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Statistical Assessment of Long-term Shoreline Changes along the Odisha Coast

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Odisha, a coastal state on eastern seaboard of India possesses a ~450 km long coastline vulnerable to a multitude of natural and anthropogenic threats. The present study reports a systematic assessment of rates of shoreline change over a period of 25 years from 1990- 2015, using Landsat 5 and 8 series of (Thematic Mapper and Operational Land Imager) satellite images. An analysis of rate of shoreline change was carried out along select regions of Odisha coast using Digital Shoreline Analysis System (DSAS). Linear Regression Method (LRR) was used to estimate net shoreline change at sub decade time scale and End Point Rate (EPR) to estimate net shoreline change rate in between two consecutive years. The highest erosion with a coastline length of 63 km was observed between Rajnagar (around Satabhaya beach) and Mahakalapara (near to Hukitola beach) block of Kendrapara district and between Ersama (around Paradeep port) and Balikuda blocks (northern parts of Devi River mouth) of Jagatsinghpur coastal district. The result suggest that both EPR and LRR techniques were used to estimate shoreline change rate and the similar result of erosion by both EPR and LRR technique indicated weaker cyclic trend in erosion.

[Keywords: DSAS, EPR, Erosion, LRR, Odisha coast, Satellite data]

Introduction

Shoreline is a very dynamic and complex expanse on earth surface and it is one of the rapidly changing features of coastal area. The causes of shoreline change *viz*: natural coastal processes, sea level rise, natural hazards and anthropogenic activities have become major concerns for maritime countries, which exerts pressure on the environment. As a result, some coastal researchers and planners have predicted as well as analysed coastal environment changes on regional scales. Most of the human populations prefer to settle near the coast due to environmental aesthetics and economic opportunities. Various development projects have been set up in the coastal zones, thereby exerts anthropogenic pressure. This leads to various impacts on coastal environment during coastal hazards. Shoreline is a dynamic system, which results sediment movement, being deposited and eroded, as it attempts to establish a sediment budget and reveals near shore marine process[1,2]. Shoreline also changes seasonally, which proves accretion during summer months whereas, drastic erosion during monsoon. Griffiths[3] predicted that the coastal zone is increasingly under pressure from human activities *viz*. fishing, sand and coral mining, mangrove harvesting, sewage disposal, harbour construction, urban expansion and tourism. These activities exert negative impact on coastal environment and disturb the equilibrium leading to erosion along the coast. Further, construction of reservoirs, check dams, aquaculture ponds result in less supply of sediment to the coastal systems. At present, coastal erosion is a worldwide problem affecting most of the sea boarding countries. This problem is expected to accelerate in future attributed to future sea level rise and also to increase the number of extreme events in the coastal regions. There are number of reports and studies on sea level rise along the coast of Odisha. Global sea level is rising at a rate of 1.7 - 1.8 mm/year over the last century and it has increased to 3mm/year in the last decades[4-6].

Different coastal process parameters such as tide, wave, sea level rise etc. are the key features which control the shoreline configuration[7,8]. In some cases, extreme events such as storm surges and tsunamis are responsible for shoreline changes[9]. It was also reported that significant changes would have occurred due to construction of breakwater[10]. Ramana Murthy et al.[11] have studied shoreline evolution and sediment transport of Ennore port, Chennai, southeast coast of India. They found that due to the interception of long shore drift by the breakwaters in the northern part, the port exhibits erosion while the southern part shows accretion. In peninsular India, several studies have reported long shore drift interception due to coastal structures leading to erosion on one side and accretion in other side of the coastal environment[12-15]. Maiti and Bhattacharya[16] applied statistics-based approach for long-term change in shoreline analysis, and prediction of future shoreline position of Midnapur coast of West Bengal. Several statistical methods namely, end point rate (EPR), linear regression rate (LRR), weighted linear regression (WLR), net shoreline movement (NSM) and least mean square (LMS) are routinely used for shoreline change rate analysis[17-24]. Recent shoreline dynamic study of Indian coastal environment shows that 45.5 % of the coast falls under erosion, 35.7 % shows accretion, and 18.8 % of the coast is stable in nature[25]. Digital shoreline Analysis System (DSAS) is use for studying quantitative analysis of shoreline dynamics using LRR and EPR methods. LRR can be calculated by long-term analysis by applying a least square regression line to all shoreline points for a particular transects and EPR is applied for short-term analysis between youngest and oldest shorelines. The current study is one such effort to estimate the shoreline change rate using the long-term Landsat data (1990-2015) with the aid of the DSAS statistical approach. Further, this study also brought out time-series sub decadal rates of shoreline change.

