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ASSESSMENT OF SHORELINE POSITIONAL UNCERTAINTY USING REMOTE SENSING AND GIS TECHNIQUES: A CASE STUDY FROM THE EAST COAST OF INDIA

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Abstract: The focus of this research was to assess the shoreline changes by comparing the satellite data from 1980 to 2020. The study area falls in the region between Kodiakarai and Nagapattinam of the east coast of India, which has frequently been distressed by storm surges and cyclones in the Bay of Bengal. The Digital Shoreline Analysis System (DSAS) detects and measures the erosional and accretional shoreline positions through the statistics of the Shoreline Change Envelope, Net Shoreline Movement, End Point Rate, Linear Regression Rate, and Weighted Linear Regression. The results show that the shoreline from Kodiakkarai to Nagapattinam suffered severe erosion of 17.7% in total with an average annual erosion rate of 3.4 m/year from 1980 to 2020 and the rate of erosion ranged between 0.1 m/year to 19.8 m/year. About 90.5% of the total shoreline was faced high erosion during the period between 2000 and 2010. The maximum erosion was about 1061 m from 2000 to 2010, the maximum accretion was found to be 1002 m in transects at Kodiakkarai during 2010 to 2020. After the effect of 2004 tsunami, the corresponding changes in littoral currents caused the drastic erosion and accretion in this shoreline. The DSAS prediction model shows that 19.3% of the current shoreline will erode in 2030. The maximum predicted erosion is 406 m at Kodiakkarai and the maximum predicted accretion is 148 m at Nagapattinam region. The coastal zone from Kodiakkarai to Nagapattinam needs special attention to prevent the erosion and it is recommended to build suitable coastal protection structures along the coast for sustainable development and to execute the coastal zone management for this region.

Keywords: shoreline; DSAS; accretion; erosion; remote sensing and GIS; East Coast of India

Introduction

Natural calamities such as storm surge, cyclones, sea level rise due to climate change; tidal actions like high tide and low tide adversely affect the shoreline position that causes the shoreline changes (Appeaning Addo, Jayson-Quashigah, & Kufogbe, 2011; Muthusamy, Sivakumar, Durai, Sheriff, & Subramanian, 2018). Erosion and accretion at shoreline occur naturally by waves, currents, winds, tectonic activities, and by coastal geomorphic changes. The anthropogenic activities that cause shoreline erosion and accretion are anchoring of fishing boats, construction of buildings near a coastline, construction of shipping and fishing harbors, sea sand mining, and felling of trees on the beaches (Jayaprakash, Sivakumar, Muthusamy, Krishnamurthy, & Patterson, 2016; Shanmugam,

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Krishnamurthy, Sivakumar, & Nethaji, 2014). The process of erosion and accretion that changes the coastal environment leads to the uncertainty of shoreline position. This change greatly affects the coastal community, though one third of the world population lives in the coastal zones (Neumann, Vafeidis, Zimmermann, & Nicholls, 2015). Detecting the shoreline changes will take place in the future since it is very important for the management of the coastal zone and natural resources (Kannan, Ramanamurthy, & Kanungo, 2016). The prediction of the rate of sea level rise due to the climate change is considered as a challenge in making the coastal land use policy.

Based on historical records of the occasional rise and fall of sea level, precautionary measures should be taken as a preventive measure to prevent significant changes in coastal zones (Baker & McGowan, 2013). Researchers strived to gather enough evidence before reaching the conclusions about the location of the past shorelines. It involved obtaining information and locating through a historical map. However, it also misled in identifying past shorelines. To get better and more accurate information, routine site inspection was required that involved human resource, and more time and more cost. The aerial images provided insufficient information due to its difficulty in continuing the usage and its limited aerial coverage. Fast growing computer technologies now make it possible to predict the shoreline changes more precisely. Remote sensing data and GIS technology with Digital Shoreline Analysis System (DSAS) are successful methods used to study the erosion and accretion processes along the coastlines (Jayaprakash et al., 2016; Kongeswaran & Karikalan, 2015; Prabakaran & Anbarasu, 2010; Shanmugam et al., 2014). DSAS analysis has given a better understanding of the coastal erosion and accretion that might be attributed to the debouching rivers in the east coast of India (Salghuna & Aravind Bharathvaj, 2015). Using recent satellite data and GIS techniques to demarcate the high erosion and vulnerable zones will give a better policy framework and adaptive methods that could prevent future ecological and economic losses (Natesan, Parthasarathy, Vishnunath, Kumar, & Ferrer, 2015). Web-based GIS is an innovative tool that will give more benefits for coastal community, decision makers and researchers. They can interact with the geospatial datasets through the web browsers (Jayakumar & Malarvannan, 2016; Krishnakumar, Lakshumanan, Viveganandan, Jonathan, & Muthukumar, 2011). It can also be used to evaluate the coastal vulnerability through numerical modelling methods for coastal zone management (Sobral, Ferreira, & Pinto, 2012; Thangaraj & Ramasamy, 2019). The natural and anthropogenic impact along the coastal zone has modified and controlled the shoreline erosion and accretion of the coastal zones of India (Kongeswaran & Karikalan, 2016a, 2016b, 2021; Kumaravel, Ramkumar, Gurunanam, & Suresh, 2012). The increasing population in the coastal areas of the changing shorelines has become more than a topic of scientific curiosity.

