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Extraction and mapping of shoreline changes along the Visakhapatnam–Kakinada coast using satellite imageries

B Gireesh[1,*], P S N Acharyulu[1], Venkateswarlu CH[1], B Sivaiah[2], K Venkateswararao[1], K V S R Prasad[1] and C V Naidu[1]

[1] *Department of Meteorology and Oceanography, Andhra University, Visakhapatnam 530 004, India.*
[2] *Indian National Centre for Ocean Information Services (INCOIS), Hyderabad 500 090, India.*
**Corresponding author. e-mail: gireeshbaggu@gmail.com*

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Extraction of shorelines using satellite imagery is an effective method because customary digitization is a long and hectic process. This study focuses on extracting and detecting shoreline changes from Landsat-8 imageries of the Visakhapatnam–Kakinada coast along the east coast of India using an object-based approach. An object-based approach for the automatic detection of coastline from Landsat imagery using the Feature Extraction Workflow by Maximum Likelihood is implemented by the maximum classification method (MLC). The resulting vector polyline is smoothened for every 100 m using ArcGIS software. Delineation of multi-temporal satellite images was performed by visual interpretation from 2014 to 2019 to detect the shoreline changes. Different available techniques and methods are employed to observe shoreline changes. In addition to this, the shoreline information simulated by satellite remote sensing is in fair agreement with RTK GPS observations. The observed and remote sensing shoreline changes help to identify the areas of accretion and eroding zones over the long term. During this study, erosion and deposition changes were observed along RK beach, Rushikonda beach, Uppada beach, and Kakinada beach. The spatial variation rates were calculated using the statistical methods of the Digital Shoreline Analysis System (DSAS) during specific periods. The maximum observed shoreline accretion and erosion rates at Kakinada are 5.3 and –4.35 m/year indicates slight accretion. The maximum observed accretion and erosion rates at Uppada beach are 3.8 and –6.78 m/year, respectively indicating erosion. Similarly, at RK Beach the maximum observed shoreline accretion and erosion rates are 3.68 and –3.68 m/year, respectively indicating the beach is in a stable state. At Rushikonda beach, the maximum observed shoreline accretion and erosion rates are 2.24 and –3.04 m/year, respectively indicating erosion.

Keywords. Shoreline; RTK-shoreline; satellite imageries; DSAS.

1. Introduction

The majority of the coastlines are affected by storms and other natural events that cause beach erosion. Coastal and shoreline erosion is the process in which the local sea-level rise, strong wave action, and coastal flooding wear down or carry away rocks, soils, and/or sands along and off the coast (Boak and Turner 2005). Shoreline change analysis and prediction are important for integrated coastal

