1. Introduction

The shoreline computation is one of the most important parameters in detection of coastal erosion and deposition as well as the study of coastal morphodynamics (Armenio et al. 2019). Shoreline lines are the interface between land and sea, which changes erratically in response to one or more factors, like morphological, climatic or geological factors in nature (Mujabar and Chandrasekar 2013). As a borderline between the land and sea, the shorelines are subject to continuous change due to their dynamic environmental setting (Mentaschi et al. 2018). The shoreline features depends on the interactions between and among waves, tides, rivers, storms, tectonic and physical processes dynamically (Passeri et al. 2015). Vulnerability of coastal area increases due to the erosion which can be risky to the human activities along the coasts. In addition, the rising number of coastal disaster makes the coasts highly vulnerable and susceptible changes (Saxena, Geethalakshmi, and Lakshmanan 2013). It is one of the most dynamic landform types of the earth (Sparks 1990) which changes rapidly depending on geology, geomorphology and wave action along the coastline as well as periodic storms, sea level, rise, sediment transport by long shore currents and anthropogenic activities (Carter and Woodroffe 1997; Zhang, Xie, and Liu 2011).

The study of shoreline change represents a vital step in understanding the dynamism and evolution of coastal area and stakeholder could do better for reducing risk of coastal erosion and also minimized social, physical and economic loss (Fuad and F. 2017). According to Williams (2013) the study of shoreline variation and forecast play an important role in coastal zone management and it becomes more crucial in the context of climate change and sea-level rise. Coastal erosion is one of the main marine geological disasters and the hazard degree of coastal erosion means that coastal erosion range may be occurred in a future period due to the occurrence mechanism of coastal erosion and its damage characteristics (Pollard, Spencer, and Brooks 2018; Mentaschi et al. 2018; Wan et al. 2019). Traditionally, the conventional field survey methods as well as aerial photographs were used for the mapping and monitoring of shoreline changes.
(Cendrero 1989). In recent times remote sensing data has been extensively used in shoreline change studies because of their synoptic and repetitive coverage, high resolution, multispectral capabilities and its cost-effectiveness in comparison to conventional techniques (Lillesand, Kiefer, and Chipman 2015; Cendrero 1989).

Shoreline change studies have been already done using the remote sensing and Geographic Information System (GIS) techniques by in several studies at different time period in India during recent past (Alesheikh, Ghorbanali, and Nouri 2007; Chandrasekar, Viviek, and Saravanan 2013; Kumar et al. 2010; Kaliraj, Chandrasekar, and Magesh 2013). Shoreline changes in the coastal areas are easily detected and computed using geospatial techniques and automatic calculations by the extended tool of ArcGIS and further the wave action and longshore currents are responsible for accretion and erosion of coasts (Nassar et al. 2019). The coast which is subjected to accretion will be considered as less vulnerable as compared to erosion trend areas as they move towards ocean which results in the addition of land areas but erosion trend increases the risk of exposure of population to coastal hazards (Jana and Hegde 2016). For example, the shoreline of Bengkalis Island is dynamically changed over time because the abrasion rate is very high due to land-use change in peat swamp forest (Sutikno et al. 2017). Wind, waves and long shore currents moves sand from shore and place deposits it somewhere else, e.g. to other beach, deep ocean floor or to an ocean dips and trenches (Seibold and Berger 2017). Beach shape and structure may change due to erosion of sand and sand sharing systems. It takes months and years to observe impact erosion and deposition so it is often called ‘Long-Term Coastal Hazard’ (Prasad and Kumar 2014).

Globally, qualitative and quantitative analysis of shoreline spatio-temporal variations has been addressed by several studies (Nassar et al. 2019; Addo, Jayson-Quashigah, and Kufogbe 2012; Maiti and Bhattacharya 2009). The End Point Rate (EPR) technique combined with the satellite imageries are accurate and reliable method for shoreline change computation and analysis (Sebat and Salloum 2018). There are many methods of shoreline change analysis but Linear Regression Rate (LRR) has the potential to use more than two shorelines (Burningham and French 2017; Sheik and Chandrasekar 2011). LRR is determined by fitting a least-square regression line to all shoreline points for a particular transects. To minimize the square residuals the regression line is placed in the computational process and the slope line is the linear regression rate (Salghuna and Bharathvaj 2015).

Further, the Digital Shoreline Analysis System (DSAS) extension tool is used to calculate the rate of shoreline change statistics from a time series of multiple shoreline positions. DSAS has been an essential component of the U.S. Geological Survey’s Coastal Change Hazards project which provides a robust suite of regression rates in a consistent and simply repeatable method so as to execute on large volumes of data collection at various scales. The software is proposed to assist the shoreline change-calculation process and also to give rate-of-change information and the arithmetical data essential to set up the consistency of the computed results (Murali et al. 2013). DSAS is also appropriate for any general purpose that calculates positional transformation over time, for instance assessing change of glacier limits in chronological aerial photos, river edge borders or land use/land-cover changes (Thieler et al. 2009). It has three main components that define a baseline, generate orthogonal transects which is determined separation along the coast and compute rates of changes like linear regression rate, endpoint rate, average of rates etc. by means of several models or methods. (Sheik and Chandrasekar 2011; Jonah et al. 2015). The most important application of DSAS is in operation of multiple layers as representation of a particular shoreline feature (e.g. mean high water mark, cliff top) at a specific point in time.

A range of statistical change measures, these include Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression Rate (WLR) are derived within DSAS, based on the assessment of shoreline positions through different time period. Reliance on Ordnance Survey (OS) mapping depends on the consistent and accurate interpretations of traditional cartographers and surveyors over decades and centuries (Fenster, Dolan, and Elder 1993; Burningham and French 2006) and usually older/traditional surveys were based on land although after that ones are being derived from aerial photography techniques (Fenster, Dolan, and Elder 1993). To ensure the accuracy in digitization, a critical review must be considered along with proper care. DSAS derivation of historical rate of change trends as an indicator of future trends assuming continuity in the physical, natural or anthropogenic forcing which have forced the historical change observed at the site has been used for prediction patterns of shoreline behaviour (Oyedotun 2014). DSAS has been used in the present study because despite the few drawbacks of this tool is good to find out the forcing of morphodynamics, it has been effective in facilitating a thoroughly analysis of historical and temporal progress of cliff geometry and
shoreline positions alteration (Moore 2000; Oyedotun 2014; Nassar et al. 2019).