Materials and methods

Study Area

The study area under the analysis is coastline of Odisha state on the eastern seaboard of India. The Odisha coastline is ~480km long and consists of six coastal districts. Four coastal districts i.e. Baleswar, Bhadrak, Kendrapara and Jagatsinghpur shown in Figure 1 are selected for shoreline mapping to

Fig. 1 — Map showing the location of the study area

quantify the erosion and accretion over the period of 1990 -2015. The other two coastal districts i.e. Puri and Ganjam coast are more dynamic as compared to selected area. In this concept, these two coastal districts were not included for the study. The area selected for the present study is 283 km long and it covers twelve blocks i.e. Bhogarai, Baliapala, Balasore sadar, Remuna, Bahanaga, Basudevpur, Chandabali, Rajnagar, Mahakalapara, Kujang, Ersama and Jagatsinghpur. The western part of the study area is well drained by major rivers namely, Subarnarekha, Budhabalanga, Baitarani and Mahanadi, which are the major sources of supply of sediment to the study region. Bhitarakanika mangrove forest and Chandipur beach are the most important eco-tourist destination. Paradeep port and Dhamara port are situated in the boundary of the study area. It lies between 17 ^{0} 49' N and 22^{0} 34' N latitudes and between 81^{0} 27' E and 87^{0} 29' E longitudes. It is pitiable that these coastal areas of Odisha experience periodic loss of lives and severe damages of property from several coastal hazards such as sever riverine flooding, tropical cyclones and coastal storm surges originating in the Bay of Bengal. About 36 cyclones occurred during 1990 – 2014[26]. An average annual total sediment load of 29.77 million tons are carried by the Mahanadi River at its delta head[27]. The coastal tract of the study area is almost flat with sandy beach along with sand dunes and mud flats. Geologically, the coastal stretch of Indo-Gangetic plain is covered by recent to sub-recent alluvium of very thick quaternary sediments. The geological history of the coast is relatively short and the coast is still in its formative state. The geomorphic divisions like beach, mudflats, sand dunes etc. have been developed within the last 6000 years[28, 29].

Data used

The satellite data used for this study was acquired from the Earth Explorer sites maintained by USGS[30]. Multi temporal ortho-rectified satellite data from Landsat 5 carried sensor Thematic Mapper (TM) of 1990 to 2010 and Landsat 8 carried sensor Operational Land image (OLI) of 2015 were selected based on the criteria: same season, cloud cover and near similar tidal condition (Table 1). The tidal data were referred from WXTide 32 tool. The scenes available in USGS were selected for the current study pertaining to pre-monsoon season and were acquired during tide levels ranging from 0.53-0.99 m with a maximum difference of 0.46 m. These datasets are consistent with tide and season enabled us to minimize the inaccuracies in shoreline positions.

Methods

Two stages of works have been carried out in the present study to analyse the shoreline changes. First was the interpretation of Landsat satellite data for shoreline mapping of individual period and second was the estimation of shoreline change rates statistical techniques by using the individual shorelines.

Shoreline mapping

Ortho-rectified satellite data projected in Universal Transverse Mercator (UTM) projection have been imported into ERDAS Imagine 9.2 software. Shorelines were manually digitized by onscreen point mode in Arc Map 9.3 using False Colour Composite (FCC) of Landsat scenes with band combination 4, 3, 2[31]. Shorelines of individual scene were saved as shape file separately.

DSAS Statistical Methods Selected for the calculation of the Shoreline change rate

The DSAS tool[32] basically uses various statistical methods such as End Point Rate (EPR), Net Shoreline Movement (NSM), LRR (Linear Regression Rate), etc. The NSM estimates the distance between oldest (1990) and youngest (2015) shoreline for each transects and EPR is achieved by dividing the NSM by the number of years between the two shorelines. The LRR or Net Shoreline Changes can be determined by fitting least-squares regression lines to all shoreline points for a particular transect. The EPR technique is easy to use and requires only two

