

Decadal shoreline assessment using remote sensing along the central Odisha coast, India

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ABSTRACT

One of the major requirements of planning coastal protection works is to understand the processes of erosion, deposition, sediment-transport, flooding and sea-level-changes which continuously alter the shoreline. Significant erosion can affect the stability and productivity of aquatic environment which may have severe implications for coastal inhabitants. The middle coastal plains of Odisha state on the east coast of India was investigated for morphological assessment of shoreline. Accurate demarcations of shoreline were carried out at parts of Odisha coast specifically along Gahirmatha, Paradip and the coast above Devi River to quantify erosion and accretion at annual to decadal scale for the years 1990, 2000 and 2012. Satellite derived remote sensing data (LANDSAT and IRS P6) was used in the study. Digital shoreline analysis system discovered the eroded and accreted parts of the study area. Gahirmatha and coast above Devi River experienced heavy erosion during 2000-2012 compared to 1990-2000, whereas Paradip coast has comparatively undergone accretion during 2000-2012. Some accreted spots are identified nearby river mouths, which are attributed to heavy accretion of eroded materials by the action of sediment transport. The detailed analysis reveals a maximum erosion of 124 m, 33 m and 154 m in a decade at Gahirmatha, Paradip and coast above Devi River respectively. Southern parts of Gahirmatha coast showed highly dynamic behavior near Hukitola bay and Barrier Island and is acting as a natural breakwater to conserve the shoreline. This region had undergone severe geomorphologic changes due to natural as well as human interventions and posing a threat. This coast exhibits unique reasons for erosion with various degrees of combinations of sediment depletion, human activities, high frequency of cyclones and floods, sea level rise, etc. This study concludes that the shoreline of Odisha coast is under heavy erosion and needs scientific and management attention.

Keywords: Remote sensing, Erosion, Accretion, Odisha coast, DSAS, Shoreline mapping

INTRODUCTION

Studies on shoreline change and its trends in spatial and temporal dimensions are required to establish a scientific understanding among the professionals across disciplines. The coastline of India comprises of a variety of habitats and ecosystems such as sandy, rocky beaches, cliffs, lagoons, bays, mangrove swamps, sea grass beds, coral reefs and estuaries. Indian coastline is about 7,500 km in length and has an exclusive economic zone (EEZ) of 2.02 million sq. km (Ramesh et al. 2011). Shoreline can be explained as the physical edge of land and water (Dolan et al. 1980). The recognition of a “shoreline” involves the selection of a shoreline indicator within the available data source (Ron et al. 2001). Shoreline change is considered as one of the most dynamic processes in the coastal region and is caused due to various physical and anthropogenic processes (Chen et al. 2005). Shorelines are always subjected to changes due to coastal processes, which are mainly controlled by wave characteristics and the resultant near-shore circulation, sediment characteristics, beach form etc. (Kumar et al. 2010). Assessment of long term erosion and accretion rate of the coastal area is essential for the selection of different types of coastal structures. Erosion and accretion index is prepared for Kuwait coast (Neelamani and Uddin 2013). This study is helpful for identifying better sites for coastal infrastructural activities in the study area. Erosion has been observed at the region around the ports of Visakhapatnam, Paradip, Ennore and Nagapattinam on the east coast of India while deposition has been observed south of these ports. These changes are attributed to construction of artificial barriers like breakwater, jetties, etc. (Nayak1992). Erosion is a big threat for all the human planned activities along the coast (Anfuso et al. 2011). In addition, the rising number of coastal disasters makes the coast highly vulnerable. As world’s coastlines are highly vulnerable, the need for better and more efficient methodologies for the assessment of coastal vulnerability is necessary. A study at Puducherry coast along the east coast of India was carried out to analyze and illustrate the vulnerability linked with various coastal hazards (Murali et al. 2013).

A fruitful management of the coastal region requires alert consideration of all the components of shoreline movement, as it is a complex phenomenon resulting from both natural processes and anthropogenic effects (Camfield and Morang 1996). Anfuso et al (2011) carried out an integrated approach for coastal erosion at northern Tuscany using the shoreline positions and field survey. Construction of seawalls has resulted in shifting of erosion sites from one place to another, whereas, breakwaters have been acting as barriers for littoral drift at Mangalore coast (Kumar and Jayappa 2009). Accretion was predominant along the coast between Kanyakumari and Tuticorin during 1969-1999, but this area had undergone erosion from 1999 onwards. Morphologic and hydrodynamic changes arise continuously subsequent to December 2004 tsunami (Mujabar and Chandrasekar 2011). Post-tsunami coastal surveys showed that the beach recovery was still in progress even after 4 years after the December 2004 tsunami (Jaya Kumar et al. 2008). A recent study demonstrated shoreline changes and morphology of spits for southern Karnataka area, India (1910-2005) utilizing satellite data and statistical techniques which can be incredibly practical in quantifying shoreline changes and spit morphology (Kumar et al. 2010). Accurate quantification of the material lost using erosion