With the scarcity of multi-decadal datasets being a major hindrance to the robust computation and acknowledgement of trends in shoreline behaviour, the problem of understanding shoreline change is often presented as one that can be determined with additional data set (Le Cozannet et al. 2014; Garcia et al. 2016). Over the last two decades have certainly facilitated new insights into the contemporary shoreline change with the availability of satellite imageries of higher frequency and accumulated high resolution airborne LiDAR altimetry (Hapke et al. 2016) and LiDAR altimetry data is useful in relating annual to decadal changes in shoreline position to local sediment budgets (Richter, Faust, and Maas 2013; Pye and Blott 2016). We are still fundamentally reliant on the analysis of composite historical datasets derived from much sparser aerial photography, mapping and hydrographic surveys as progressive trends in shoreline and coastal dynamism tend to appear over multi-decadal timescales (Burningham and French 2017). Mapping and monitoring of the shoreline changes with the help of multi-temporal satellite images along the Vishakhapatnam district coast could be prior for the formulation of mitigation and regulatory policies. The study has following specific research objectives (i) to analyse the shoreline change along the coast over the past 28 years (1991–2018) and (ii) to explicate the phenomenon responsible for the shoreline change. Besides its local impacts, the present work may contribute to the literature and research field more generally in terms of shoreline change analysis at local with more comprehensively at regional and global level. It could also be used for further research endeavour especially in the field shoreline dynamics and management of shoreline erosion and reduction of vulnerability (Liew et al. 2020). The study investigates the shoreline change and the coastal erosion and accretion variation in long-term scenario using multi-temporal Landsat satellite imageries. The results of the study could useful for erosion hazard management in Vishakhapatnam district of Andhra Pradesh which is one of the most vulnerable Coastal regions of India (Kantamaneni et al. 2019) and also be use as reference for future research endeavour and coastal hazard management at local, regional and global level.

2. Study area

Coastal belt of Vishakhapatnam District is selected for present study, which is one of the thirteen districts in the state of Andhra Pradesh. The district is bounded by Odisha in north, Vizianagram district in east, East Godavari district in the south-west and Bay of Bengal in the south. Four taluks (sub-division of district) of Vishakhapatnam District coast namely Bhemunipatnam, Vishakhapatnam, Ankapalle and Yellemanchili were chosen for shoreline change analysis as they share coastline boundary of the respective district. These taluks have been designated as Zones 1, 2, 3 and 4 respectively which shares coastal boundary with Bay of Bengal. The climate of Visakhapatnam district is wet and dry type (Koppen: Aw) with average annual temperature ranges between 24.6 and 30.7°C. Annual average temperature ranges between 24.6 and 30.7°C. The minimum and maximum temperatures are recorded during the January and June, respectively. The summer temperature reaches up to 40°C while the winter temperature hardly goes below 10°C. South-West and North-East monsoon contribute approximately 1201 mm annual rainfall in the district. Inland mandals receive more rainfall from the South-West Monsoon, while Coastal Mandalas get larger rainfall from North-East Monsoon. Forest cover is more than the one third of the district area. Majority of forest cover is of moist and dry deciduous type. Red loamy soils predominate in the district, and cover about 69.9% of the villages of the district. The soils are poor textured and easily drained. The next most commonly found soil is of the sandy loam variety which is largely confined to the coastal areas and black cotton soils are found in sizable chunks in few mandals.

The coastal zone of Visakhapatnam contains stacks, wave-cut platform, beach and sand dunes (Raju and Vaidyanadhan 1978). A study of logs of more than 1000 bores put in the tidal basin and features reported and observed here and elsewhere along the coast belts of Visakhapatnam indicate that during the commencement of Holocene. The wave activity is significant both during southwest and northeast monsoons but extreme wave conditions occur under severe tropical cyclones and storm surges which likely to hamper the coastal area of the study and susceptible to coastal erosion and accretion. In terms of geology the rock structure coastal belt of Visakhapatnam is of tertiary in nature which is having sunstones overlying crystalline Precambrian rocks. Due to long coastal length the study area has been divided into four discreet zones (Figure 1) on the basis of taluk which share coastal boundary for shoreline change analysis.

3. Material and methods

Multi-temporal (1991–2018) imageries of Landsat sensors viz. Thematic Mapper (TM) (1991, 2001, 2011, 2018), has been used to detect shoreline changes
Landsat data have synoptic and repetitive data coverage, multi-spectral resolution capabilities to observe and measure land and sea surface geophysical characteristics and distinguished these, hence proven valuable for studies related to coastal zone management since 1970s (Moore 2000; Woodcock et al. 2008; Mishra et al. 2019). All the downloaded satellite images are in UTM projection with zone 44 and WGS 84 datum. To study the shoreline change analysis along the coastal tract of Vishakhapatnam, a process has been followed as given in Figure 2. The multi-date (1991–2018) shorelines extracted through digitization of satellite images of different time period in the form of shape file and given as input in Digital Shoreline Analysis System (DSAS) tool to calculate the shoreline change rate. After creation of base line (buffering of 500 m), transects were generated using DSAS to 1 km length with 50 m spacing to study

![Figure 1. Location of the study area.](image)

(Table 1). Landsat data have synoptic and repetitive data coverage, multi-spectral resolution capabilities to observe and measure land and sea surface geophysical characteristics and distinguished these, hence proven valuable for studies related to coastal zone management since 1970s (Moore 2000; Woodcock et al. 2008; Mishra et al. 2019). All the downloaded satellite images are in UTM projection with zone 44 and WGS 84 datum. To study the shoreline change analysis along the coastal tract of Vishakhapatnam, a process has been followed as given in Figure 2. The multi-date (1991–2018) shorelines extracted through digitization of satellite images of different time period in the form of shape file and given as input in Digital Shoreline Analysis System (DSAS) tool to calculate the shoreline change rate. After creation of base line (buffering of 500 m), transects were generated using DSAS to 1 km length with 50 m spacing to study

| S. no. | Satellite/ Sensors | Resolution | Date of acquisition | Spectral bands | Path/Row |
|-------|-------------------|------------|---------------------|----------------|----------|
| 1     | Landsat 5 (TM)    | 30 m       | 1/04/1991           | 7 141/47, 141/48 & 142/48 |          |
| 2     | Landsat 7 (ETM+)  | 30 m       | 12/04/2001          | 8 141/47, 141/48 & 142/48 |          |
| 3     | Landsat 7 (ETM+)  | 30 m       | 05/03/2011          | 8 141/47, 141/48 & 142/48 |          |
| 4     | Landsat 8 (ETM+)  | 30 m       | 24/04/2018          | 9 141/47, 141/48 & 142/48 |          |

![Table 1. Details of the satellite data.](image)
the changes occurred along Vishakhapatnam coast and shoreline change statistics has been calculated in the form of Linear Regression Rate (LRR), Weighted Linear Regression and End point Rate (EPR). Final decision matrix prepared on the basis of the results and output (Figure 2).

3.1 Material

The long-term shoreline change assessment of Vishakhapatnam district coast is studied for a period of 28 years from 1991 to 2018. Shoreline change evaluations are based on comparing four shorelines extracted from different time period satellite imageries. Multi-temporal Landsat satellite data (TM, ETM+ and OLI) were downloaded from the USGS website (https://earthexplorer.usgs.gov/) for 1991, 2001, 2011 and 2018. To get the cloud and haze free data and to avoid other kind of atmospheric errors, it is good to use the satellite data of either pre-monsoon (March to April months) or post-monsoon season data (September to October months) (Lima et al. 2019; Wentz et al. 2014). Therefore, the satellite data were downloaded for the months of March and April months for the each study year. The details of the satellite data used and its details are shown in Table 1.