Coastal areas are dynamic with changes occurring over many time scales (Moore, 2000). Based on the review, the objectives have been made to identify the shoreline changes using remote sensing data and GIS techniques, which are sensitive to shoreline movement and coastal oscillation over a period, to respond to the socio-economic and environmental factors with appropriate planning, management and regulations (Puustinen, Pouta, Neuvonen, & Sievänen, 2009; Rahayuningsih, Muntasib, & Prasetyo, 2016; Valjarević, Djekić, Stevanović, Ivanović, & Jandziković, 2018; Valjarević, Mijajlović, Živković, Nović, & Mihajlović, 2019). Eventually, this study aims to identify the temporal position of shoreline for the past four decades and to determine the amount of erosion and accretion behaviors over the period. This study also evaluates the spatial pattern of erosion and accretion through the shoreline prediction model. The statistical results of Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR), Linear Regression Rate (LRR), and Weighted Linear Regression Rate (WLR) were derived from the GIS integrated shoreline analysis system and analyzed to understand the positional uncertainty of the shoreline of the study area.

Study area

The bounding coordinates of the study area in the coastal region from Kodiakkarai to Nagapattinam falls between 79°44'24" E, 10°16'19" N and 79°52'53" E, 10°45'57" N. Kodiakkarai is the low headland on the Coromandal coast, that is also called Point Calimere from Nagapattinam District in Tamil Nadu, India (Figure 1). The district is well known for the ancient port city Poompuhar or Kaveripoompattinam. Several historic documents have details about this port city as Periplus of the Erythraean sea (Huntingford, 1980).

This study investigates the southern coastal region where the ancient port city was reportedly located. Figure 2 shows the geomorphology map (a), land use/land cover map (b), and the true color composite map with bathymetry (c) of the study area. The geomorphology map (Figure 2a) shows that the study area is majorly comprised of a coastal plain which is followed by the alluvial plain and older coastal plain. Mud flats are the fourth major geomorphologic feature found in the study area. The land next to the shoreline is chiefly used for cropping and plantations (Figure 2b). The major part of the offshore region of the investigated area is found in the depth range of 10 m from the bathymetry map (Figure 2c). This study area has complex river channels and it is mostly covered by a part of the Cauvery delta. The Kodiakarai region, called Vedaranyam forest, is one of the last remnants of the dry evergreen forest with birds' sanctuary in southern India. This includes dry evergreen forests, mangrove forests, and wetlands. Anthropogenic activities limited the entry of high tides and tributaries into the mainland, which is the main source of wetlands on the Vedaranyam coast (Prabaharan, Raju, Lakshumanan, & Ramalingam, 2010). The sanctuary was enlarged in 1988 and renamed Point Calimere Wildlife and Bird Sanctuary, with a reserve spread of 377 km^2 (DestiMap, n.d.). The coast from Kodiakkarai to Nagapattinam has the shoreline of the total length of 69 km. The study area has major settlements named Kodiakkarai, Muthupet, Pushpavanam, Vedaranyam, Kameshwaram, Naluvethapathy, Nagapattinam, and Thirupoondi. This coastline was highly affected by the 2004 tsunami and later cyclones. Hence, this region is very important for studying the shoreline changes along the coast for erosion, accretion, and the rate of changes. These statistics are needed to determine the vulnerable zones and to understand the social impact of the shoreline change.

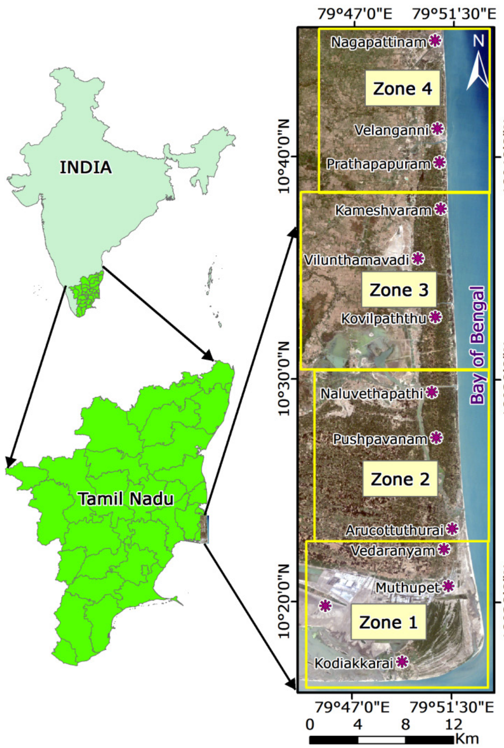

Figure 1. Map shows the investigated area at the part of the east coast of India. The satellite image was obtained from "Landsat Collection 1 U.S. Landsat Analysis Ready Data," by United States Geological Survey, Earth Resources Observation and Science Center, 2016 (https://doi.org/10.5066/F7319TSJ). In the public domain.