risk mapping assists decision making for the implementation of protective measures. A study was carried out to establish soil loss rates due to erosion by water and wind in protected natural areas, to predict the environmental effects of different land uses (Martinez-Grana et al. 2014). Another study discussed an alternative cost-effective methodology involving satellite remote sensing images and statistics during their study for shoreline change analysis and its application to prediction (Maiti and Bhattacharya 2008). Digital Shoreline Analysis System (DSAS) is used for studying Quantitative analysis of shoreline changes at the Coast in Turkey (Kuleli T, 2010). LANDSAT satellite data for the years 1972 (MSS), 1987 (TM) and 2002 (ETM) was used after image processing and coastline was detected by self organizing data analysis technique classifications, edge detection and overlay technique. DSAS was used to calculate erosion and accretion rate at different time intervals. A combined use of cartographic data and statistical methods could be a trustworthy technique for shoreline related studies (Kuleli 2010). Application of such data seems to be trustworthy in qualitative monitoring of shoreline changes, while it is the only available method for long term studies (Bagdanaviciute et al. 2012). Dynamic geomorphology of Mahanadi delta and problems of coastal dynamics and shoreline changes after the construction of Paradip port was studied (Meijerink 1983; Rao 1989). The extent of coastal geomorphological changes induced by the grounded ship MV River Princess was analyzed on the Candolim–Sinquerim coastline of Goa, India (Murali et al. 2013). In this study, dynamics behind erosion is discussed based on the southwest and northeast monsoon wave patterns and alignment of the ship with respect to the shoreline. Rupali et al. (2007) studied the spit stability adjacent to the Jatadharmohan creek based on hydrodynamic conditions of the creek and slope stability. Studies were conducted to understand nearshore erosion, deposition, sediment budget and longshore transports off Paradip area (Ananth and Sundar 1990; Sarma and Sundar 1988). Erosion, that is observed north of Paradip and Ennore ports on the east coast of India, is due to construction of artificial breakwaters and jetties (Nayak et al. 1992, 1997; Chauhan et al. 1996). Coastal processes along the Indian coast with reference to the erosion and accretion was studied (Sanilkumar 2006). Another study was carried out to monitor the shoreline environment of Paradip using remote sensing for the period 1973-2005 in which the years 2001, 2002 and 2003 exhibited loss in shoreline length as well as the beach area (Murali et al. 2009). Increase in the length of Ekakula spit shows the accretion in the northern most part of Gahirmatha coast (Mani Murali and Vethamony 2014). Impact of wave energy and littoral currents on the erosion (Kaliraj et al. 2014), environmental characteristics on the lagoon environment (Nobi and Dinesh Kumar 2013), topographic profile surveys (Anfuso et al. 2008) and Evolution of estuarine banks (Kumar et al. 2012) are related studies on the decadal variations of the geomorphology of the regions. Lack of understanding of coastal processes on coastal landforms and bad coastal management decisions will invite heavy losses to ecology and economy (Anfuso et al. 2012). The Objective of this study is to monitor and quantify the erosion and accretion from annual to decadal scales at select regions of Odisha coast using remote sensing data and GIS tools.

STUDY AREA

The area under investigation is the coastline of Odisha state located on the east coast of India. The Odisha coastline is 480 km long and consists of six coastal districts. Three different coasts (Gahirmatha coast, Paradip coast and coast above Devi River) are targeted in this study for shoreline mapping to quantify the erosion and accretion over a period of 2 years (1990 – 2012). The study area is located between 20°43'17.26" N - 20°2'51.875" N, and 87°4'6.915" E - 86°26'0.235" E and the total length of shoreline considered is 121 km (Fig. 1). The study area has a tropical climate and summer maximum temperature ranges between 35°-40° C and the low temperatures are usually between 12°-14°C. The average rainfall is measured to be 1482 mm and receives an average of 78% of rainfall between the months of June and September and the remaining 22% of the rainfall throughout the year. The source of the sand that feed the beaches, dunes, and barrier beaches comes primarily from the erosion of coastal landforms (Ramesh et al. 2011). A unique feature of the adjacent Bay of Bengal (BoB) is the occurrence of tropical cyclones during October-November and April-May (Sehgal et al. 1991). Storm surges that are generated by the cyclones in the BOB cause tremendous destruction along the east coast of India. A study was carried out for projected sea level rise estimation for regions surrounding Nagapattinam, Kochi (Mani Murali and Dinesh Kumar 2015) and Paradip (Mani Murali 2014). Paradip is known for the occurrence of storm surges resulting from the passage of cyclones (Unnikrishnan et al. 2010). The cyclones that affected the Orissa coast between 1877 and 1987 show irregular tracks and they occurred in between the mouth of the Dhamra River and Paradip. Between 1891 and 1970, there were 1036 depressions in the BOB and among them, 360 intensified into storms (Ramesh et al. 2011). There were 36 cyclones during 1990 – 2014 (www.imd.gov.in). The Mahanadi River deltaic coast is micro-tidal with a mean tidal range of 1.29 m. The currents measured in the coastal waters of Odisha indicate that the flow is towards south with speeds varying between 14-29 cm s^{-1} . An average annual total sediment load of 29.77 million tons are carried by the Mahanadi River at its delta head (Kumar et al. 2010). Mudflats, spits, bars, beach ridges, creeks, estuaries, lagoons, flood plains, paleo-mudflats, coastal dunes and salt pans are observed along the Mahanadi delta of Orissa. Even though, the study region is experiencing the erosion; inundation, lot of developmental activities such as setting up of iron ore factory, development of ports, tourism villages, etc have been proposed.

MATERIALS & METHODS

The LANDSAT satellite images were downloaded from Global land- cover facility website (www.glcf.umd.edu) and IRS-Resourcesat satellite imagery was procured from National Remote Sensing Centre, Hyderabad. The satellite images of the study region listed in Table 1 were used for this study. The cloud cover, tide conditions, projection system and seasonal data are pre-requisite factors for finalizing the satellite imagery for further processing.

In the present study, these factors were considered for the available images. All images were geo-referenced with UTM projection and WGS84 datum parameters.

One of the objectives was to understand the annual to decadal scale shoreline changes along the different parts of the study area using remote sensing and GIS. The study was conducted for two different decades, 1990-2000, 2000-2012. Pre-processed satellite imagery was used to digitize shorelines. These marked boundaries are then overlaid for different years and changes were brought out in GIS environment. DSAS is used to compute rate-of-change statistics for a time series of shoreline vector data (Thieler et al. 2009). Transects were created on the baseline at a distance of 50 m for all shorelines in the study area as shown in Table 2.

RESULTS & DISCUSSION

Mapping of shoreline length for coasts of Gahirmatha, Paradip and above Devi River was carried out for the temporal scale of 22 years (Fig. 3a; Fig. 5a; Fig. 7a). Detailed results of length of shorelines are given in Fig.2. It is observed that Gahirmatha coast gained a length of 1.88 km from 1990 to 2012 (Fig. 2). Ekakula spit is formed again on this coast which was hitherto eroded during heavy floods of 1990 (Mani Murali and Vethamony 2014). These results are promising because of the biodiversity of the area (supports sea turtle activities). Paradip coast also gained 1.58 km in southern most part (Fig. 2), because of high sediment transport activities at Jatadharmohan creek during past two decades. On the Coast above Devi River, a net loss of 4.13 km in length is observed due to opening of the Jatadharmohan creek at the northern most part (Fig. 2).