Table 1 — Satellite data used for the study

Satellite/ Sensor	Date of Acquisition	Path / Row	Tidal level (m)	Season
Landsat TM	22-02-1990	139/45	0.58	Pre monsoon
	22-02-1990	139/46		
Landsat TM	21-12-1995	139/45	0.99	Pre monsoon
	21-12-1995	139/46		
Landsat TM	05-03-2000	139/45	0.53	Pre monsoon
	05-03-2000	139/46		
Landsat TM	22-05-2005	139/45	0.99	Pre monsoon
	22-05-2005	139/46		
Landsat TM	13-02-2010	139/45	0.97	Pre monsoon
	13-02-2010	139/46		
Landsat OLI & TIS	15-03-2015	139/45	0.53	Pre monsoon
	15-03-2015	139/46		

shorelines (oldest and youngest) but magnitude or cyclical trends may be missed[33,34]. Linear regression is vulnerable to outlier effects and usually underestimate the rate of change relative to other statistics such as EPR[35]. With these limitations, EPR was used to estimate the rate of shoreline change during different periods (1990-95, 1995-2000, 2000-2005, 2005-2010, 2010-2015 and 1990-2015). However, LRR was also estimated by using all the shorelines pertaining to the period 1990-2015 for assessing the rate in order to consider the cyclic trends.

Preparation of inputs for the DSAS

DSAS 4.0 tool developed by United States Geological Survey (USGS) was used for the calculation of the shoreline change rate. The necessary fields ("DATE" and "UNCERTAINITY") in the attribute table of individual shorelines were added as per the requirement of the DSAS and the corresponding scene acquisition date was added in the "DATE" field. All these shorelines pertaining to individual scenes of different periods were merged to make a single shape file comprising 'multi shoreline'. This 'multi shoreline' shape file is one of the inputs for the calculation of the shoreline change rate at user specified interval by statistical techniques. Another input also required by DSAS is the baseline created by buffering of the multi shoreline shape file. The necessary attribute fields such as ID, Group, OFFshore and CastDir were added to baseline shape file as per the requirements of the DSAS. Then these two shape files multi shoreline and baselines were used as inputs to estimate the shoreline change rate.

Estimation of shoreline change rate

A total of 2549 transects were generated perpendicular to the coastline with a spacing of 100 m and the length of 3500 m were used to estimate the change of different shore line with relative to the baseline. The shorelines shifting towards offshore with transects was considered as a positive value and represented accretion, while these shifted towards onshore was considered as a negative value corresponding to erosion. Shoreline change was very dynamic along the mouth of rivers. It suggested that more accretion and erosion was along the river mouth due to different coastal activities. Focus on this situation; remove shorelines along the river mouth.

Generation of output maps and graphs

The maps showing (Figs. 2 & 3) distribution of the net shoreline change rate (1990-2015) and the change rate between individual periods (1990-1995, 1995-2000, 2000-2005, 2005-2010 and 2010-2015) were generated. Shoreline change rate calculated in DSAS are depicting negative values as erosion and positive values as accretion. These rates were further categorized into 'erosion' with value less than -2 m/y, 'accretion' with value more than 2.4 m/y and lastly the coastal segments having erosion and accretion up to 2.4 m/y considered as 'no change'. This 'no change' category limit of ± 2.4 m/y corresponds to 60 m (2 pixel of TM) of erosion or accretion over a period of 25 years. The idea of taking this threshold for 'no change' category was to account for the limitation of spatial resolution (30 m) and interpretation errors of one pixel (30 m). Hence, the changes above and below 2.4 m are significant to decipher accretion and erosion respectively considering the sensitivity of the satellite data used and errors induced due to the interpretation of the shoreline. The graphs (Fig. 2) depicting the erosion and accretion along the coast were prepared.

Results

The total length of the shoreline slated for assessment was ~283 km covering Baleswar, Bhadrak, Kendrapara and Jagatsinghpur districts. Some parts of the current study area experienced higher shoreline change dynamics (Fig. 3, erosion: Devi River Mouth, Paradeep Port and Accretion: Bhitarakanika, Balasore Sadar) in the recent past[36]. Mapping of shoreline length for coasts of selective area of Odisha was carried out over a temporal scale of 25 years. Detailed results of length of shorelines.