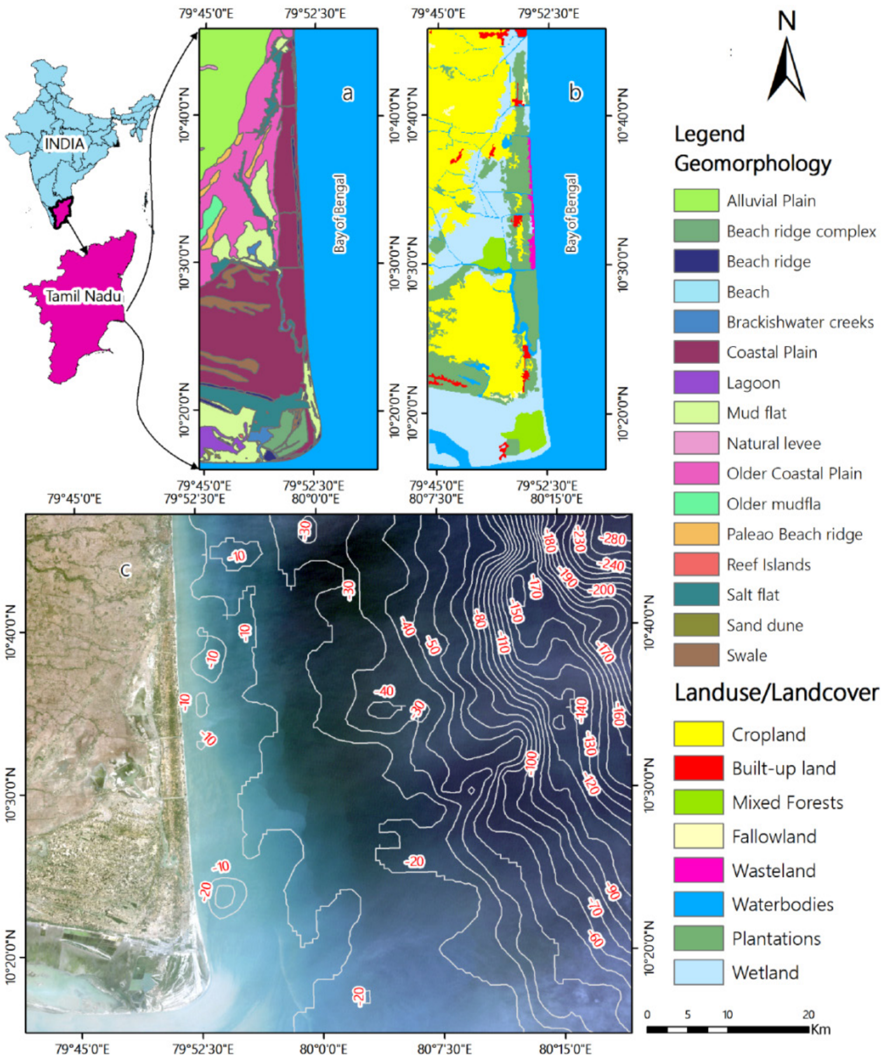

Figure 2. Geomorphology (a), land use/land cover (b), and bathymetry data (c) of the study area. Bathymetry data are from "Centenary Edition of the GEBCO Digital Atlas," by Intergovernmental Oceanographic Commission, International Hydrographic Organization, & British Oceanographic Data Centre, 2003 (https://www.gebco.net/). In public domain.

Materials and methods

The methodology adopted has utilized the data of Landsat satellite images which are visually interpreted with ground truth verification and extracted the shorelines of the past four decades

(Table 1). Landsat data were processed to identify and delineate the shorelines through the investigation of specific land-water boundary, which was obtained by a nonlinear edge-enhancement method. This function was used for image interpretation to provide enhanced image quality in order to visually identify the edges made by the boundaries of different surface features. Enhancement techniques improve the displayed features to increase the visual contrast between the features within a scene and clearly define the land-water boundary (Sivakumar, Muthusamy, Jayaprakash, Mohana, & Sudharson, 2017). After the pre-processing, the enhanced data were used and the shorelines were manually digitized with the help of ArcGIS10.8 software. Line segment tool was used to manually digitize the shorelines indifferent years. The shoreline of the recent period was delineated in the processed satellite images and were checked, modified, and corrected after the ground truth verification. The shoreline change analysis was done by DSAS v5.0 tool on ArcGIS platform (Himmelstoss, Henderson, Kratzmann, & Farris, 2018). The changes of the shoreline from Kodiakkarai to Nagapattinam were studied for the past 40 years, from 1980 to 2020, and the shoreline where they will occur in the future were also predicted for the period 2020 to 2030 through the built-in prediction model in DSAS v5.0. The shoreline changes for the study area were evaluated based on comparing the five years of the historical shorelines which were extracted from the satellite imageries. Along the shoreline, the field measurements and field photos were collected during the fieldwork. The study area was classified into four zones, as shown in Figure 1 for the ground truth verification of the recent shoreline. The zones were divided based on the major coastal habitats. Each zone covered the administrative boundaries of the three important locations. The field investigations were conducted with the support of Global Positioning System (GPS) device to collect the precise positions.

Table 1
The satellite data and their acquisition years

Satellite data/Sensor	Year of Acquisition	Spatial Resolution (m)
Landsat 3 (MSS)	1980	83
Landsat 5 (MSS & TM)	1990	30
Landsat 5 (MSS & TM)	2000	30
Landsat 7 (ETM+)	2010	30
Landsat 8 (OLI & TIRS)	2020	30

Note. MSS = Multi Spectral Scanner; TM = Thematic Mapper; ETM+= Enhanced Thematic Mapper; OLI = Operational Land Imager, TIRS =Thermal Infrared Sensor.