Erosion and accretion measurement was carried out using DSAS by creating transects at a fixed distance spacing of 50 m. High distance spacing of transects reduces the uncertainty in results and very low distance spacing increases the data values to a large amount. Therefore, the transect spacing was taken as 50 m in the study and the results are calculated for 1990-2000 and 2000-2012. Each coast in the study area shows different dynamic behavior under different time scale. Detailed results for each study site are described below.

Gahirmatha Coast:

A maximum erosion of 124 m at transect id number 692 and accretion of 265 m at transect number 750 is observed between 1990-2000 (Fig. 3b) at Gahirmatha coast. Transect id 612 shows 225 m erosion and transect id 01 shows 256 m accretion for the period between 2000-2012 (Fig. 3c).

Gahirmatha coast is subjected to higher rate of erosion in the recent decade compared to the past decade (Fig. 6). Average erosion rate was 4.66 m/year in 1990-2000 which is increased to 5.23 m/year in 2012. Overall net increase in erosion was observed to be 12% for 2000-2012 relative to 1990-2000. An extent of 23 km was observed for erosion condition during 1990-2000 and the extent length observed during 2000-2012 was 28 km (Table 3).

Northern part of coast is under erosion at the mouth of Maipura River and the southern part near Hukitola bay resulted in accretion. This accretion may be due to presence of the Barrier Island, which acts as a breakwater and Ekakula spit length was increased to more than 2 km in 2012 which was not visible in the 1990 satellite

imagery. This spit was totally lost due to high floods of 1990 and is now found to be forming again, which is a good signal, because this area is famous and known for sea turtle nesting.

Paradip Coast:

At Paradip coast a maximum erosion of 211 m at transect id 341 and accretion of 63 m at transect id 74 are observed in 1990-2000(Fig. 4b). Transect id 147 shows 33 m erosion and transect id 339 shows 365 m accretion in 2000-2012(Fig. 4c). Paradip coast revealed positive results in terms of morphological assessment in 2012 in comparison with that of 1990 (Fig. 7). Erosion was decreased to 5% in 2012 compared to 46% in 1990 (Table 4). This coast is important as a hub of commercial activities and stabilization of the coast by shore protection works might have resulted in accretion during last few years. Numerous artificial breakwaters and jetties were constructed. However, highly dynamic behavior was observed at Jatadharmohan creek in southern most end of the coast during the last two decades. This area was under erosion in 1990 and now accretion is noticed. This resulted in the shift in position of creek mouth as observed from 1990 to 2012. Recently, this coast is under stable condition and witnessed accretion in 2012. Accretion, observed at some spots nearby river mouths may be because of heavy sediment dynamics.

Coast above Devi River:

A maximum erosion of 201 m at transect id 439 and accretion of 104 m at transect id 125 is observed in 1990-2000 (Fig. 5b) at coast above Devi River. Transect id 383 shows 154 m erosion and transect id 447 shows 100 m accretion in 2000-2012 (Fig. 5c). The study region above Devi Coast is the stretch from Jatadharmohan creek to Devi river in north to south direction. This coast experienced erosion all along the stretch except southernmost and northernmost parts. Some accreted patches are observed at Devi river mouth and Jatadharmohan creek. The total part of the coast under erosion was about 87% during 1990 – 2000 and 72% during 2012 (Fig. 8). A slight decrease in erosion is observed, yet a very high portion of the coastline is undergoing erosion. Average erosion was 6.82 m/year in 1990 – 2000 and 4.57 m/year in 2000 – 2012 (Table 5).

Discussion on possible causes:

The present study elaborates the shoreline change behavior during last 22 years at selected regions of Odisha coast. The different parts of Odisha coastline studied in this work, show dynamic behavior of erosion and accretion processes at different time intervals. Annual to decadal shoreline mapping clearly shows that erosion was high during 2000-2012 comparatively, excluding Paradip coast. The results indicate that shoreline behavior is highly dynamic in the area, which could be due to reduced deltaic characteristics of rivers and intense cyclonic activities in the area. To augment this statement, analysis was carried out on number of dams built, cyclones and floods occurred in this region, landuse/landcover changes of the area were analysed. Archived cyclone track data from Indian Meteorological Department (IMD) was used to retrieve the cyclones that passed in the study region since 1990. Overall 36 events of depressions, severe cyclones and super severe cyclones occurred in this region during 1990 to 2014(Fig.9). Every year, this region experienced more than

one cyclone which obviously generated rough conditions conducive for coastal erosion. Orissa super cyclone which occurred in 1999 triggered heavy erosion and uprooted thousands of trees. Coastal inundation was upto 35 km inside the land. Most of the cyclones occurred after the southwest monsoon which did not allow the beaches to build from the available materials. All the eroded materials were carried away by the northeast flowing littoral currents and deposited in the north or northeast regions. Horizontal shift of shorelines was evident due to this in addition to the monsoonal erosion. Hence, coastlines have increased its length along N-NE directions, but lost the beach materials towards landward.

Because of low lying nature, this region is prone to floods also due to heavy rainfall during the monsoon and cyclone times. Gushing flood water breaches and erodes the spits, river banks, river mouths, tidal inlets, shallow sandy bars, etc. The Ministry of Water resources, Odisha Govt. has reported 11 severe floods from 1991 to 2008 (Ministry of water resources, Govt. of Odisha). Almost all these floods were in Mahanadi, Brahmani and Baitarani rivers which are located in the present study region. Also, the heavy rains in the higher altitude catchments influence the river flow and mostly stored by the dams. After independence in 1947, the Indian government built 211 dams of all kinds along the Mahanadi River (Central water commission, Ministry of Water resources, Govt. of India). In that 69 dams were built and commissioned during the period considered in this study. All these dams were built for irrigation and hydro-electric power generation purposes. It clearly indicates that there is no river discharge from Mahanadi River into the sea. Landuse/landcover study of 1999 (Fig. 10a) and 2014 (Fig. 10b) supports the significant increase of agricultural and fallow lands in this region. Agricultural lands have increased to 345.4 sq km from 148.12 sq km in 15 years time (Table 6). This shows that continental erosion which is contributing the sediments to rivers is reduced. Due to this; source of sediments from this river to sea has reduced because of anthropogenic activities. This situation forces this coastal region as sediment deprived and does not allow for any natural accretion. No fresh sediment is reaching the coast in the last few decades other than during the flood discharges. This is inducing the recent coastal erosion along this region. This region was also listed as sinking delta due to human activities (Syvitski et al. 2009). Long-term land use and land cover changes and the impact of its transformation on the environment is worth attempting research in future. Based on the above facts, it is evident that the coast of central Odisha Coast is eroding in most of the places and few places getting accreted with few of the eroded material. This region had undergone severe geomorphologic changes due to natural as well as human interventions. This coast is definitely vulnerable for many reasons and posing threat to many coastal inhabitants. This coast exhibits unique reasons for erosion with various degrees of combinations of sediment depletion, human activities, high frequency of cyclones and floods, sea level rise, etc.

