data and comparative study with survey of India toposheet, satellite images and field data it is found that during 1931-2011 the eastern part of this coastal tract from Digha estuary to Pichaboni estuary was under prominent erosion and landward shifting of shoreline. In New Digha, the Low Water Line (LWL) has shifted by about 240 m towards the land in front of the Jatra nala sluice gate in comparison between 1936 and 2011 (Fig. 11).

According to author the total landward shift of the coastline from 1950 to 2015 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(Old Digha - Chandpur) corresponds to the shift above 1500 m, cell 2 (Mandarmoni) between 1000 m and 1500 m, Cell 3 Western Dadanpatrabar) 500 m to 1000 m and Cell 4 (Eastern Dadanpatrabar) below 500 m.

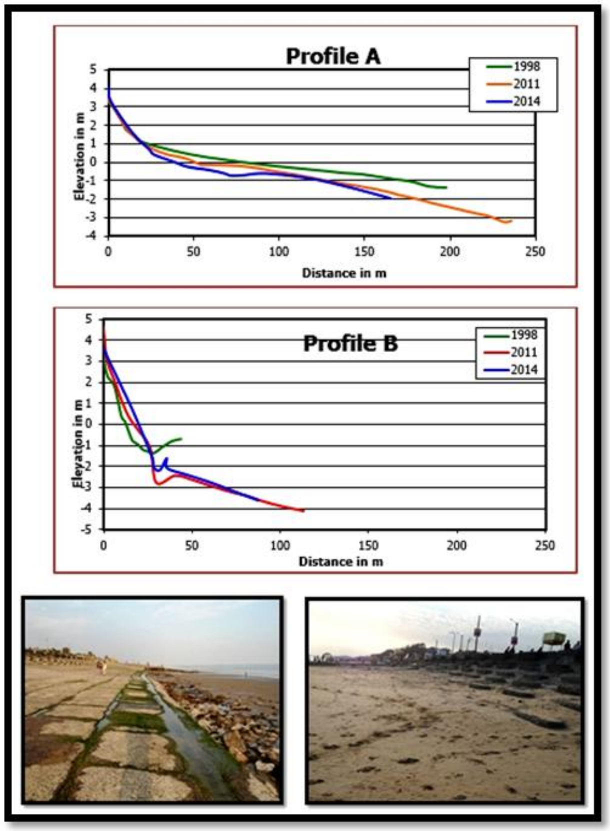

Fig. 9. Relationship in between beach width and beach gradient

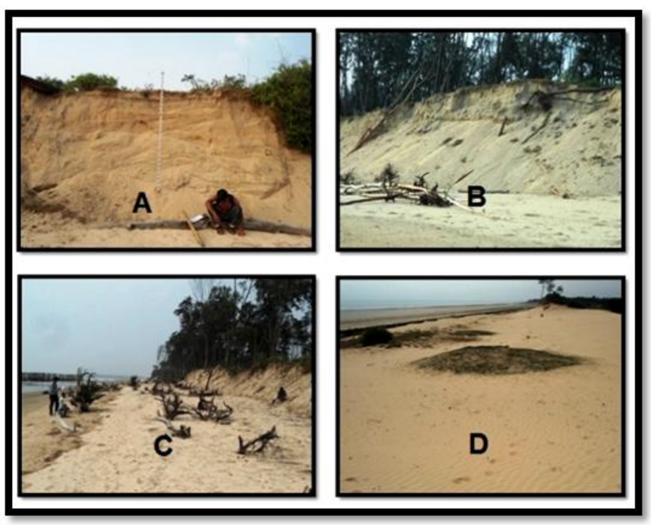

Fig. 10. Removal of frontal dunes and dunes barrier by shoreline recession

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

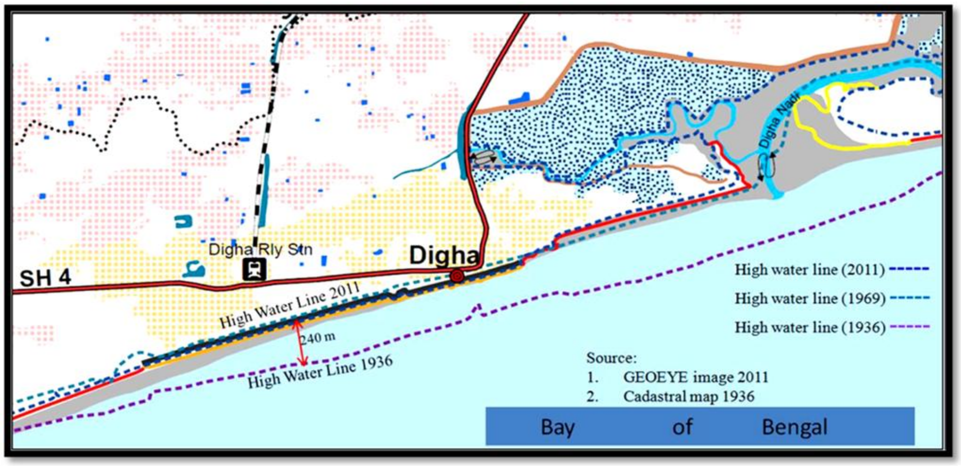

Fig. 11. Map of Digha showing the shifting of High Water Level (HWL) from 1936-2011

the conclusion that the entire study area can be divided into two regimes depending on the spatio-temporal coastal change pattern-

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

3.7.4 Coastal flood

The study area divided in to five floods category that is very high, high, moderate, low and very low. The several places of estuary based like Digha, Shankarpur, Jaldah, Mandarmani and Pichaboni of all on very high flood zones. The high flood zones are near the very high flood zones that are predominantly adjacent to the embankments. The moderate floods zones are river based like Rasulpur river and inter chenier area cover the low flood and also the chenier area cover the very low flood.

4. CONCLUSION

Evidences of climate change are numerous in Kanthi coastal plain. These are duly supported by the feedbacks from local people, the scientific studies and the survey reports. Broadly the changes are: increase in air and water temperature, rise in sea level, enhanced erosion of land, amplification in frequency and intensity of extreme weather events like cyclone and storm *etc.