The collected locations information was loaded in GIS. All the location values were converted into point shape file, later into line shape file, and then plotted into the base map of the study area on ArcGIS platform. The coastal evolution is a combination of processes resulted by tectonic, fluvial, marine, and fluvial-marine activities. Such applicable information was collected during the field investigation. The DSAS generated transects that were vertical to the baseline and bisected all the given shorelines. It determined the shoreline movement by distance and statistical measurements such as SCE, NSM, EPR, LRR, WLR, and shoreline forecasting to predict the future shoreline position. The SCE determined the proximity of the farthest shoreline position from the nearest shoreline position to the given base line at each transect. It generally reports the distance and not the rate of movement. Similar to SCE, the NSM also reports the distance not the rate of movement between the positions of the oldest shoreline and the youngest shoreline in all transects from the baseline (Oyedotun, 2014). The DSAS tool calculates the average changes in the coastline position. The value of naturally occurring uncertainty and horizontal accuracy was calculated in the field. Changes in the shoreline position due to wind and wave actions caused uncertainty in measurements (Joesidawati & Suntoyo, 2016).

EPR is a simple mathematical model; it was used to measure the amount of shoreline change and its future positions based on empirical observations (Mukhopadhyay et al., 2012). The EPR calculates the rate of changes from the oldest to the current shoreline by dividing the distance with time elapsed. It requires only two shoreline positions with corresponding dates of the shorelines, which is considered as a major advantage of the EPR computation (Genz, Fletcher, Dunn, Frazer, & Rooney, 2007). Fitting the least square regression line to all the points where transect bisects each shoreline gives the LRR statistics. The LRR calculated by the sloping line was placed to minimize the sums of the squared residuals. This is a purely computational method based on the accepted statistical concepts which is easy to employ and all the data are used in LRR, regardless of changes in the trend or accuracy (Crowell, Leatherman, & Buckley, 1991; Dolan, Fenster, & Holme, 1991). Susceptibility to the effects of outliers and tendencies to underestimate the other relative statistical change rates such as EPR are the limitations of LRR. The WLR is generally used to determine the best-fit line by giving more importance or weight to the more reliable data. It was applied to compute the rate-of-change statistics for shorelines by giving greater emphasis to the points that have minimum positional uncertainty. The weight is defined as a function of the variance in the uncertainty of the measurement (Himmelstoss et al., 2018). Shoreline forecasting model of DSAS v5.0 is an option to predict a shoreline (10 or 20 years into the future) based on the statistics of historical shoreline positions (Himmelstoss et al., 2018; Salauddin, Hossain, Tanim, Kabir, & Saddam, 2018). This model has the assumption to monitor the progress of shoreline conditions. The particular model is the best measure to anticipate things coming up along the coastline that has no earlier information with respect to all the impact of the underlined total activity. It will require residual transport or wave extraction based on the considered history. This model was used to view the coastal events and calculate the future shoreline position based on the information provided (Himmelstoss et al., 2018).

$$SCE = Y_2 - Y_1 \tag{1}$$

$$SCE = Y_2 - Y_{x1} \tag{2}$$

$$EPR = \frac{(Y_1 - Y_2)}{(X_2 - X_1)} \tag{3}$$

Where Y_1 and Y_2 are the farthest and the nearest coastline positions to baseline, X_2, and X_1 are time difference between the two coastlines.

$$EPR = (X_t - X_2) + Y_2 \tag{4}$$

Where X_t is the predicted time and Y_2 is the last position of the coast.

DSAS processing

DSAS v5.0 software is an add-in to ESRI ArcGIS desktop 10.4 and above versions that enables a user to calculate the rate-of-change statistics from multiple historical shoreline positions. DSAS is an extension developed by USGS for ArcGIS which is an automated tool that gives the change statistics for the given shorelines. DSAS creates transects that bisect the shorelines from a base line from which the change statistics were calculated. This gives a mechanized technique to set up the estimation of areas, performs rate counts that give the information to evaluate the vigor of the rates, and incorporates a prediction model of the shoreline. It determines the alternatives of 10-year as well as 20-year shoreline change positions and its vulnerability (Himmelstoss et al., 2018; Salauddin et al., 2018). This subchapter provides the guidelines for proper and basic construction and lists the required attributes that users need to develop within the basic feature class. The input of shoreline data should be present in a feature class in the personal geodatabase. The appended shoreline data was imported from the personal geodatabase from ArcCatalog. Projected coordinate system was followed throughout the DSAS analysis and the units had to be expressed in meters. DSAS consisted of three principle segments to help a client characterize a landward baseline, create orthogonal transects and calculate the rate of changes (Sheeja & Ajay Gokul, 2016). A landward baseline was built to serve as a starting point to all transects, and it was also used to calculate the change rate statistics for the given time series of the coastline (Leatherman, 1983).