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zone management. A shoreline is idealistically defined as the fringe of land at the edge of a large body of water, such as an ocean or sea (Mangor and Drønen 2017). As per the recent IPCC 2019 projections, the global sea level rise has accelerated more than anticipated, which highlights the importance of shoreline monitoring. Shoreline detection can be carried out by using different techniques. They are direct field measurement; GPS is used for digitizing the visible shoreline features (Boak and Turner 2005), aerial photography analysis by LIDAR or three-dimensional scanners, and remote sensing analysis by using satellite imagery (Lipakis *et al.* 2008; Toure *et al.* 2019). The continuous shoreline monitoring outcomes allow a local, regional and national comparison that may assist to understand and monitor the coastal erosion or accretion vulnerability and strategies (Kantamaneni *et al.* 2022). In addition to shoreline change monitoring, the coastal erosion vulnerability index was also used to study the erosion vulnerability in the coastal areas using remote sensing. The spatial concept that identifies people and places that are susceptible to disturbances resulting from coastal hazards is coastal vulnerability. Coastal vulnerability index tools are used to estimate coastal vulnerability, and more details are found in Kantamaneni *et al.* (2018). They were classified into three, based on using the blend of novel and existing parameters given as physical coastal vulnerability index (PCVI), economic coastal vulnerability index and combined coastal vulnerability index (CCVI). However, the present study is confined to only the extraction of shorelines using the maximum likelihood classification method (MLC) and the application of DSAS to study shoreline change statistics in the study area. The conventional *in-situ* methods are tedious and time-consuming. Moreover, it requires operator skills and knowledge of the study area. However, remote sensing technology provides a fast and effective method for detecting dynamic changes in the shoreline. With the satellite data, the image is corrected for distortion and then standardized to the correct scale before a shoreline is either traced directly or scanned and digitized. It allows semi-automated or automated detection of shorelines. Automatic coastline detection is a complex process due to the presence of a water-saturated zone at the land–water boundary (Selvan *et al.* 2014). However, recent technological developments have led to extensive use of satellite imagery in shoreline change analysis (Raj *et al.* 2019). These changes can have different manifestations over long periods. Coastline detection from Landsat imageries had faster-growing development due to its wide spatial coverage, high resolution, strong penetration ability, and all-weather imaging capabilities. Shoreline change variabilities are measured by comparing historical shorelines extracted from given satellite imageries data for the selected period and limited field surveys (Bama *et al.* 2020). In recent times, a developed approach has been designed based on Landsat satellite images combined with GIS to estimate accurate shoreline changes and to study the effect of seawalls on it (Elnabwy *et al.* 2020). The Landsat 8 mission objective is to provide timely, high-quality visible and infrared images of all landmass and near-coastal areas on the Earth, continually refreshing an existing Landsat database. Data input into the system is sufficiently consistent with currently archived data in terms of acquisition geometry, calibration, coverage, and spectral characteristics to allow for comparison of global and regional change detection and characterization as outlined in Landsat 8 (L8) data user's handbook, Department of the Interior U.S. Geological Survey (Vaughn Ihlen and Karen Zanter 2019). Moreover, Baig *et al.* (2020) found remote sensing and Digital Shoreline Analysis System (DSAS) are very helpful to study long-term shoreline change variability using multi-spectral images with reasonable accuracy. Shorelines change boundary conditions in an estuary or ocean due to sea level fluctuations, circulation patterns, waves, and tides (Mangor and Drønen 2017). The DSAS is a tool that collaborates with the ArcMap software package and is created by the USA Geological Survey. It is a useful tool to measure the changes in shoreline movement with different statistical rates (Himmelstoss *et al.* 2018). Several statistical methods, such as EPR (end-point rate), LRR (linear regression rate), and NSM (net shoreline movement), are used for calculating the rate of shoreline change. Here EPR is simply calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline positions while LRR is an estimate of the average rate of changes of shoreline positions over time and NSM is nothing but the distance between the oldest and the youngest shorelines for each transect.

The primary purpose of this work is to provide a recent study on shoreline changes along the Kakinada and Visakhapatnam coasts using multi-resolution satellite data (Landsat OLI, TIRS, and