3.2 Methods

Globally, National and state governments have used the DSAS tool in support of resource management and critical coastal decision-making and developmental activities (Himmelstoss et al. 2018). It gives a robotized technique to build up estimation areas, performs rate figuring, gives the factual information important to evaluate the heartiness of the rates, and incorporates a beta model of shoreline determining with the alternative to produce 10- as well as 20-year shoreline skylines and ambiguity bands (Himmelstoss et al. 2018).

The shorelines using multi-temporal satellite is extracted through online visual digitization in the vector data form in ArcGIS 10.6. Each multi-temporal satellite image was digitized manually and individually for shoreline extraction. After that the different time period shoreline data has been put into Digital Shoreline Analysis System (DSAS) for further computation of shoreline change for 28 years from 1991 to 2018 (Figure 2). In DSAS tool shorelines positions are compiled with five attribute fields which includes ObjectID (a unique
number assigned to each transect), shape (polygon), date (original survey year), and shape length, ID and uncertainty values. Shorelines extracted of different time were merged as a single feature in the attribute table, which create a single shapefile of the multiple shorelines. By closely digitizing the direction and shape of the outer shoreline baseline is obtained and generated the cross shore transects for calculating the shoreline change. The rates of shoreline change were generated using the DSAS version 4.2 using an ArcGIS tool developed by the United State Geological Survey (USGS) (Himmelstoss et al. 2018). DSAS computed total transacts 2740 for whole Vishakhapatnam Coast. DSAS calculated transects, Zone 1 has 339 transects and covers 24.7 km length. Zone 2 includes 943 DSAS transects and comprised of 62.3 km of coastal length (Table 2). Zone 3 covers approximately 7 km of coastal length considering only 141 DSAS transects whereas Zone 4 covers 41.2 km in coastal boundary and it has 1318 DSAS transects which is highest amongst all the zones.

The statistical technique like Linear Regression Rate (LRR) and End Point Rate (EPR) in DSAS were used in the study (Figure 2). The LRR method has been dogged by fitting a least squares regression line to all shoreline points for a particular transects. The slope of the line is rate of shoreline change. The linear regression method of determining shoreline-change rates was based on an assumed linear trend of change between the earliest and latest shoreline dates. The long- and short-term transect metadata files provide descriptions of the two fields related with the linear regression rate calculation. LRR method consists of fitting a least squares regression line to multiple shoreline position points for a particular transect (Figure 3). The shoreline change rate along each transect for all periods (i.e. 1991, 2001, 2011 and 2018) is computed by plotting the points where shorelines are intersected by transects and calculating the linear regression equation, which has the form: \( L = b + mx \), where, \( L \) represents the distance (m), from the base line (i.e. baseline is buffered at distance of 500 m from shoreline 1991), \( x \) shoreline dates interval (years), \( m \) the slope of the fitted line (m/year) (i.e. represents the shoreline change rate, LRR), and \( b \) is the y-intercept (Figure 3). In this study, the regression equation value is achieved as \( L = 3.701x - 7368 \) and regression coefficient \( R^2 = 0.959 \) (Figure 3). Here \( R^2 > 0.87 \) and has been retained as the limit of certainty. The uncertainty of the reported rate is considered with a confidence interval (CI) of more than 95%.

The EPR is computed by dividing the distance of shoreline movement by the time passed between the initial and most recent measurements. Both the methods tend to provide small differences for computed results in many cases. Though, the LRR method is easier to use and based on accepted statistical concepts with satisfactory accuracy of output.

DSAS is used to create orthogonal transects starting from a reference baseline and intersecting the shoreline positions at 20-m intervals (Nassar et al. 2019). The distance measurements between the transect/shoreline intersections and the baseline are then employed to calculate the rate-of-change statistics. Shoreline change rate was calculated using weighted linear regression (WLS), which accounts for ambiguity in each shoreline.

| Zone no. | Zone                  | DSAS transect numbers | Coastal length (in km) |
|----------|-----------------------|-----------------------|------------------------|
| 1        | Bhemunipatnam Taluk   | 1–339                 | 24.7                   |
| 2        | Vishakhapatnam Taluk  | 340–1282              | 62.3                   |
| 3        | Ankapalli Taluk       | 1283–1424             | 6.8                    |
| 4        | Yellamanchili Taluk   | 1425–2740             | 41.2                   |

**Figure 3.** Representation of a typical cross-plot showing LRR for shoreline change.
position when calculating a trend line. Assigned weight for each shoreline position is the contrary of the positional uncertainty squared, so that shorelines with higher uncertainty have less influence on the trend line than data points with smaller uncertainty. Rates of change and ± uncertainty values (at the 95-percent confidence interval) were calculated in metres per year over the long term (all available years), and short term to capture possible changes in trends or rates and these are measured in the DSAS tool itself.

Statistical analysis satellite data was performed in GIS to determine the level of shoreline change or the rate of coastal erosion. Using DSAS consists of three main stages, such as: (i) to set up baseline parallel to the shoreline as the reference line, (ii) to choose parameter for transects perpendicular to the baseline that divides coastline in sections and (iii) to calculate the rate of change each section. Linear Regression Rates (LRR) and End Point Rate (EPR) formula (equation 1), two statistical techniques that were chosen to present the computational results. By fitting a least squares regression line to all shoreline points for a particular transects the LRR can be determined. To minimize the squared residuals the regression line is placed. The slope of the line is rate of shoreline change. The advantages of linear regression comprise: (i) all the data are used, in spite of change in trend or accuracy; (ii) the method is plainly computational; (iii) it is based on traditional statistical concepts and (iv) it is easy to take up (Figures 3 and 4). The DASA tool itself chooses the shoreline transects and gives them dependent and independent variables and automatically calculates (LRR) the rates of erosion and deposition using multi-temporal digitized. DSAS is completely an arithmetical tool which gives yield results based on input features such as date and year and digitized shape file of shoreline and it is considered to be one the efficient and effective as well as less time consuming in shoreline change analysis rather than many traditional tools and methods. It is chosen for this study as in single processing we get Net Shoreline Movement, End Point Rate, Linear Regression Rate, Weighted Linear Regression of the shorelines of the selected study area within limited time and with better accuracy. The accuracy level would be higher as when

![Figure 4. Shoreline accretions and erosion of Vishakhapatnam coast with LRR.](image-url)
more years satellite data set has been incorporated with proper care while digitization till DSAS processing (Sekovski et al. 2014). For example, 4 years TM satellite images have been chosen for shoreline change analysis of coastal Vishakhapatnam.

\[ EPR = \frac{\text{Distance in metres}}{\text{time between old estand mostrecentshore line}} \]  