The Landsat 3 image was registered in the GIS environment to digitize the data in the year 1980 for the shoreline of the study area that was buffered to 200 m to create the baseline (Thieler, Himmelstoss, Zichichi, & Ergul, 2009). The buffer tool is available in the ArcGIS platform which produces a buffer polygon from the given line polygon on the basis of an interval. This buffer polygon was later converted into a line file to be considered as a baseline for the DSAS analysis. The sequence of shoreline data was manually digitized for the five different time periods between 1980, 1990, 2000, 2010, and 2020 at a scale of 1:50,000, i.e., with six key attribute fields of object ID, ID, date, SHAPE, SHAPE length, and uncertainty values for DSAS analysis. Different historical shoreline positions close to the assumption benchmark are the key need for exploring the shoreline. All different shoreline features have been merged within a single line on the attribute table, which enabled the multiple coastline files to fix together into a single shapefile for further analysis. DSAS v5.0 software was used to measure the shoreline change statistics from different periods of shoreline positions about 69 km of coastal length. The coastline from Kodiakkarai to Nagapattinam was taken into account to assess the shoreline changes for the past decades from 1980 to 2020 using various satellite data. The extracted vector layers were the shorelines of the corresponding years; these lines were compiled as a single geodatabase file in ArcCatalogue. Further, the geodatabase was statistically analyzed using the DSAS v5.0 as the ArcGIS10.8 extension tool. In this analysis, the 1980 shoreline that was derived from the satellite data was the initial shoreline. A new baseline was drawn for plotting all the shoreline layers put together to generate a single layer.

Results and discussion

The total number of transects generated is 327 with 200 m interval. The percentage of the erosion and accretion transects in total are illustrated as histograms in Figure 3. During the overall study period from 1980 to 2020, about 82.3% of transects measured accretion of shoreline and 17.7% were found as erosional shoreline in total. The highest percentage of shoreline erosion of 90.5% was recorded during the period 2000 to 2010 which is followed by the period between 2010 and 2020 with 23.9% erosion, 1980–1990 with 16.2% erosion, and 1990–2000 with 12.2% erosion of shorelines. The east coast of India experienced the devastating natural calamity of Tsunami in 2004 and numerous cyclonic impacts during 2000 to 2010. It changed the coastal dynamics that led to more erosion during this period. Respectively, the highest accretion was recorded as 87.8% during the period from 1990 to 2000 followed by 83.8% between 1980 and 1990, 76.1% between2010 and 2020, and 9.5% during the period from 2000 to 2010 (Figure 3). These statistical products also explain the erosion of southern coastal regions due coastal dynamics.

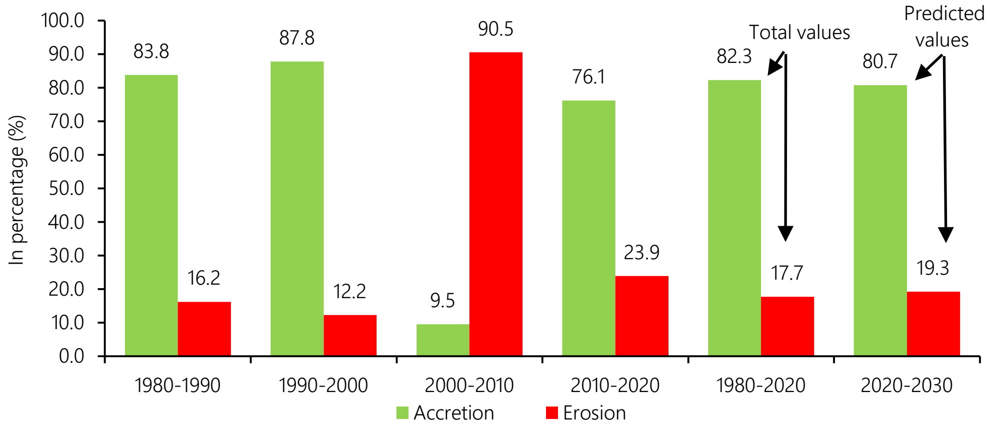

Figure 3. Bar chart depicts the percentage of erosional and accretional transects in total during the study period (1980–2020) and the prediction period (2020–2030).

According to Table 2, the highest erosion of 1060.7 m was recorded during the period from 2000 to 2010, and the highest accretion was recorded as 1001.94 m during the period from 2010 to 2020 in Zone 1 of the coastal region from the Kodiyakkarai to Muthupet. Pushpavanam and Vedaranyam coastal stretch in the studied Zone 2 faced the highest erosion during the period 2000–2010 at 151.84 m, as well as the highest accretion of 212.95 m which occurred during the period from 1980 to 1990. The Kameshwaram and Naluvethapathy coastal region in Zone 3 was greatly eroded from 2000 to 2010 with 82.83 m and accretion was recorded during the period from 1980 to 1990 as 286.17 m. The major settlements Prathapapuram and Nagapattinam in Zone 4 experienced maximum erosion of 165.74 m from 2000 to 2010, and the maximum accretion observed during the period from 1980 to 1990 was 416.64 m. Zone 1 consists of the natural wetland which is a relatively low lying region; hence the shoreline drastically changed due to the coastal dynamics and faced erosion of the highest intensity, whereas Zone 3 has many river drainages that continuously feed the shore with sediments to build up.