CONCLUSION

The present study concludes that shoreline of Odisha coast is under high pressure of erosion due to natural as well as anthropogenic activities in the area. Processes of Erosion increased during recent years due to increased frequency and intensity of cyclones and floods. Gahirmatha coast showed highly dynamic behavior near Hukitola bay and adjoining Barrier Island in the southern part of the coast that worked as a natural

breakwater which helped in shoreline conservation. The behavior of shoreline changes near river delta area is very dynamic and uncertainties are found in morphological assessment using remote sensing techniques. A physical approach of shoreline change detection is recommended for better accuracy of morphological assessment. Anthropogenic activities such as damming of rivers, port dredging, sand mining, etc. also contributed in erosion at study site. Studies of sediment dynamics from land into oceans by rivers in this region is suggested for future study. Further anthropogenic activities should be considered only with proper planning to conserve nature and avoid the economic losses in future.

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Tables

Table 1: Satellite data information used

Date and Year	Path/Row	Satellite ID	Sensor	Resolution (m)	Cloud/ Haze Cover	Tide water level (m)
28.11.1990	140-46	Landsat 5	TM	30	Nil	0.54
23.10.2000	139-46	Landsat 7	ETM+	30	Nil	0.73
24.02.2012	107-58	IRS-R2	L3	23.5	Nil	1.28
28/02/1999*	107-58	IRS-1D/LISS III	L3	23.5	Nil	NA
24/02/2014*	139-46	Landsat 8	ETM+	30	Nil	NA

*Used for Land use/land cover mapping

Table 2: Transect details for study area

Coast name	Number of transects created	Length of transects (m)	Transect spacing (m)	Cast direction
Gahirmatha	778	600	50	offshore
Paradip	345	600	50	offshore
Above Devi River	446	600	50	offshore

Table 3: Shoreline change assessment for Gahirmatha coast from 1990 to 2012

Sr. No.	Duration	Average Erosion/Yr (m)	Average Accretion/Yr (m)	Eroded Shoreline (km)	Accreted Shoreline (km)
1.	1990-2000	4.66	5.79	23.35	15.55
2.	2000-2012	5.23	4.66	28.10	10.75

Table 4: Shoreline change assessment for Paradip coast from 1990 to 2012

Sr. No.	Duration	Average Erosion/Yr (m)	Average Accretion/Yr (m)	Eroded Shoreline Length (km)	Accreted Shoreline Length (km)
1.	1990-2000	5.79	2.29	7.90	9.35
2.	2000-2012	0.94	6.24	0.80	16.60

Table 5: Shoreline change assessment for coast above Devi river from 1990 to 2012

Sr. No.	Duration	Average Erosion/Yr (m)	Average Accretion/Yr (m)	Eroded Shoreline Length (km)	Accreted Shoreline Length (km)
1.	1990-2000	6.82	4.49	19.50	2.80
2.	2000-2012	4.57	2.28	15.20	5.85

Table 6: Landuse/landcover details (in sq.km)

Year	Fallow lands	% of change	Agricultural lands	% of change
1999	2715.51	-	148.12	-
2014	2433.08	-10.4	345.40	+133