3.2.1 Long-term changes

For computation of long-term shoreline changes multi-temporal Landsat satellite data is used. After digitization of multi-temporal satellite data, we used a linear regression rate of change statistics which is determined by fitting a least square regression line to all shoreline points for a particular transects. After that weight value was added in Weighted Linear Regression (WLR) method and it is the uncertainties associated with each shoreline (equation 2). According to (Genz et al. 2007) the weight \((w)\) is defined as a function of the variance in the uncertainty of the measurement \((e)\)

\[ W = 1(e)^2 \]  

3.2.2 Uncertainties and errors

Datum changes, distortions from uneven shrinking, stretching and folds, different surveying standards, different publication standard, projection errors and partial revision etc are potentials errors which are associated with coastal maps (Kankara et al., 2015). For calculating the rate change five different errors are identified (eq. 3). These could be both positional and measurement related errors. The features and phenomena that reduce the precision and accuracy of defining a shoreline position from a given data set such as, seasonal errors \(E_s\), tidal fluctuations \(E_{td}\) (tide range from nearest station) are comes under positional uncertainties. Satellite data are of same season and having a uniform spatial resolution (~30 m). Hence \(E_s\) and \(E_{td}\) has been neglected. Tidal fluctuations are 0.83, 0.68, 1.2 and 1.09 in metres for years 1991, 2001, 2011 and 2018. Measurement uncertainties are digitizing error \(E_d\), rectification error \(E_r\) are 7.6 (1991), 5.9 (2001), 7.2(2011) and 0 for base year (2018), Pixel error \(E_p\) etc which are related to skill and approach. The \(E_d\) was ±15 m for Landsat TM image (1991) and lesser, i.e. ±7.5 m for Landsat E TM + (2001, 2011, 2018) (Table 3). Ultimately, total uncertainty value was calculated for each shoreline by accounting both positional and measurement uncertainties as:

\[ E_t = \pm \sqrt{E_s^2 + E_{td}^2 + E_d^2 + E_r^2} \]

Where, \(E_t\) = Total uncertainty value, \(E_s\) = seasonal errors, \(E_{td}\) = tidal fluctuations, \(E_d\) = digitizing error, \(E_p\) = pixel error and \(E_r\) = rectification error. Total uncertainty \((E_t)\) of 4 years are 16.83, 9.57, 10.46 and 7.5 (Table 3).

| Table 3. Positional and measurement errors to extract temporal shorelines from satellite images. |
|---------------------------------------------|
| Positional Errors (m) and measurement error (m) | 1991 | 2001 | 2011 | 2018 | Remarks |
| Seasonal Errors \(E_s\) | 0 | 0 | 0 | 0 | All data are collected in the same season |
| Tidal fluctuations \(E_{td}\) | 0.83 | 0.68 | 1.2 | 0.9 | As per tidal data |
| Digitizing Error \(E_d\) | 15 | 7.5 | 7.5 | 7.5 | As per spatial resolution |
| Pixel error \(E_p\) | 0 | 0 | 0 | 0 | All data set have uniform spatial resolution |
| Rectification error \(E_r\) | 7.6 | 5.9 | 7.2 | 0 (base image) | All data are ortho- rectified |
| Total uncertainty \(E_t\) | 16.83 | 9.57 | 10.46 | 7.5 |

4. Results

4.1 Rate of shoreline change in different zones

The rate of shoreline change for four zones of Vishakhapatnam has been discussed in terms of LRR method. The study shows that the zone 1
(Bhemunipatnam taluk), has 24.7 km shoreline and observed both erosion and accretion, but majority of the transect shows deposition. The average rate over 339 transects, was \(-0.50\) m/year along those transects with erosion trend. The average accretion rate of the coast is recorded as 2.51 m/year. Erosion is reported along Nellavalam Beach and Startuo Village whilst accretion is observed along Bheemli Beach and Thalkonda Beach. In zone 2 (Vishakhapatnam), the overall shoreline change rate shows negative trend throughout the zone except few transects (Figure 5). The rate of change of shoreline is measured along the 62.3 km coastline. The average rate over 943 transects, was \(-0.29\) m/year along those transects with erosion trend. The average erosion and accretion rate was \(-1.80\) m/year and 1.47 m/year respectively. Erosion is observed along transects of Sagar Nagar Beach, Jalari Peta, Vadu park, R K Beach Vizag, RelliVeddhi coast whereas Yendada and Peddipushikonds show accretion.

For zone 3 (Ankapalli taluk), the shoreline change analysis shows both erosion and accretion trend but erosion is significant. In this zone, the average erosion and accretion rate was \(-1.16\) m/year and 1.25 m/year respectively. Erosion is observed along Thanthadi beach whereas Mutyalammelam beach has accretion rate. In the zone 4, i.e. Yellamanchili taluk, the average shoreline change rate was \(-0.54\) m/year. Over all the taluk experience erosion as more than 756 transects showed erosion trend whereas only 239 transects showed accretion rate. Mean erosion rate is \(-1.18\) m/year and accretion rate is 1.25. Villages like Jogannapalem, Thallapalem, Laluumkoduru, ChinnaUpalam and Penta Kotta are vulnerable to erosion trend whereas villages like Chipada, Pudimadaka and Sitapalem showed accretion trend.

4.2 Mean shoreline change trend in the selected zones of Vishakhapatnam

There is a variation in the mean rate of accretion and erosion in the four selected coastal Taluk using Linear Regression Rate (LRR). Mean accretion rate 2.51 m/year is found in the zone 1 taluk which is highest amongst all,
whereas zone 3 and 4 have common accretion rate, i.e. 1.25 which is low and zone 2nd rate is 1.47 m/year. Over the entire mean accretion rate is 1.62 m/year for the Vishakhapatnam Coast. Mean erosion for zone 1, 2, 3 and 4 are −0.5, −1.8, -1.16 and −1.18 m/year respectively. Highest rate is found along the zone 4 whereas least rate is in zone 1. Average erosion rate for the entire coastal tract is 1.16 m/year. (Figures 5, 6 and 7). Figures 4 and 5 shows that the four zones data of shoreline change rate. The maximum mean shoreline change rate is found along zone 1 and zone 4 has shown minimum value amongst all. The Overall mean shoreline change rate is 0.27 m/year for the coast of Vishakhapatnam.

There is a deviation in the mean rate of accretion and erosion in the four selected coastal Taluk in terms of End Point Rate (EPR). Mean accretion rate 1.88 m/year is found in the zone IV taluk which is highest amongst all, whereas zone I and II have accretion rate 1.27 m/year and 1.26 m/year respectively and zone II rate is 1.46 m/year. Over the entire mean accretion rate is 1.46 m/year for the Vishakhapatnam Coast. Mean erosion for zone I, II, III and IV are −1.30, −1.29, -1.19 and −1.83 m/year respectively. Highest rate is found along the zone IV whereas least rate is in zone III. Average erosion rate for the entire coastal tract is 1.40 m/year. The maximum mean shoreline change rate is 0.40 m/year found along zone IV and zone I have −0.83 m/year which is minimum value amongst all. The overall mean shoreline change rate is −0.33 m/year for the coast of Vishakhapatnam and Zone I and IV shows accretion trends unlike Zone II and III (Table 4).