Results of the shoreline change reveal dynamic changes in the erosion and accretion regimes along the coastline of administrative district and block (taluk) during different period within the study period (Tables 2 & 3). Map representing the distribution of the erosion and accretion along the study area are presented in Fig. 3 and the length statistics are given in Table 2. Shoreline change rate pertaining to different periods were also calculated using EPR for the whole stretch of the coastline at each transect and is represented in the graph as Figure 2 and changes at each administrative block as Figure 3 and the area of erosion and accretion is tabulated (Table 2). Different consecutive time spans shorelines (1990-1995, 1995-2000, 2000-2005, 2005-2010, and 2010-2015) were grouped in order to summarize the EPR interpretation and is shown in (Fig. 3).

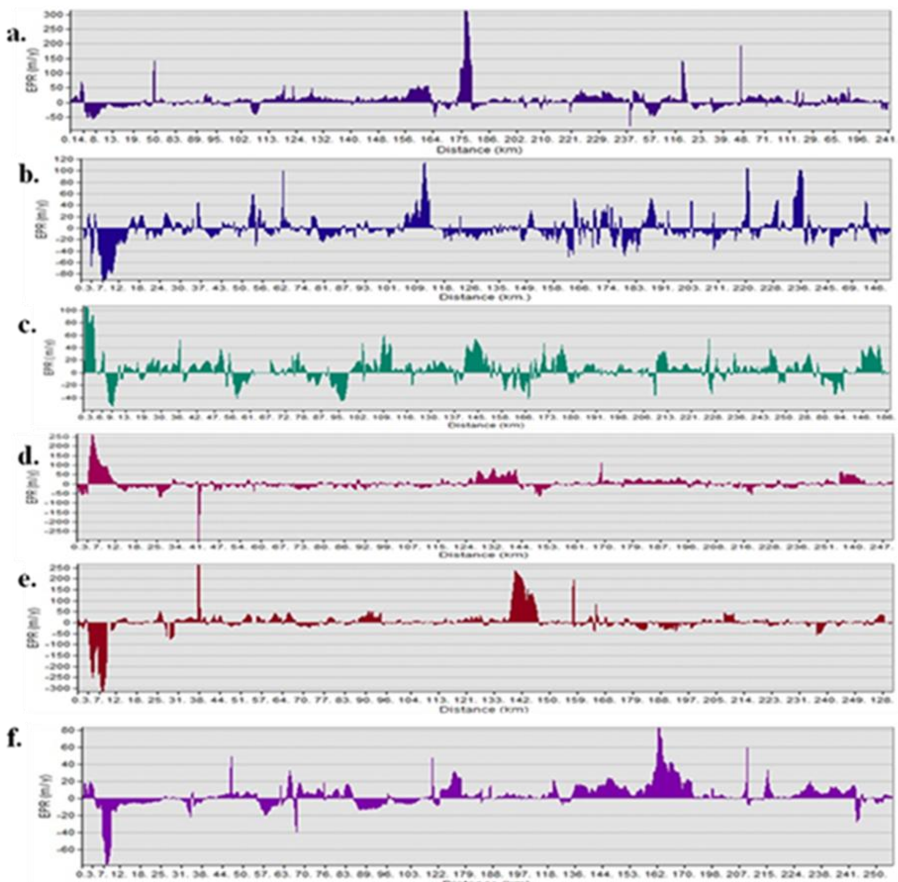

Fig. 2 — Plate depicting the maps of shoreline change (classes Erosion, Accretion and No Change) recorded during a. 1990-1995, b. 1995-2000, c. 2000-2005, d. 2005-2010, e. 2010-2015 and f. 1990-2015 showing temporal variations along the coast from south to north.