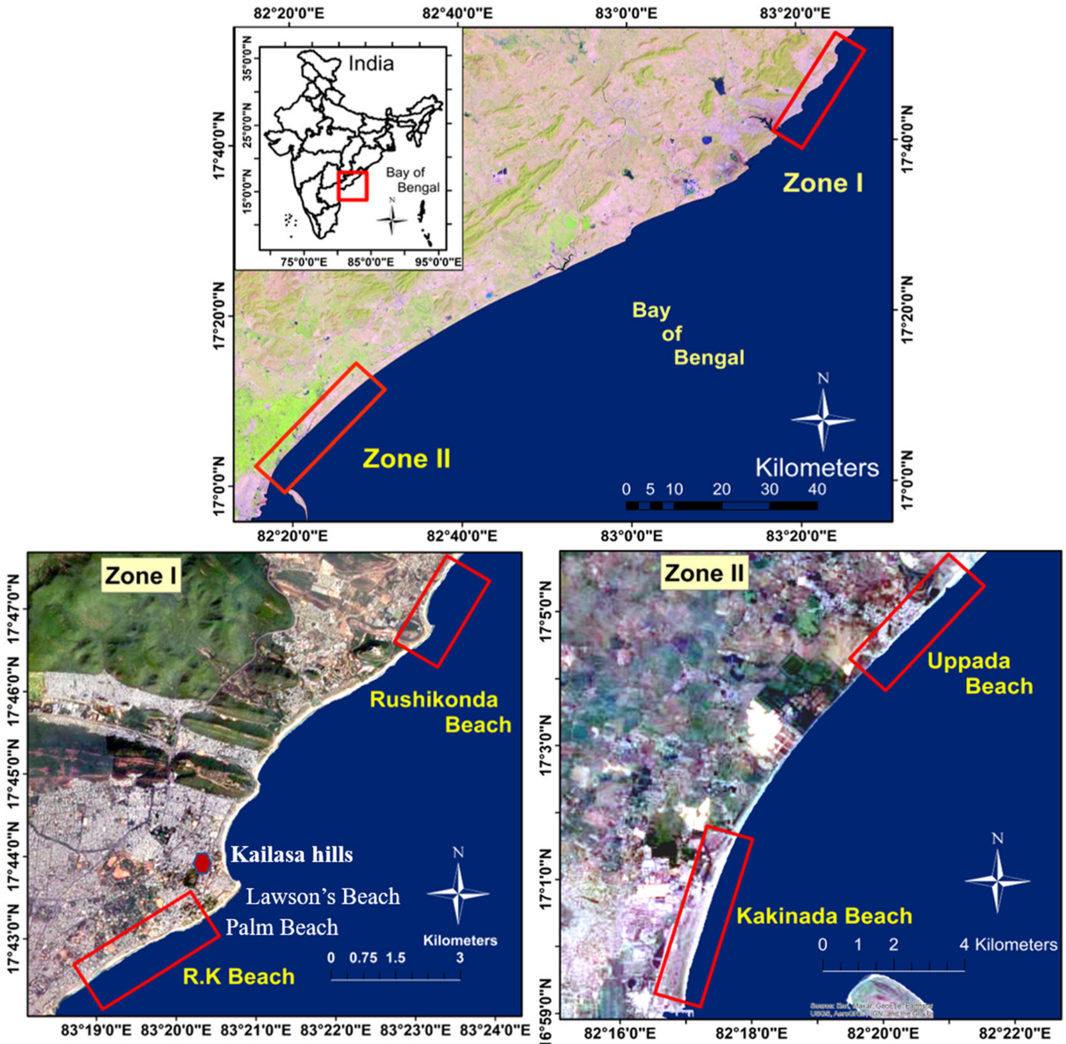

Figure 1. Geographical location of the study area. Zone I (RK and Rushikonda beaches) in the northern part and Zone II (Uppada and Kakinada beaches) in the southern part.

ETM+) and to use ESRI ArcGIS and DSAS application software to calculate shoreline rate of change statistics like area and perimeter from a long time change in shoreline positions. These coasts have been subject to increasing anthropogenic stress in recent times due to the construction of Gangavaram port near the Visakhapatnam coast and offshore oil and natural gas exploration near the Kakinada region. In addition to this, the effect of numerous cyclones in recent years, especially on pre- and post-monsoon seasons, and the intrusion of saltwater into the farming lands creates a hassle for the coastal agrarian population (Kakani *et al.* 2008). Sediment erosion, transport, and deposition are the most important factors, and their understanding has a direct impact on the development of the coast, marine structures, and coastal management in general. The sediments are usually deposited in the course of low wave energy conditions and are eroded during high wave energy periods, and the rate of shoreline change is significant during times of high wind speed and wave height (Anand *et al.* 2016). The study area experiences northeast (NE) and southwest (SW) monsoons, and during the southwest monsoon period, there is a possibility of huge transport of sediments over the beach via surface currents and waves along the east coast of India (Warnasuriya *et al.* 2018). Several interpretation techniques like visual interpretation and object-oriented classification were used to analyze Landsat satellite images to study and analyze the coastal changes by many researchers (Barnhardt 2009; Mahendra *et al.* 2011; Basheer Ahammed and Pandey 2019). Recently, Basheer Ahammed and Pandey (2022) analyzed shoreline change using