(+) denotes increase and (-) denotes decrease

Figures

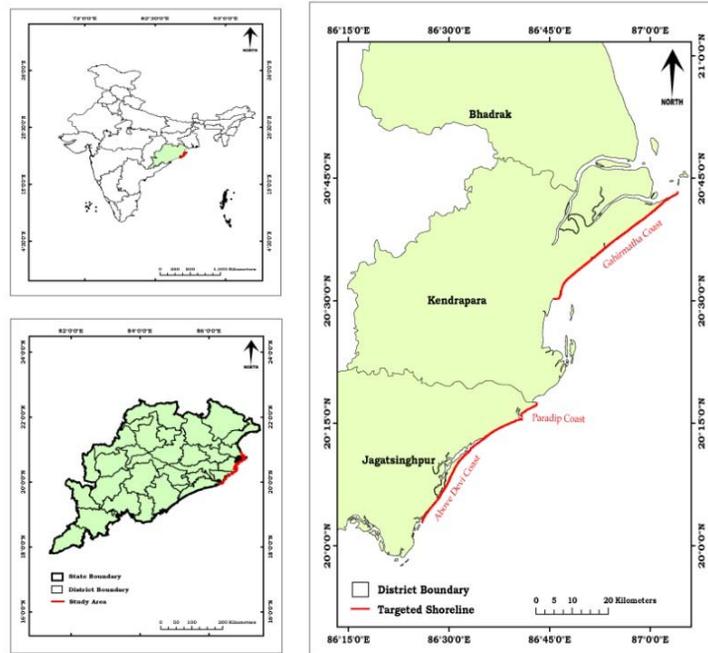


Figure 1: Location of Study Area

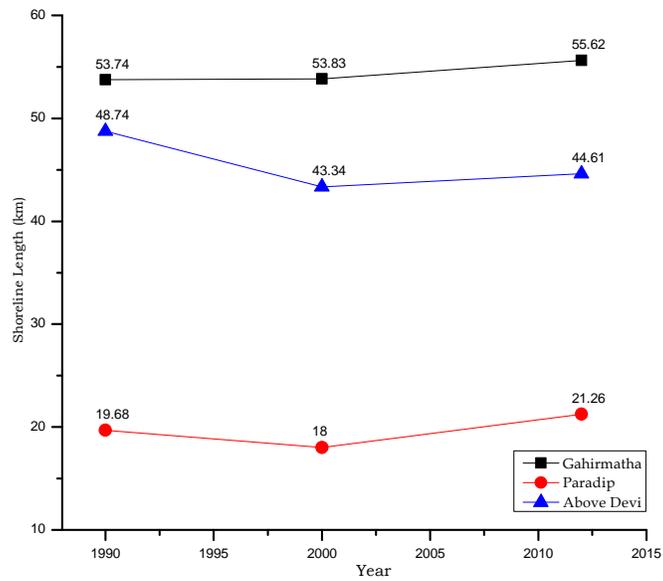


Figure 2: Shoreline length change during different years

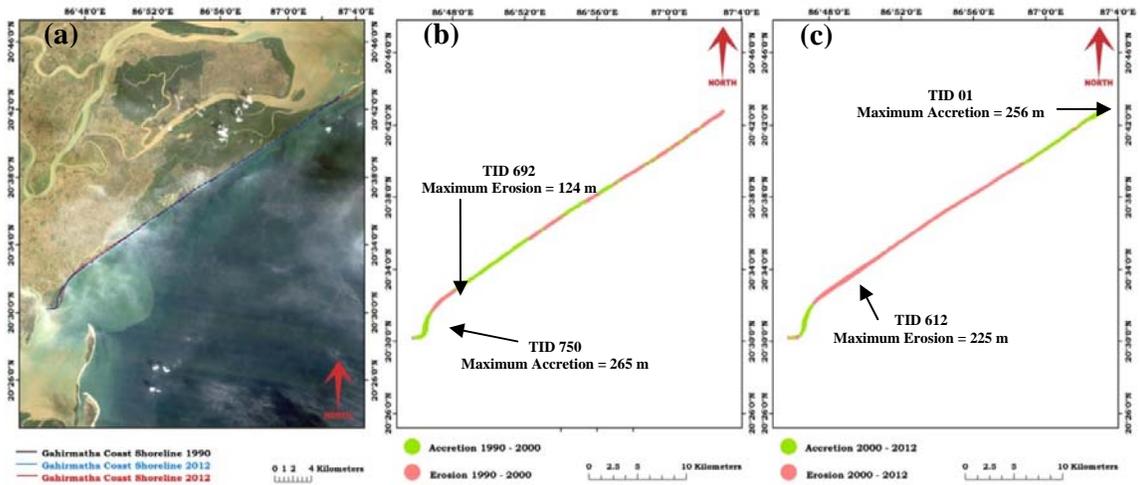


Figure 3: (a) Gahirmatha coast shoreline mapping for 1990, 2000 and 2012, (b) Erosion and accretion mapping for 1990-2000, (c) Erosion and accretion mapping for 2000-2012