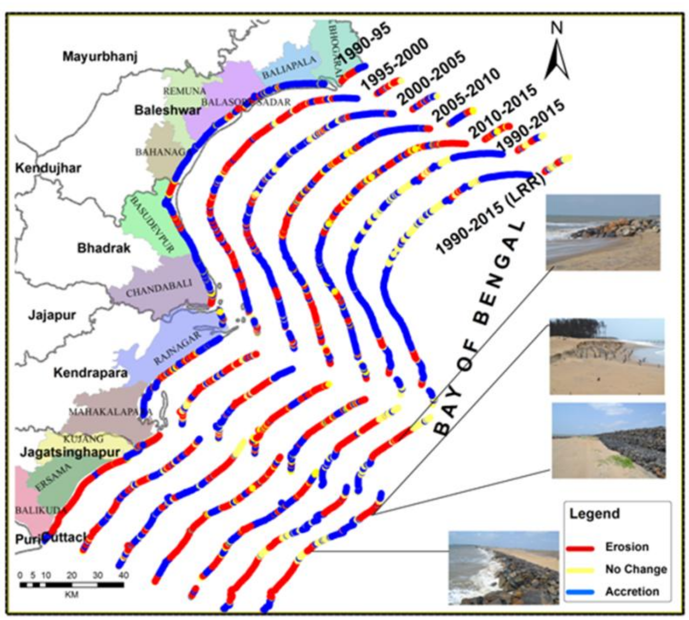

Fig. 3 — Maps showing distribution of different shoreline change classes (Erosion, Accretion and No Change) recorded during different bi-decadal periods in comparison of the net shoreline change rate (1990-2015). Locations of the field photos (as shown in Fig.4) are marked on this map.

Table 2 — Erosion accretion observed in the parts of study area from 1990 to 2015.

Year	Erosion		Accretion		No Change	
	Length in (km)	Percentage	Length in (km)	Percentage	Length in (km)	Percentage
1990-1995	93	38	144	59	7	3
1995-2000	155	63	82	33	8	3
2000-2005	82	33	156	64	7	3
2005-2010	134	55	105	43	6	2
2010-2015	121	49	117	48	7	3

Table 3 — Comparison of length and percentage of erosion and accretion calculated using the EPR and LRR techniques

Method	Erosion		Accretion		No Change	
	Length in (km)	Length in %	Length in (km)	Length in %	Length in (km)	Length in %
EPR (1990-2015)	91	37	132	53	22	9
LRR (1990-2015)	84	35	132	53	28	12

Fig. 4 — Field photo captured at erosion sites near Paradeep Port (A) and near Satavaya beach (B) showing the sea wall constructed to prevent the erosion, the wire mesh rock wall constructed at Pentha coast of Jagatsingpur District (C) and erosion at Mahanadi River mouth (D) reveals the severity of the erosion. Locations of these photos are marked on the map (Fig. 3)

Shoreline change rate during different periods

1990-1995: A total 93 km (38 %) of the entire coastline recorded erosion, 144 km (59 %) showed accretion regime, and 7 km (03 %) coast as no change regime during 1990-95 (Table 2). The southern parts of the study area along the coasts of Ersama and Balikuda blocks (Fig. 3) showing high erosion The erosion was also reported along a few stretches of Rajnagar, Basudevpur, Kujang and Balasore Sadar blocks.

1995-2000: 155 km (63 %) length of the coast fell in the erosion category, 82 km (33 %) coast was experiencing accretion phase and 8 km (03 %) of coasts fells under no change condition during 1995-2000 (Table 2). The distribution of erosion and accretion during this period reveals dominant erosion all along the coasts except a few stretches (Fig. 3). However, the coastal blocks of Basudevpur, Remuna and Balasore Sadar were experiencing erosion based on the average EPR values that lie under erosion category (Fig. 4).

2000-2005: 83 km (33 %) of the coastline were under erosion category, 156 km (64 %) under accretion category and 7 km (3 %) under no change category during 2000-2005 (Table 2). Erosion during this period was comparatively less, but the maximum coastal stretches of Rajnagar and Mahakalapara blocks recorded higher erosion (Fig. 3). The average values of EPR pertaining to each block was calculated which revealed dominant transects along Ersama, Balikuda, Rajnagar, and Balasore Sadar blocks were under erosion category (Fig. 3).

2005-2010: During 2005-2010, 134 km (55 %) of coastal area fell under erosion category, 105 km (43 %) length in accretion category and 6 km (02 %) lengths under no change category (Table 2). The maximum stretches of the coastline were under erosion in the central and southern parts of the study area covering Chandabali, Rajnagar, Mahakalapara, Kujang and Ersama blocks. The average value of the EPR of transects pertaining to each block was calculated which reveal erosion along Chandabali, Bahanaga, Ersama, Kujang, Mahakalapara, Rajnagar and Balasore Sadar blocks (Fig. 3).