* These are impact on coastal environment i.e. dune erosion, beach erosion, shifting of shore line etc. The shoreline has shifted about 92.5 meters towards land during 2002 to 2014. Nearly 12641.2 sqm of land area has eroded due to non-cohesive sediment transport by long shore current and by various coastal processes prevailing in the coastal region. Since Old Digha is not at all suitable for bathing and hence tourists prefer to take bath in New Digha. However, high water line in New Digha is reaching up to sluice gate. In this connection it may be stated at several vulnerable locations, the crest width is already narrowed 1 to 2 metre only. Besides, it is also revealed from the records that during high tide, the sea water level started rising abruptly (on an average up to 5 m) since 1998 in comparison to that of earlier years when the level usually remain below 3 metre . This variation of levels of sea water obviously cause of severe effect for rapid engulfment of bank line. We observed the average beach width was 263.25 m in 2006; it was reduced by 15.875m in 2012 and the extension of beach is decreasing from 250 m to 150 m and beach elevation is 3 m to 4 m on an average.

The situation can be tackled by enhancing risk preparedness and adaptive capacity of vulnerable communities. Developing policies and programs to improve the resilience of natural resources, through assessments of risk and vulnerability by increasing awareness of climate change impacts and strengthening key institutions may help the communities adapt to climate change. We need a policy that reviews the scenarios starting from their natural state to the development of a coast. So, some recommendation policies are given below:

1. Risk zones can be identified using geological, ecological and meteorological factors. Placing development in hazardous zones needs mitigation in the form of structural modifications, a process that ends up being unsustainable.
2. Immediate implementation of shore protection measures with appropriate technology (coupled with bio-engineering and geo-tube application). Construction of groins and Gabion revetments in appropriate places of the open coast and estuary to arrest sediment movement and nourish the coast.
3. A public policy for coastal hazard management, by considering suitable options for adaptation, together with appropriate setbacks in the form of forested natural landforms, may well be the last chance to save coastal lowlands and its inhabitants from the ravages of recurring hydrometeorological events.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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