Table 2
Shoreline fluctuation with distances from 1980 to 2020

Zones	Max/min/avg	1980 to 1990	1990 to 2000	2000 to 2010	2010 to 2020	1980 to 2020
	Minimum	−672.7	−89.64	−1060.7	−95.23	−793.79
Zone 1	Average	−10.36	60.79	−103.54	38.36	−24
	Maximum	174.52	352.56	38.71	1001.94	274.76
	Minimum	74.09	19.15	−151.84	−9.21	84.24
Zone 2	Average	129.9	81.62	−87.08	45.35	174.63
	Maximum	212.95	171.17	−23.7	116.4	256.79
	Minimum	128.72	17.59	−82.83	7.68	221.17
Zone 3	Average	210.71	64.61	−36.89	32.2	284.97
	Maximum	286.17	107.52	−7.68	55.61	341.6
	Minimum	227.53	53.32	−165.74	−37.16	256.28
Zone 4	Average	322.99	91.72	−119.71	29.88	324.59
	Maximum	416.64	136.68	−41.76	96.7	434.85

Note. Negative values indicate erosion, while positive ones indicate accretion in meters.

The minimum, maximum, and average of erosion and accretion activities are shown in Figures 4a and 4b. The two decades, 1980–1990 and 1990–2000, faced accretions. This shows that before 2000, the coastal stretch experienced the minimum effect of sea level rise and cyclonic impact, whereas intensive erosional activity has been recorded since 2000.

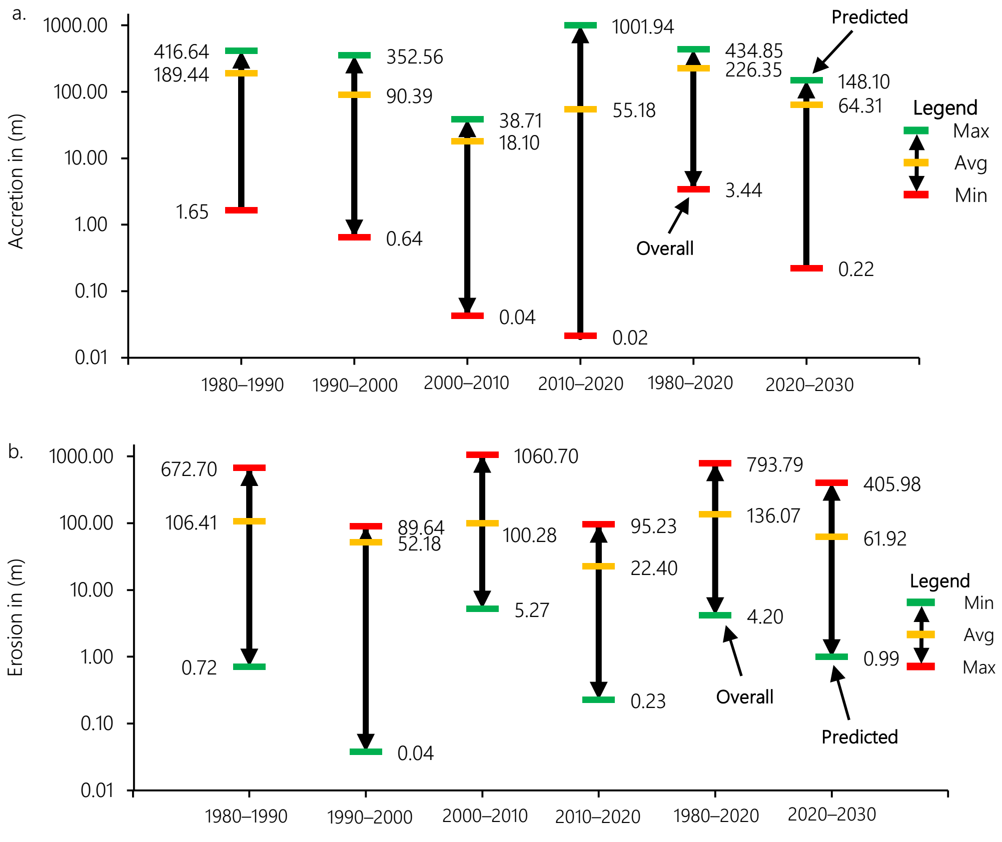

Figure 4. Statistics of accretion (a) and erosion (b) processes during the study period.

The EPR model was used to predict the future shoreline positional changes that are expected to occur along the coast between 2020 and 2030. In this estimation, the rate of shoreline change was calculated without observations such as effects of disasters like tsunamis and hurricanes. The anticipated shoreline demonstrates that maximum erosion will be about 406 m from 2020 to 2030 and the average accretion will be 64.3 m (Figure 4a and 4b). The maximum accretion will be observed in the study area with 148.10 m from the prediction model.

The spatial pattern of the obtained change statistics are shown in Figure 5. The shoreline movements with respect to distance as SCE and NSM are depicted spatially in Figures 5a and 5b. They show that the southern coastal zone is facing severe erosion and northern coastal region is accreting with respect to SCE and NSM. The change statistics of EPR, LRR, and WRR are illustrated spatially in Figures 5c, 5d, and 5e. Based on the spatial pattern of EPR, Zones 3 and 4 represents accreting shoreline (Figure 5c). Similar spatial pattern was identified in LRR and WRR statistics

(Figure 5d and 5e). These statistics show that southern coastal regions (Zone 2 and Zone 1) faced moderate to severe erosion. The reason for the development of Point Calimere pit may be due to the after effects of December 2004 tsunami at Vedaranyam coast (Natesan, Thulasiraman, Deepthi, & Kathiravan, 2013). The tidal and current direction in the Bay of Bengal is observed as south to north trend during winter and north to south trend during summer in the east coast of India. This change impacts the shoreline of the east coast of India and induces the erosion and accretion processes along the coast.