There is a difference in the mean rate of accretion and erosion in the four selected coastal Taluk. With Weighted Linear regression (WLR), mean accretion rate 1.86 m/year is found in the zone IV taluk which is highest amongst all, whereas zone II and III have accretion rate 1.23 m/year

**Figure 6.** Shoreline change trend in the selected zones of Vishakhapatnam.

**Figure 7.** Average trends of erosion, accretion and shoreline change rate in the study area.
and 1.28 m/year respectively and zone I rate is 0.54 m/year which is lowest amongst all. Over the entire mean accretion rate is 1.23 m/year for the Vishakhapatnam Coast. Mean erosion for zone I, II, III and IV are −0.84, −1.17,−1.27 and −1.74 m/year respectively. Highest rate is found along the zone IV whereas least rate is in zone I. Average erosion rate for the entire coastal tract is 1.26 m/year. The maximum mean shoreline change rate is 0.42 m/year found along zone IV and zone I have −0.59 m/year which is minimum value amongst all (Table 7). The Overall mean shoreline change rate is −0.27 m/year for the coast of Vishakhapatnam. With this technique all the four zone shows erosion trends in terms of overall nature (Table 5 and Table 6).

### 4.3 Categorization of overall trends of shoreline change

Considering the maximum and minimum values of the shoreline change rate (LRR), the coastline of Vishakhapatnam district is divided into five categories (Figure 8 and Figure 9) as high erosion, lowerosion, stable or little change, low accretion and high accretion. Out of 135 km coastal length studied high erosion occupied 5.8 km of coast followed by moderate erosion 46.2 km. Almost 34.7 km coastal length showed little or no change. Moderate accretion is found along 30.5 km whereas high accretion trend found around 17.8 km (Table 4). Erosion is dominant in I, II and IIId Zones (Vishakhapatnam, Ankapalli and Yellamanchilli taluk) but accretion trends is mostly found in the Bhemunipatnam taluk coast (Table 3).

### 3. Discussion

The study conducted for assessment of shoreline change for Visakhapatnam Coast. The result shows that most of the coastal tract is vulnerable to erosion (Table 3). By comparing erosion and deposition in the four zones of the study area, it is seen that erosion is dominant in Vizag, Ankapalleand Yellamanchilli and accretion is more active in Bhemunipatnam taluk coast. According to District Survey Report, Vishakhapatnam District (2018), 18.12 km² coastal areas have wetlands and theses include estuaries, lagoons, creeks, backwater, bay tidal flat/mud flat, mangrove, salt marsh etc whereas 9.83 sq² coasts are manmade Saltpans which are saline ecosystem and salt is extracted during summer. There is maximum concentration of sandy loamy soil in the coastal tract of Vishakhapatnam district and the soil is having nature of easily eroded by agents as compared to other soil type. (District Survey Report, 2018). The study conducted by Govt. of Andhra Pradesh (2018) stated that Visakhapatnam coast have severe erosion since few decades and most of the coast has accretion and rest has eroded due severe wave action and slope of the coast. Oceanographic and meteorological conditions and geologic factors affect the phenomena of shoreline changes (Nikolakopoulos et al. 2019).

Vishakhapatnam District coastal tract has heterogeneous features in terms of geology, land use/land cover,
vegetation, geomorphology and other physical as well as cultural features. Rocky, sandy, mudflats, riprap, sand dunes, deltas, estuaries etc are features of Andhra Pradesh Coastline (Kankara et al. 2015). North coast of Visakhapatnam is identified as primary emergent and south and north are erosional in nature and the shelf zone is gentle and at places and steep zone is found where cliffed shore occurs (R and A 2016). A research has shown that variability in the comparative dominance of model wave directions in Suffolk and its high angle interaction with the local shoreline platform can lead to individual years that are variously dominated by either north or south by the sediment transport directly (Burningham and French 2017).

To understand the processes of erosion, deposition, sediment transport, flooding and sea level changes which alter the shoreline is very important task for planning coastal protection work as stability and productivity of aquatic environment can be affected by erosional

Table 6. Zone wise shoreline change rate using Weighted Linear Regression (WLR).

| S. no. | Zones                        | I   | II  | III | IV  |
|-------|------------------------------|-----|-----|-----|-----|
| 1     | Total Number of Transect     | 339 | 943 | 141 | 995 |
| 2     | Shoreline length (km)        | 24.7| 62.3| 6.8 | 41.2|
| 3     | Mean shoreline change rate (m/year) | −0.59 | −0.42 | −0.48 | 0.43 |
| 4     | Mean erosion rate (m/year)   | −0.84| −1.17| −1.27| −1.74|
| 5     | Mean accretion rate (m/yr) I | 0.54| 1.23| 1.28| 1.86|
| 6     | Shoreline Change Rate (minimum) | −3.43 | −6.46 | −2.98 | −20.96 |
| 7     | Shoreline Change Rate (maximum) | 1.78 | 9.93 | 6.54 | 8.68 |
| 8     | Total Transect that Record Erosion | 277 | 650 | 98 | 524 |
| 9     | Total Transect that Record accretion | 62 | 293 | 43 | 471 |

Table 7. Different classes of shoreline analysis of Vishakhapatnam district coast.

| S. no. | (Erosion and accretion) | Classes (m/year) | Length (in km) |
|-------|-------------------------|------------------|----------------|
| 1     | High erosion            | < −8.9           | 5.8            |
| 2     | Moderate Erosion        | −8.9 to −0.8     | 46.2           |
| 3     | Almost No Change        | −0.8 to −0.9     | 34.7           |
| 4     | Moderate Accretion      | 0.9 to 3.2       | 30.5           |
| 5     | High Accretion          | > 3.2            | 17.8           |
| Total |                         |                  | 135            |

Figure 8. Shoreline accretions and erosion map of Vishakhapatnam coastal Taluks.
processes which may have severe implications for coastal community (Murali et al. 2013). Newly exposed and steep slope area is more active in erosion process because of the tidal water pressure, loose bank materials and shoreline configuration. Gentle slope area show more active accretion rate because of sedimentation by Meghna River (Salauddin et al. 2018). Coastal erosion causes shoreline to migrate to land or tidal zone and bottom bed erosion under the action of oceanic power. Coastal erosion can cause disaster but its formation mechanism is more complicated. Natural as well as anthropogenic factors are responsible for disaster in the coastal areas. Storm surge, wave intrusions, rising sea level etc are natural factors. Anthropogenic factors comprise coastal sand mining; river water conservations projects intercepting sediment, coastal engineering to enhance water power, beach vegetation damage (Wan et al. 2019). Various factors affect the shoreline like wind, waves, tides, sediment supply, changes in relative sea level and human interventions and these processes constantly made coast to changes over a variety of time scales. On this note reliable and accurate information on accretion and erosion could be useful for implantation in sound coastal zone management (Armenio et al. 2019).