Net shoreline change rate

The results of the shoreline change rate, calculated by using EPR revealed that 91 km of coastline was under erosion, which corresponded to 37 % of coastline pertaining to the coastal blocks Rajnagar, Mahakalapara, Ersama and Balikuda blocks (Table 3 and Fig. 3). Whereas the net shoreline change rate, calculated by using LRR reveals that 84 km was under erosion representing 35 % of coastline pertaining to the same coastal blocks given above. Both EPR and LRR techniques used to estimate shoreline change rate here, depicted the nearly similar distribution of erosion classes with a coastline length of 91 and 84 km for ERP and LRR respectively. Similarly, both EPR and LRR technique showed the similar distribution of accretion with a coastal length of 132 km. The similar result of erosion and accretion by both EPR and LRR technique indicated weaker cyclic trend in erosion. However, the higher magnitude was recorded in EPR when compared to LRR as the LRR technique tend to underestimate[35]. In recent decades, the higher erosion was recorded in Balikuda block of Jagatsinghpur district. Maximum erosion was observed in southern coastal parts of the study area in comparison to northern and central parts of the coast. This might be due to higher wave action, impact of monsoon tidal current, sea level rise, and tropical cyclones. Frequent occurrence of tropical cyclones with resultant heavy rainfall and floods could have played major role in shoreline change. High accretion in the northern part could be attributed to weaker coastal processes and coastal morphology. Further, central and northern parts of the coasts supplied with the sediment into the coastal environment by major rivers joining the sea in these areas.

Discussion

Different parts of the Odisha coastline were studied in the present piece of work that discerned dynamic behaviour of erosion and accretion processes at temporal scale. Annual to lustrum shoreline study clearly predicted that erosion was high along the northern parts of Devi River, Paradeep coast and Jatadhar Creek of Jagatsinghpur District. The results indicated that shoreline behaviour was highly dynamic in the study area, which could be due to reduced deltaic characteristics of rivers and intense cyclonic activities. This part of the study area was victimized by 341 depressions, 82 cyclonic surge and 28 severe cyclone surges during the 1891-2007 as reported in the Indian Metrological Department's (IMD) Cyclone E-Atlas (IMDs). This region experienced more than one cyclone per year, which obviously generated stronger coastal processes leading to coastal erosion. Odisha super cyclone, which occurred on 29th and 30th October 1999 triggered heavy erosion and uprooted thousands of trees. This region is also prone to floods due to heavy rainfall during the monsoon and cyclone times. Almost all the floods were in Mahanadi, Brahmani and Baitarani Rivers which are located in the present study area. In general, southern parts of the coasts are more vulnerable to erosion as depicted in the results. This is due to the high exposure of these coasts to the natural environment continuously affected by strong coastal processes and extreme events (cyclones and floods). The higher erosion recorded near Paradeep port might be triggered by the breakwater constructed across the port. Whereas, northern parts dominantly under the accretion to no change classes indicated less exposure to coastal processes and revealed less vulnerability to coastal erosion. This could be due to comparatively weaker coastal process and the coastal morphology. The development of port also leads to significant role for changes of the seabed as well as shoreline. These changes can be effect on currents, waves and water quality of the coastal tract. On the other hand, construction of breakwaters, Jetties and other structures on the coast also affect the shoreline.

Conclusion

The Odisha coast is extremely dynamic in terms of the shoreline change as revealed by 299 changes estimated by more than 4000 transects along the study area pertaining to 25 years (1990-2015) period. The result suggests that the applicability of satellite data along with GIS technology and statistical methods are suitable for extraction and monitoring of shoreline change analysis. The present study concludes with the higher exposure of the coastal environment especially southern parts of the study area to erosion especially the coastal tracts of Rajnagar, Mahakalapara, Ersama and Balikuda blocks. This erosion could be attributed to strong coastal processes, frequent extreme events (tropical cyclones) and continuously rising sea levels. The northern parts were comparatively less vulnerable to erosion with weak coastal processes and the local morphology. The presence of the mudflats and mangroves in these areas are indicative of low energy condition along the coast with weak coastal processes. The study further concludes that weaker cyclic trend in erosion observed as the results of erosion in the EPR and LRR were similar. The study also depicted effective use of multi-resolution satellite images in estimating and monitoring of shoreline changes in extremely dynamic coastal regimes. Therefore, shoreline delineation from high-resolution satellite data in future studies will be more precise as compared to the medium resolution satellite data. Future shoreline prediction can be adopted for improvement of this research. Studies of sediment dynamics from land to oceans by rivers in this region is also suggested for future study. The results of the current study forms vital information for the coastal zone management especially shoreline management.

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