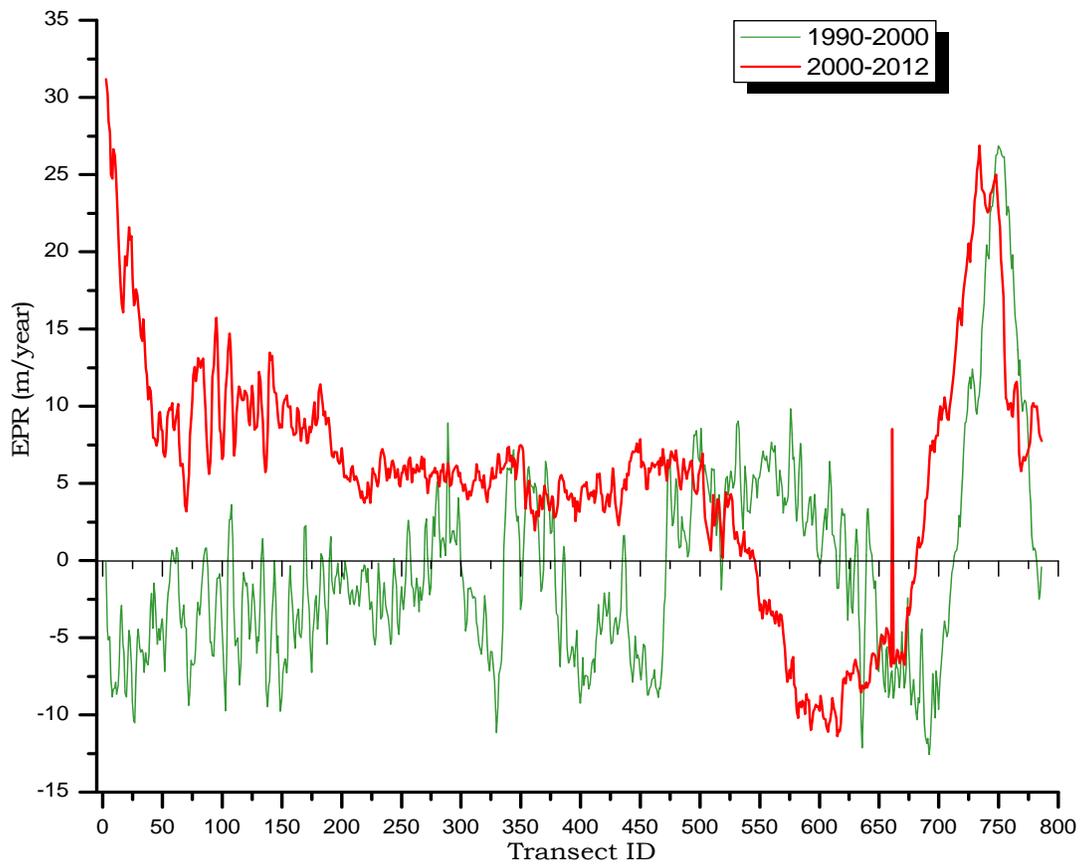


Figure 4: (a) EPR at transects of Gahirmatha Coast

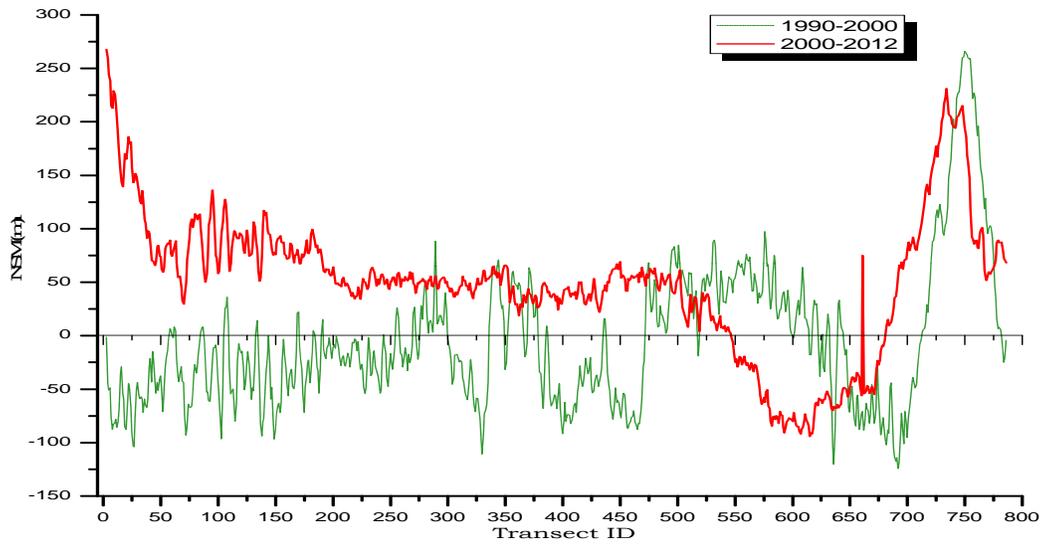


Figure 4: (b) NSM at transects of Gahirmatha coast

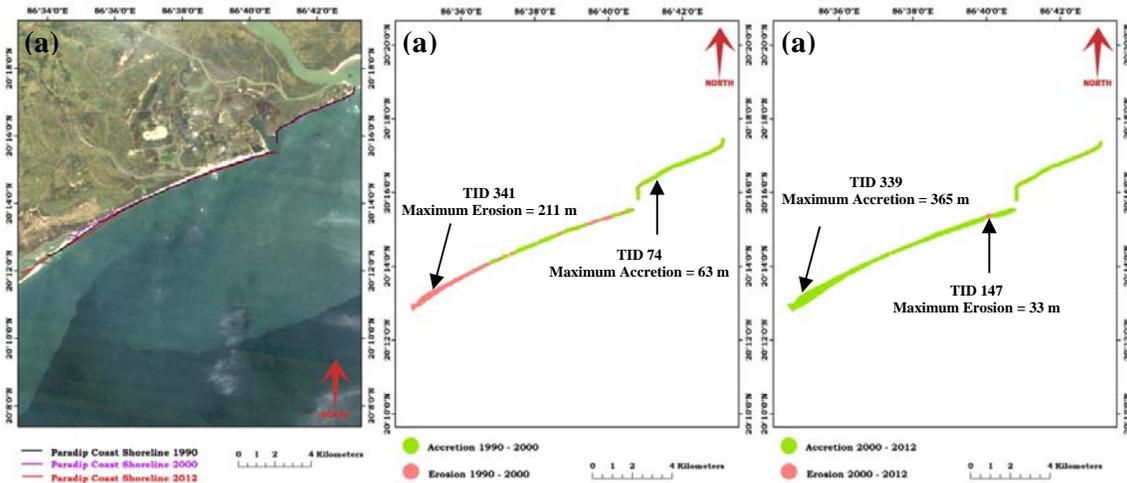


Figure 5: (a) Paradip coast shoreline mapping for 1990, 2000 and 2012, (b) Erosion and accretion mapping for 1990-2000, (c) Erosion and accretion mapping for 2000-2012