Vishakhapatnam Port Trust (VPT) and Dredging Corporation of India (DCIL) collaborated for beach nourishment. VPT would be nourishing highly vulnerable areas such as R.K. Beach and INS Khurana Submarine Museum. Experts of several committee from National Institute of Open technology, Chennai and Deltares (an independent Dutch institute) suggested measures to decrease the pace of damage to fishing harbour and boundary wall of Kursura Museum caused by sea surge (The Hindu 2020).

Concrete jungles culture violating Coastal Regulation Zonation regulations changing the beach morphology and extreme weather conditions are responsible for erosional processes as stated by green activities (United Nations 2008; Down to Earth 2019). Out of 135 km coastal length studied high erosion occupied 5.8 km of coast followed by moderate erosion 46.2 km. Almost 34.7 km coastal length showed little or no change. Moderate accretion is found along 30.5 km whereas high accretion trend found around 17.8 km. Vishakhapatnam city beach erosion is caused due to construction of harbour-breakwaters and seawalls. Prominent beach erosion in the city coast collapsed the walls built around the parks and museum and electric lampposts (Rao, Subraelu, and Rajawat 2008). Mangrove is one of natural barrier against shoreline erosion so conservation of mangrove forest is essential as sea shore is dynamic in nature (Wan et al. 2019).

The study conducted on vulnerability of south east coastal villages has identified and mapped the Low Elevation Coastal Zones (LECZ) on basis of average population density and it may help disaster management planners for east coast of India. So as to reduce the risk of hazards, land area use for constructions housing and commercial purposes should be discouraged.
Remote Sensing and Geographic Information Centre (GIS) played a crucial role in Coastal Vulnerability Assessment. A better understanding of sea level rise and others parameters is required for impactful coastal zone and management and planning (Haritha et al. 2019). Vishakhapatnam-Kakinada coastal corridor is vulnerable due to natural calamities. Severe coastal erosion led to the landward movement of coastline which ultimately impact on coastal infrastructure and features like sand dunes and salt marshes (Rajawat et al. 2014).

The above study has implications in planning and developmental activities of coastal tract of Vishakhapatnam district and other coastal areas in terms of infrastructure development, tourism and recreational areas etc. It can also be useful in identification of coastal vulnerability in terms of shoreline dynamics and resulting hazards associated with it. Broadly the endeavour has implication at local, regional and global regarding shoreline modification phenomena along with the research and developmental applications in terms future prospects.

4. Conclusion

This study clearly demonstrated that the integration of remote sensing and GIS technology is very useful for long term shoreline change studies using multispectral images with reasonable accuracy. The study shows that average erosion rate in study area is 1.16 m/year and accretion rate is 1.62 m/year. Over all mean shoreline change rate is 0.27 m/year for the Vishakhapatnam Coast. Out of 135 km coastal length studied high erosion occupied 5.8 km of coast followed by moderate erosion 46.2 km. Almost 34.7 km coastal length showed little or no change. Moderate accretion is found along 30.5 km whereas high accretion trend found around 17.8 km. Beach areas have sand bars and free stone particles and topographically delicate stone which is effectively erodible. Further, this study may be carried out using high resolution satellite images or RTK (real-time kinematic) GPS surveys with new invention like DGPS and Geo tagging applications so as to demarcate the shoreline more accurately. Littoral drift, tidal action, near shore bathymetry, construction of seawalls, groins or breakwaters etc. are factors which are natural as well as manmade and modify the shoreline configuration. Map output could be more useful for coastal engineers, planners and coastal zone management authorities to facilitate suitable management plans and regulation of coastal zones of Vishakhapatnam as well as other coastal areas of India with similar geographic conditions.

Acknowledgements

The lead and second author of this study are thankful to ICSSR for providing doctoral fellowship during this research work. The authors also thank USGS for making the Landsat data freely accessible.

Disclosure statement

The authors declare that they have no conflict of interest.

References

Addo, K. A., P. N. Jayson-Quashigah, and K. S. Kufogbe. 2012. “Quantitative analysis of shoreline change using medium resolution satellite imagery in Keta, Ghana.” Marine Science 1 (1): 1–9. doi:10.5923/j.ms.201110101.01.

Alesheikh, A., A. Ghorbanali, and N. Nouri. 2007. “Coastline change detection using remote sensing.” International Journal Of Environmental Science & Technology 4 (1): 61–66. doi:10.1007/BF03325962.

Armenio, E., F. D. Serio, M. Mossa, and A. F. Petrillo. 2019. “Coastline evolution based on statistical analysis and modeling.” Natural Hazards and Earth System Sciences 19 (9): 1937–1953. doi:10.5194/nhess-19-1937-2019.

Burningham, H., and J. French. 2006. “Morphodynamic behaviour of a mixed S and–gravel Ebb-tidal delta: Deben Estuary, Suffolk, UK.” Marine Geology 225 (1–4): 23–44. doi:10.1016/j.margeo.2005.09.009.

Burningham, H., and J. French. 2017. “Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation.” Geomorphology 282: 131–149. doi:10.1016/j.geomorph.2016.12.029.

Carter, B., and C. D. Woodroffe. 1997. Coastal Evolution: Late Quaternary Shoreline Morphodynamics: A Contribution to Igcp Project 274: Coastal Evolution in the Quaternary. Cambridge: Cambridge University Press.

Cendrero, A. 1989. “Mapping and evaluation of coastal areas for planning.” Ocean and Shoreline Management 12 (5–6): 427–462. doi:10.1016/0951-8312(89)90023-4.

Chandrasekar, N., V. J. Viviek, and S. Saravanam. 2013. “Coastal vulnerability and shoreline changes for southern tip of india-remote sensing and GIS approach.” Journal of Earth Science & Climatic Change 04 (4): 1000144. doi:10.4172/2157-7617.1000144.

“District Survey Report, Vishakhapatnam District.” (2018). https://www.mines.ap.gov.in/miningportal/downloads/applications/vishakhapatnam.pdf (Accessed 9 January 2020).

Down to Earth. (2019). “Why we need a coastal zone protection Act.” 18 February 2020, Retrieved from https://www.down toearth.org.in/blog/environment/why-we-need-a-coastal zone-protection-act-62876

Fenster, M. S., R. Dolan, and J. F. Elder. 1993. “A new method for predicting shoreline positions from historical data.” Journal of Coastal Research 9 (1): 147–171.