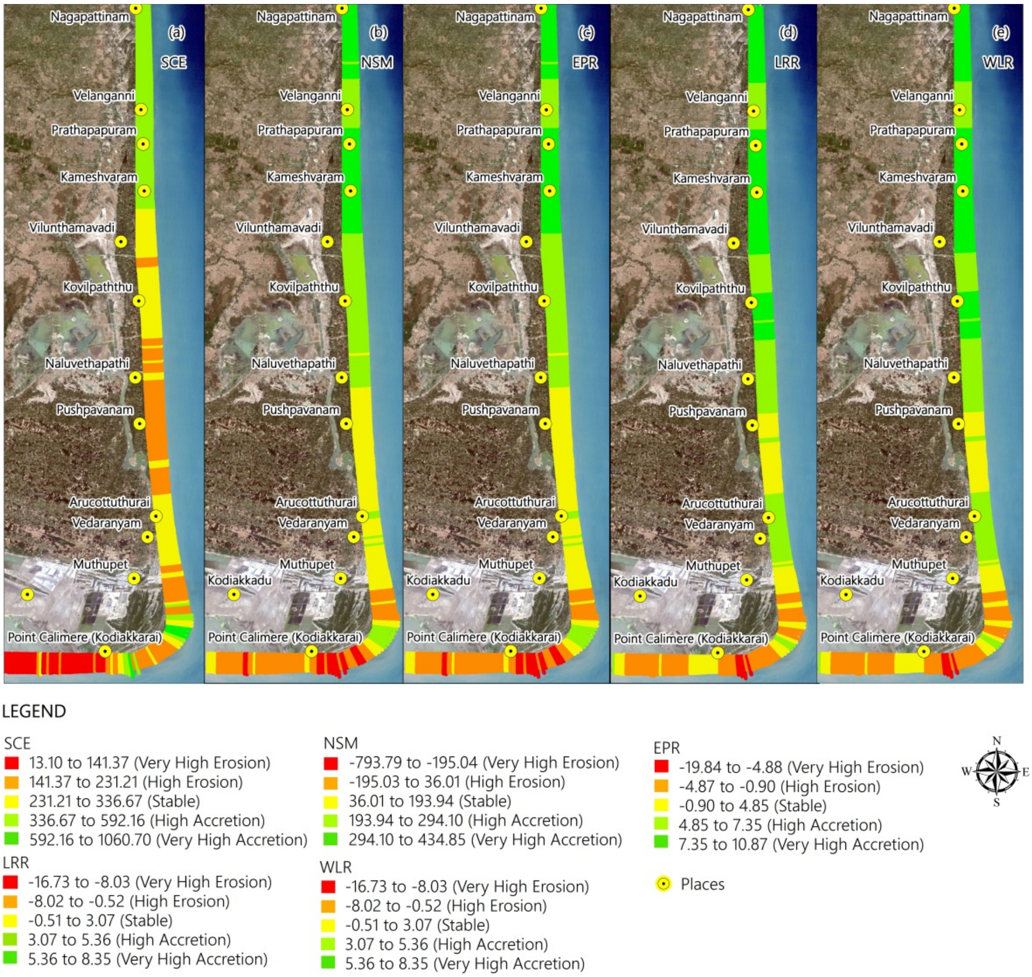

Figure 5. Spatial pattern of SCE in m (a), NSM in m (b), EPR in m/year (c), LRR in m/year (d), and WLR in m/year (c). The satellite image was obtained from "Landsat Collection 1 U.S. Landsat Analysis Ready Data," by United States Geological Survey, Earth Resources Observation and Science Center, 2016 (https://doi.org/10.5066/F7319TSJ). In the public domain.

The prediction results were used to calculate the maximum accretion along the shoreline, which will be 80.7%, whereas erosion will be 19.3% as estimated in the study area (Figure 3). According to Table 3, the prediction results of the minimum EPR is obtained in Zone 1 as −18.17 m/year (erosional) and the maximum EPR is obtained in Zone 4 as 14.71 m/year (accretional). The average EPR values obtained range from −1.27 m/year (erosional at Zone 1) to 9.13 m/year (accretional at Zone 4). Similar to EPR prediction results, the NSM values show the minimum of −181.73 m (erosional) in Zone 1 and the maximum value of 147.11 m (accretional) in Zone 4 obtained from the DSAS prediction computation. The average value of the obtained NSM varies between −12.69 m in Zone 1 and 91.27 m in Zone 4.

Table 3
Predicted shoreline distance and statistics for 2030

Zones	EPR	2020−2030	NSM	2020−2030
Zone 1	Minimum	−18.17	Minimum	−181.73
	Average	−1.27	Average	−12.69
	Maximum	12.37	Maximum	123.65
Zone 2	Minimum	0.00	Minimum	0.00
	Average	3.44	Average	34.42
	Maximum	8.06	Maximum	80.63
Zone 3	Minimum	5.23	Minimum	52.30
	Average	7.70	Average	77.00
	Maximum	10.36	Maximum	103.63
Zone 4	Minimum	6.59	Minimum	65.88
	Average	9.13	Average	91.27
	Maximum	14.71	Maximum	147.11

Note. Negative values indicate erosion, while positive ones indicate accretion in meters.