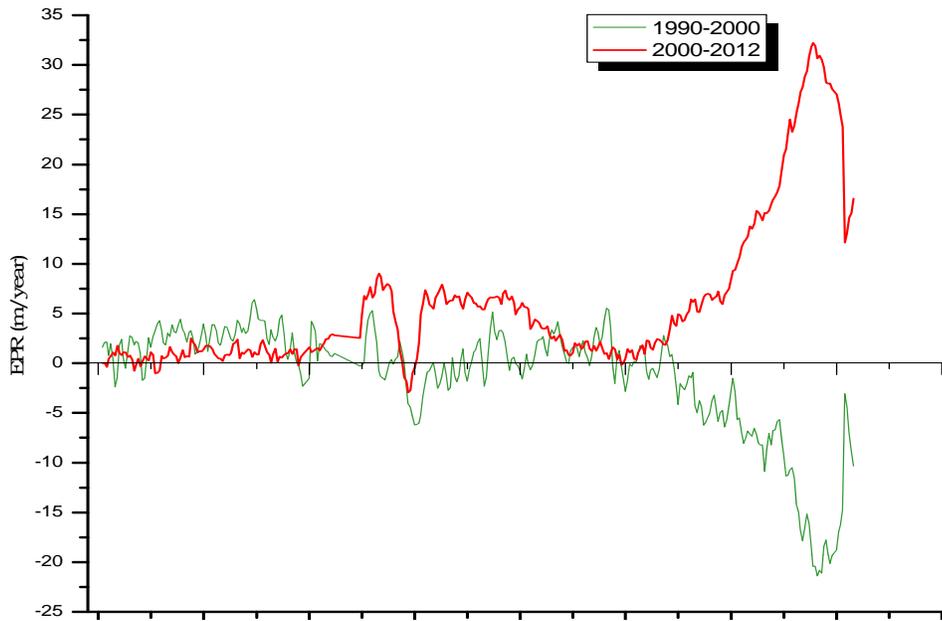


Figure 6: (a) EPR at transects of Paradip Coast

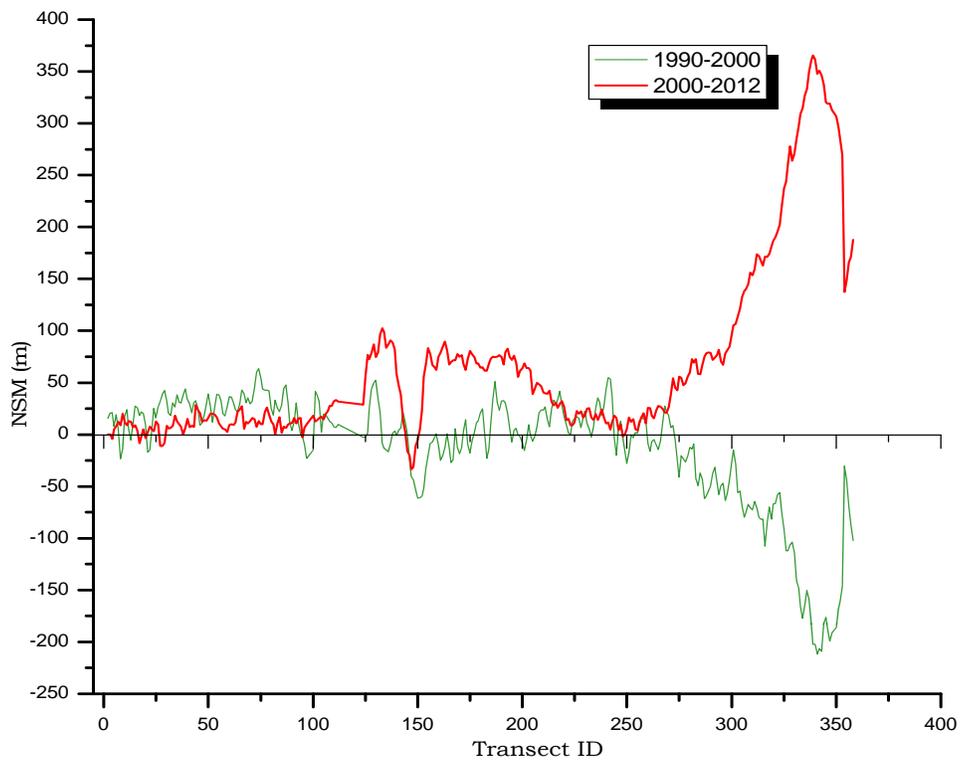


Figure 6: (b) NSM at transects of Paradip coast

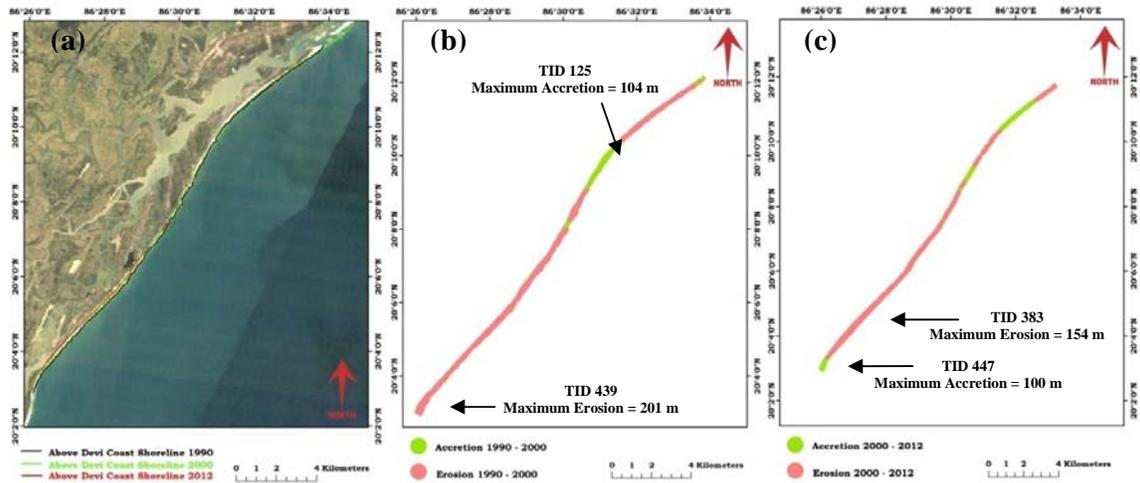


Figure 7: (a) Coast above Devi River shoreline mapping for 1990, 2000 and 2012 (b) Erosion and accretion mapping for 1990-2000 (c) Erosion and accretion mapping for 2000-2012