Fuad, M. A. Z., and D. A. M. F. 2017. “Automatic detection of decadal shoreline change on northern coastal of Gresik, East Java – Indonesia.” IOP Conference Series: Earth and Environmental Science 98: 012001. doi:10.1088/1755-1315/98/1/012001.
Garcin, M., M. Vendé-Leclerc, P. Maurizot, G. Le Cozannet, B. Robinseau, and A. Nicolea-Leurma. 2016. “Lagoon islets as indicators of recent environmental changes in the South Pacific – the new caledonian example.” *Continental Shelf Research* 122: 120–140. doi:10.1016/j.csr.2016.03.025.

Genz, A., C. Fletcher, R. Dunn, L. Frazer, and J. Rooney. 2007. “The predictive accuracy of shoreline change rate methods and shoreline beach variation on Maui, Hawaii.” *Journal of Coastal Research* 231: 87–105. doi:10.2113/05-0521.1.

Hapke, C., N. Plant, R. Henderson, W. Schwab, and T. Nelson. 2016. “Decoupling processes and scales of shoreline morphodynamics.” *Marine Geology* 381: 42–53. doi:10.1016/j.margeo.2016.08.008.

Hapke, C. J., Himmelstoss E.A., Kratzman, M.G., List, J.H., and E.R. Thielert. 2010. “National assessment of shoreline change: historical shoreline change along the New England and Mid-Atlantic Coasts. US geological survey.” Open-file Report 2010–1118. https://pubs.usgs.gov/of/2010/1118/.

Haritha, V. S., K. R. Sreenath, M. Anakha, K. K. Joshi, and P. Shelton. 2019. “Vulnerability of south east coastal villages of India on sea level rise.” *Journal of the Marine Association of India* 61 (1): 31–37. doi:10.6024/jmabi.2019.61.1.2085-04.

Himmelstoss, E.A., Henderson, R.E., Kratzman, M.G., and A.S. Farris. 2018. “Digital shoreline analysis system (DSAS), version 5.0 user guide.” U.S. Geological Survey Open-File Report 2018–1179. 110. p. doi:10.3133/ofr20181179. 2331–1258 (online).

The Hindu, (2020). “VPT Launches Work to Nourish Eroded Beaches.” https://www.thehindu.com/news/national/andhra-pradesh/vpt-launches-work-to-nourish-eroded-beaches/article30763231.ece

Jana, A. B., and A. V. Hegde. 2016. “GIS based approach for vulnerability assessment of the Karnataka Coast, India.” *Advances in Civil Engineering* (2016): 1–10. doi:10.1155/2016/5642523.

Jonah, F., D. Adjei-Boateng, N. Agbo, E. Mensah, and R. Edzidie. 2015. “Assessment of sand and stone mining along the coastline of Cape Coast, Ghana.” *Annals of GIS* 21 (3): 223–231. doi:10.1080/19475683.2015.1007894.

Kaliraj, S., N. Chandrasekar, and N. Magesh. 2013. “Evaluation of coastal erosion and accretion processes along the north-west coast of Kanyakumari, Tamil Nadu using geospatial techniques.” *Arabian Journal of Geosciences* 8 (1): 239–253. doi:10.1007/s12517-013-1216-7.

Kankara, R., S. C. Selvan, V. J. Markose, B. Rajan, and S. Arockiaraj. 2015. “Estimation of long and short term shoreline changes along Andhra Pradesh coast using remote sensing and GIS techniques.” *Procedia Engineering* 116: 855–862. doi:10.1016/j.proeng.2015.08.374.

Kantamaneni, K., N. S. Rani, L. Rice, K. Sur, M. Thayaparan, U. Kulatunga, L. Campos, K. Yenneti, and L. Campos. 2019. “A systematic review of coastal vulnerability assessment studies along Andhra Pradesh, India: a critical evaluation of data gathering, risk levels and mitigation strategies.” *Water* 11 (2): 393. doi:10.3390/w11020393.

Kumar, T., R. Mahendra, S. Nayak, K. Radhakrishnan, and K. Sahu. 2010. “Coastal vulnerability assessment for Orissa State, East coast of India.” *Journal of Coastal Research* 263: 523–534. doi:10.2112/09-1186.1.

Le Cozannet, G., M. Garcin, M. Yates, D. Idier, and B. Meyssignac. 2014. “Approaches to evaluate the recent impacts of sea-level rise on shoreline changes.” *Earth-Science Reviews* 138: 47–60. doi:10.1016/j.earscirev.2014.08.005.

Liew, M., M. Xiao, B. Jones, L. Farquharson, and V. Romanovsky. 2020. “Prevention and control measures for coastal erosion in Northern high-latitude communities: a systematic review based on Alaskan case studies.” *Environmental Research Letters* 15 (9): 093002. doi:10.1088/1748-9326/ab9387.

Lillesand, T. M., R. W. Kiefer, and J. W. Chipman. 2015. *Remote Sensing and Image Interpretation.* Hoboken: N.J: John Wiley.

Lim, C. B., S. S. Prijith, M. V. R. S. Sai, P. V. N. Rao, K. Niranjan, and M. V. Ramana. 2019. “Retrieval and validation of cloud top temperature from the geostationary satellite INSAT-3D.” *Remote Sensing* 11 (23): 2811.

Maiti, S., and A. K. Bhattacharya. 2009. “Shoreline change analysis and its application to prediction: a remote sensing and statistics based approach.” *Marine Geology* 257 (1–4): 11–23. doi:10.1016/j.margeo.2008.10.006.

Mentaschi, L., M. I. Vousdoukas, J.-F. Pekel, E. Voukouvalas, and L. Feyen. 2018. “Global long-term observations of coastal erosion and accretion.” *Scientific Reports* 8 (1): 12876.

Mishra, M., P. Chand, N. Pattnaik, D. Kattel, G. Panda, M. Mohanti, U. D. Baruah, et al. 2019. “Response of long- to short-term changes of the Puri coastline of Odisha (India) to natural and anthropogenic factors: a remote sensing and statistical assessment.” *Environmental Earth Sciences* 78 :11. doi:10.1007/s12665-019-8336-7.

Moore, L. 2000. “Shoreline mapping techniques.” *Journal of Coastal Research* 161:111–124. 19 July 2020 Retrieved from www.jstor.org/stable/4300016.

Mujabar, P. K., and N. Chandrasekar. 2013. “Shoreline change analysis along the coast between Kanyakumari and Tuticorin of India using remote sensing and GIS.” *Arabian Journal of Geosciences* 6: 647–666. doi:10.1007/s12517-011-0394-4.

Murali, R. M., M. Ankita, S. Amrita, and P. Vethamony. 2013. “Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process.” *Natural Hazards and Earth System Sciences* 13 (12): 3291–3311. doi:10.5194/nhess-13-3291-2013.

Nassar, K., W. E. Mahmod, H. Fath, A. Masria, K. Nadaoka, and A. Negm. 2019. “Shoreline change detection using DSAS technique: case of North Sinai coast, Egypt.” *Marine Georesources & Geotechnology* 37 (1): 81–95. doi:10.1080/10646119.2018.1448912.