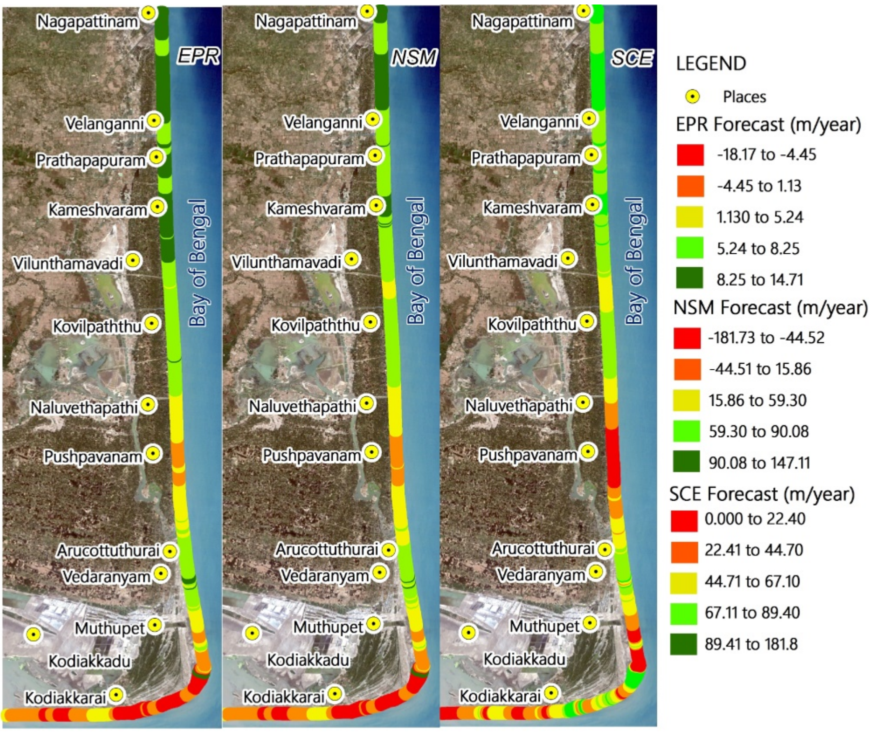

Figure 6. Spatial pattern of the predicted EPR, NSM, and SCE in (m/year). The satellite image was obtained from "Landsat Collection 1 U.S. Landsat Analysis Ready Data," by United States Geological Survey, Earth Resources Observation and Science Center, 2016 (https://doi.org/10.5066/F7319TSJ). In the public domain.

Shoreline change map is very helpful for coastal zone management authorities and coastal engineers for the regulation of coastal zones (Mageswaran et al., 2015). The spatial pattern of the predicted shoreline changes is illustrated in Figure 6. The maps show that southern coastal stretch will face severe erosion and the northern regions will accrete towards sea. With the support of these maps, prior preventive actions should be taken by the local government authorities to avoid losses of livelihoods and properties in Zone 1 that are facing high erosion.

Similar study conducted by Shanmugam et al. (2014) at Puducherry to Villupruam coast reports high erosion from 1984 to 2014 which was caused by the construction of the port and other related human activities. As reported by the Natesan et al. (2013), the Vedaranyam coast is accreting naturally due to the sediment source from the Kodiyakkarai, whereas the Kodiakkarai coast is faced with high erosion. Another study by Natesan et al. (2015) confirms that the beach ridge occurrences with continuous sediment supply from the adjacent rivers along the Vedaranyam coast indicate the prograding of shoreline in the seaward direction. The other reason for the development of Point Calimere pit may be due to the fact that littoral current has changed which was reported after the tsunami.

Conclusion

The results obtained from the study conclude that the use of GIS technology with the integration of remote sensing data is very efficient in shoreline detection and shoreline change analysis. Field check with GIS investigation, as well as DSAS study, confirms that southern Kodiakkarai coast is accreting naturally. Spatial modeling, with a temporal representation of the dynamic shoreline of northern Nagapattinam coast indicates that the shoreline has eroded and some places have moved landwards for up to 1 km. The Kodiakkarai to Muthupet witnessed the high erosion and accretion processes; this is followed by Parathapapuram-Nagapattinam region where there were high erosion and accretion. This study points out that the erosion occurred frequently from 2000 to 2010 at about 90.5%. It was due to the effects of catastrophic event of tsunami that occurred in 2004 and the cyclones formed in the Bay of Bengal. The prediction model shows that the eroding shoreline of Point Calimere in 2030 will need prior attention to stop further erosion of the present shoreline. The study proposes to generate the coastal protection structures such as seawalls, bulkheads, groins, and jetties which should be built in the appropriate places to prevent erosion and increase the rate of accretion in the shoreline region. Shoreline prediction (or change) map is very helpful for the coastal authorities and coastal engineers of government organization, private sectors, and publics to manage and regulate the coastal zones. This research clearly recommends that proper beach management project should be made along the shoreline to conserve the coastal region from natural calamities. The derived prediction model from DSAS can be evaluated with the results of modern computational technique such as multi linear regression analysis and artificial neural network models. It will be a scope for future investigation and that may lead to finding the optimal solution for coastal management in such dynamic coastal regions.

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