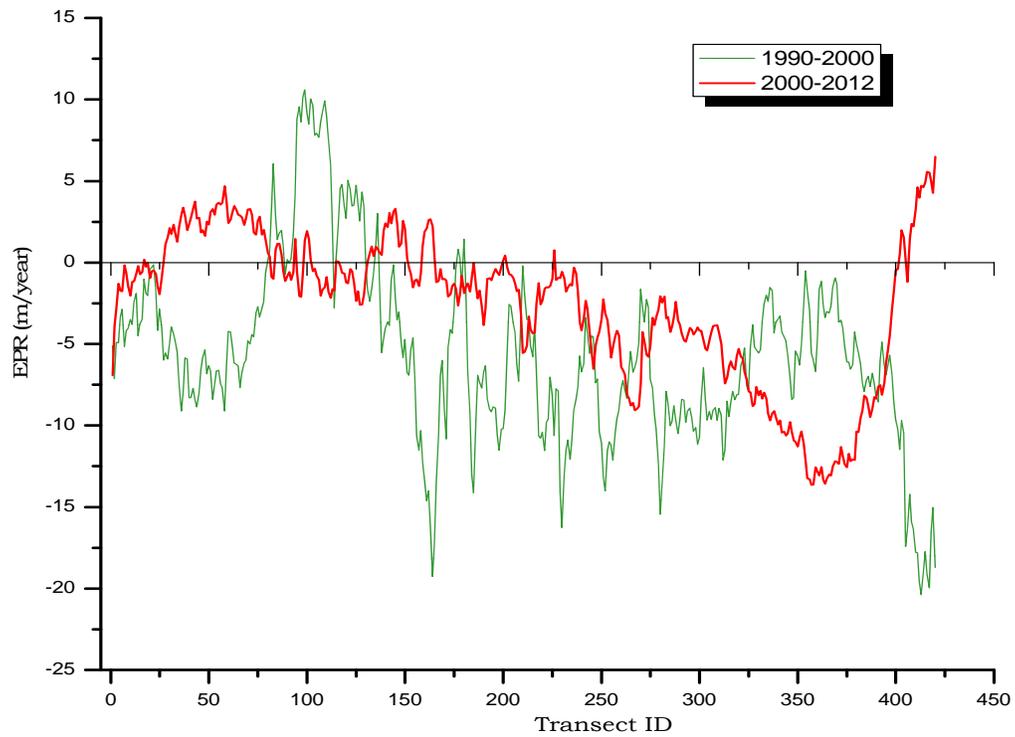


Figure 8: (a) EPR at transects of Coast above Devi river

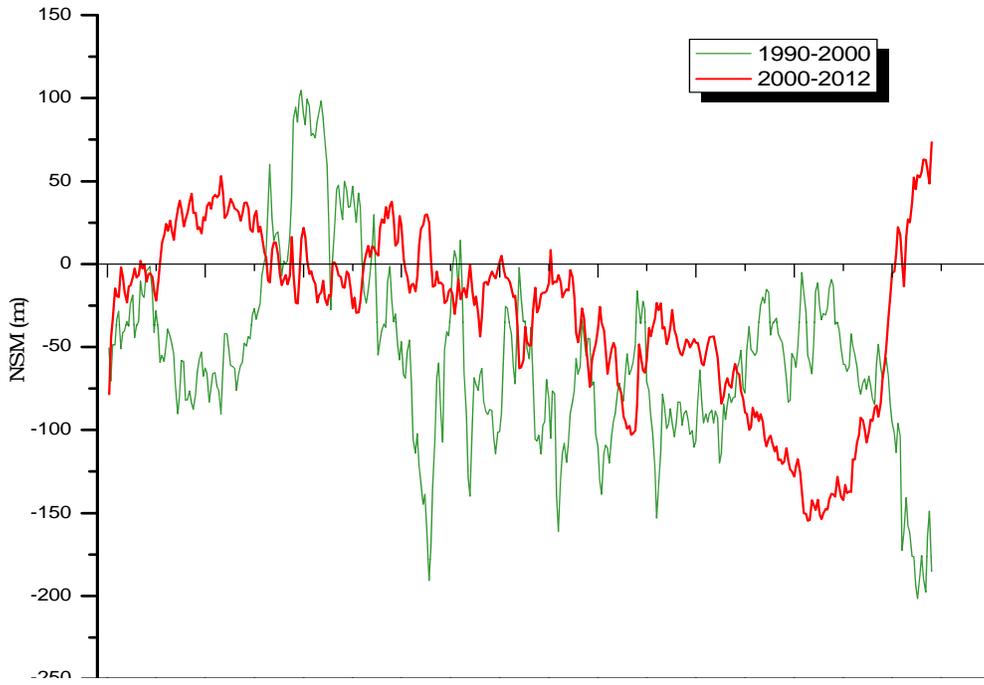


Figure 8: (b) NSM at transects of Coast above Devi river

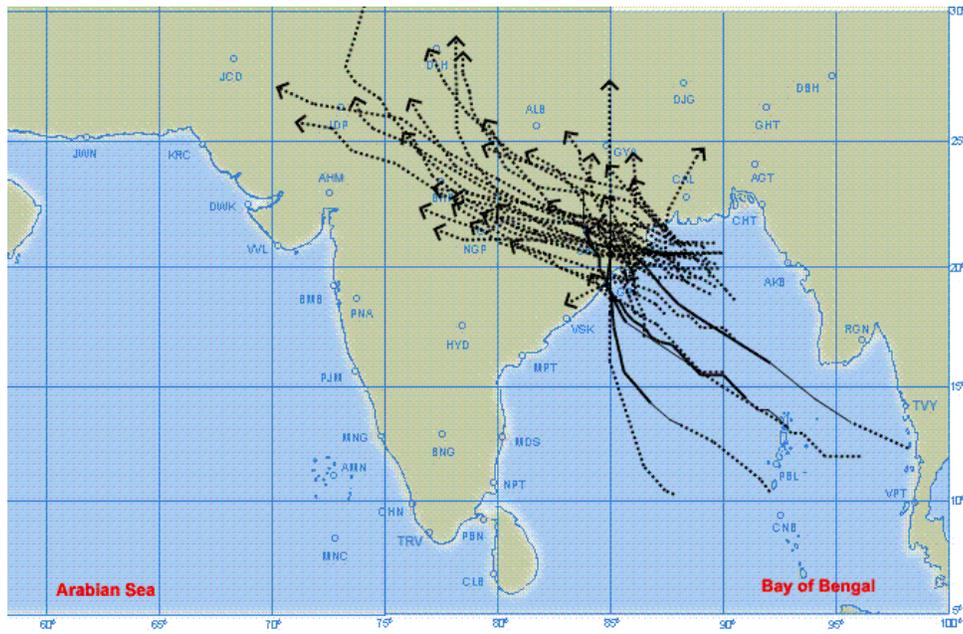


Figure.9 Cyclone tracks of the study region during 1990-2014 (Source : Cyclone atlas,IMD)

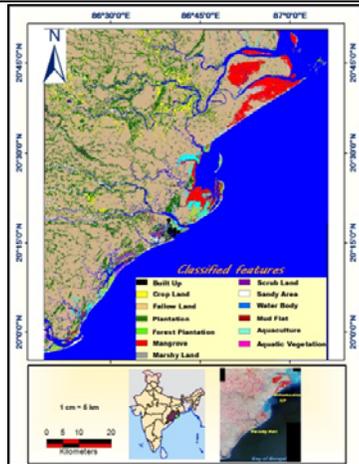


Fig 10 a Landuse/landcover map of the study region for the year 1999

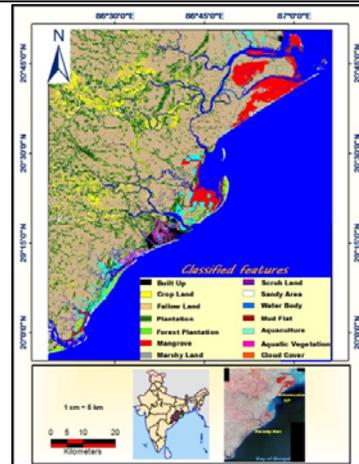


Fig 10 b Landuse/landcover map of the study region for the year 2014