Nikolakopoulos, K., A. Kyriou, I. Koukouvelas, V. Zygouri, and D. Apostolopoulos. 2019. “Combination of aerial, satellite, and UAV photogrammetry for mapping the diachronic coastline evolution: the case of Lefkada island.” *ISPRS Journal of Photogrammetry and Remote Sensing* 155 (2019): 125–137.

Oyedotun, T. D. T. 2014. “Shoreline Geometry: DSAS as a Tool for Historical Trend Analysis.” In *Geomorphological Techniques* edited by Clarke, L. and Nield, J. M. British Society for Geomorphology: London,UK. 1-12. ISSN:2047–0371 http://geomorphology.org.uk/assets/publications/subsections/pdfs/OnsitePublicationSubsection/42/3.2.2_shorelinegeometry.pdf

Passeri, D. L., S. C. Hagen, S. C. Medeiros, M. V. Bilskie, K. Alizad, and D. Wang. 2015. “The dynamic effects of sea level rise on low-gradient coastal landscapes: a review.” *Earth’s Future* 3: 159–181.

Pollard, J., T. Spencer, and S. Brooks. 2018. “The interactive relationship between coastal erosion and flood risk.”
Progress in Physical Geography: Earth and Environment 43 (4): 574–585. doi:10.1177/0309133318794498.

Prasad, D. H., and N. D. Kumar. 2014. “Coastal erosion studies—a review.” International Journal of Geosciences 05 (3): 341–345. doi:10.4236/ijg.2014.53033.

Pye, K., and S. Blott. 2016. “Assessment of beach and dune erosion and accretion using LiDAR: impact of the stormy 2013–14 winter and longer term trends on the Sefton coast, UK.” Geomorphology 266: 146–167. doi:10.1016/j.geomorph.2016.05.011.

R. K., and K. A. 2016. “Detection of shoreline changes Visakhapatnam coast, Andhra Pradesh from multi-temporal satellite images.” Journal Of Remote Sensing & GIS 05: 01. doi:10.4172/2469-4134.1000157.

Rajasree, B. R., M. C. Deo, L. Sheela Nair. 2016. “Effect of climate change on shoreline shifts at a straight and continuous coast.” Estuarine, Coastal and Shelf Science 183 :221–234. doi:10.1016/J.ECSS.2016.10.034.

Rajawat, A. S., H. B. Chauhan, R. Ratheesh, S. Rhode, R. J. Bhandari, M. Mahapatra, Kumar, and M. Ajai. 2014. “Assessment of coastal erosion along Indian coast on 1: 25, 000 Scale using satellite data.” ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XL-8: 119–125. doi:10.5194/isprsarchives-XL-8-119-2014.

Raju, K., and R. Vaidyanadhan. 1978. “Geomorphology of Visakhapatnam, Andhra Pradesh.” Journal of Geological Society of India 19 (1): 26–34.

Rao, K., P. Subraelu, and A. Rajawat. 2008. “Beach erosion in Visakhapatnam: causes and remedies.” Eastern Geographers 14 (1): 1–6.

Richter, A., D. Faust, and H. Maas. 2013. “Dune cliff erosion and beach width change at the northern and southern spits of sylt detected with multi-temporal lidar.” CATENA 103: 103–111. doi:10.1016/j.catena.2011.02.007.

Salauddin, M., K. Hossain, I. Tanim, M. Kabir, and M. Saddam. 2018. “Modeling spatio-temporal shoreline shifting of a coastal island in bangladesh using geospatial techniques and DSAS extension.” Annals of Valahia University OfTargoviste, Geographical Series 18 (1): 1–13. doi:10.2478/avutgs-2018-0001.

Salguhena, N. N., and S. A. Bharathiva (2015, March 17). “Shoreline change analysis for northern part of the coromandel coast.” Retrieved from https://www.sciencedirect.com/science/article

Saxena, S., V. Geethalakshmi, and A. Lakshmanan. 2013. “Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India—a case study.” Weather and Climate Extremes 2: 48–57. doi:10.1016/j.wace.2013.10.001.

Sebat, M., and J. Salloum. 2018. “Estimate the rate of shoreline change using the statistical analysis technique (Epr).” Business & It Vi (1): Pp.59–65. doi:10.14311/bit.2018.01.07.

Seibold, E., and W. Berger. 2017. The Sea Floor: An Introduction to Marine Geology. Springer Textbooks In Earth Sciences, Geography And Environment. Cham: Springer 45–61. https://doi.org/10.1007/978-3-319-51412-3_1

Sekovski, I., F. Stecchi, F. Mancini, and L. D. Rio. 2014. “Image classification methods applied to shoreline extraction on very-high-resolution multispectral imagery.” International Journal of Remote Sensing 35 (10): 3556–3578. doi:10.1080/01431161.2014.907939.

Sheik, M., and Chandrasekar. 2011. “A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India, using digital shoreline analysis system.” Geo-Spatial Information Science 14 (4): 282–293. doi:10.1007/s11806-011-0551-7.

Sparks, B. 1990. Geomorphology. London: Longman Scientific & Technical.

Sutikno, S., A. Sandhyavitrin, M. Haidar, and K. Yamamoto. 2017. “Shoreline change analysis of peat soil beach in Bengkalis island based on GIS and RS.” International Journal of Engineering and Technology 9 (3): 233–238.

Thieler, E. R., E. A. Himmelstoss, J. L. Zichichi, and A. Ergul, (2009). “Dig-ital shoreline analysis system (DSAS) version 4.0—an ArcGIS exten-sion for calculating shoreline change.” U.S. Geol. Survey Open File Rep.. 2008–1278. United Nations. (2008). “Achieving sustainable development and promoting development cooperation.” New York.

Wan, L., H. Zhang, G. Lin, and H. Lin. 2019. “A small-patched convolutional neural network model for Mangrove mapping at species level using high-resolution remote-sensing image.” Annals of GIS 25 (1): 45–55. doi:10.1108/19475683.2018.1564791.

Wentz, E. A., S. Anderson, M. Fragkias, M. Netzband, V. Mesev, S. W. Myint, D. Quattrochi, A. Rahman, and K. C. Seto. 2014. “Supporting global environmental change research: a review of trends and knowledge gaps in urban remote sensing.” Remote Sensing 6 (5): 3879–3905.

Williams, S. J. 2013. “Sea-level rise implications for coastal regions.” Journal of Coastal Research 63: 184–196. doi:10.2112/SI63-015.1.

Woodcock, C., R. Allen, M. Anderson, A. Belward, R. Bindschadler, W. Cohen, Gao, F, et al. 2008. “Free access to landsat imagery.” Science 320 (5879): 1011. doi:10.1126/science.320.5879.1011a.

Zhang, Y., J. Xie, and L. Liu. 2011. “Investigating sea-level change and its impact on Hong Kong’s coastal environment.” Annals of GIS 17 (2): 105–112. doi:10.1080/19475683.2011.576268.