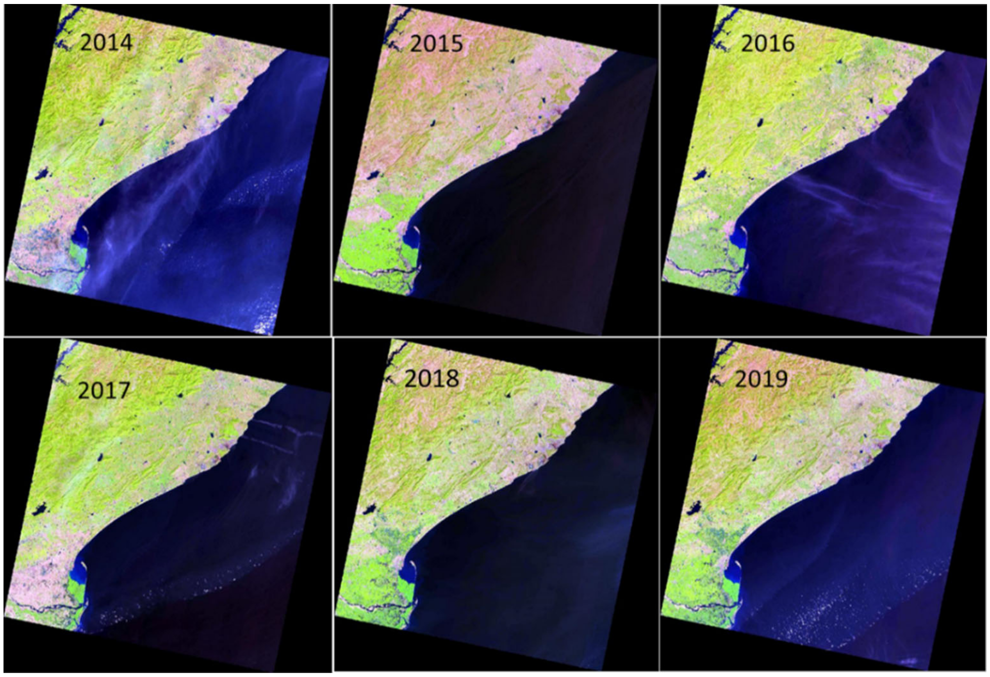

Figure 2. Landsat 8 OLI, TIRS imageries of the study area from 2014 to 2019.

on-screen point mode digitization technique by using standard FCC (false colour composite) with blue, green, and near-infrared bands to separate land water boundaries. In the current study, the Landsat 8 OLI/TIRS images from 2014 to 2019 were analyzed to monitor the recent shoreline changes using MLC on the central east coast of India, especially the Kakinada and Visakhapatnam coasts and DSAS to shoreline change statistics.

2. Study area

The study area considered for the present study is located on the central east coast of India between 18°4′53″–16°49′44″N latitudes and 82°21′06″–83°40′13″E longitudes and the total length of the shoreline (Rushikonda–Kakinada) is about 300 km. This coastal belt is marked by numerous river mouths, major and minor ports, lagoons, bays, sand dunes, and sand spits, in addition to extensive mangrove forests. It plays a key role in the economy of coastal Andhra Pradesh. Although rocky outcrops, dunes, sea defences, and groins play a vital role in coastline protection, there are certain areas generally more vulnerable to shoreline changes, where there are no rocky outcrops, dunes, or protection measures (Kantamaneni *et al.* 2018). As the entire stretch of the study area is very long, a few coastal stretches earmarked are chosen for specific study and analysis (RK Beach (2.8 km stretch), Rushikonda Beach (1.8 km), Uppada (3.3 km), and Kakinada (7 km)) as shown in the location map. Detailed satellite imagery (map) of the study area is shown in figure 1. In the present study, the study area is divided into two zones for convenience as RK beach and Rushikonda under Zone I, and Kakinada and Uppada beaches belong to Zone II.

2.1 *Zone I*

In Zone I, RK beach and Rushikonda beaches are one of the most beautiful, serene, and attractive beaches in the country. Tourists across the globe visit these beaches to experience the view and pristine beauty of these beaches. RK Beach and the adjacent Palm Beach are mostly sandy with scattered rocky outcrops and towards the north, there is a Lawson's Bay beach, which has a concave shape. Rushikonda beach (1.8 km) well known for surfing and fishing, is in the farther north part of the Visakhapatnam coast. Recently Rushikonda Beach has been conferred the coveted eco-label 'Blue Flag' in India. In general, Visakhapatnam beach undergoes seasonal changes with erosion and deposition.

2.2 *Zone II*

In Zone II, Uppada beach is located about 13 km north of the Kakinada port. It is the worst affected

Table 1. *List of data sources used for detecting shoreline changes.*

Satellite and sensor	Acquisition date (YYYYMMDD_HHMMSS)	Tide height during the acquired time	Tide time/height (Low tide time)	Tide time/height (High tide time)
Landsat 8 OLI/TIRS	20141207_084630	1.30 m	03:00 AM/0.3 m	08:46 AM/1.3 m
			02:46 PM/0.2 m	09:18 PM/1.6 m
Landsat 8 OLI/TIRS	20151023_050015	1.20 m	11:04 AM/0.4 m	04:27 AM/1.4 m
			11:20 PM/ 0.5 m	05:20 PM/1.3 m
Landsat 8 OLI/TIRS	20161126_070510	1.20 m	12:40 AM/0.5 m	06:30 AM/1.3 m
			12:46 PM/0.4 m	09:18 PM/1.4 m
Landsat 8 OLI/TIRS	20171129_050430	1.15 m	10:58 AM/0.4 m	04:20 AM/1.3 m
			11:24 PM/0.5 m	05:27 PM/1.3 m
Landsat 8 OLI/TIRS	20181116_030520	1.0 m	09:11 AM/0.6 m	02:03 AM/1.3 m
			08:48 PM/0.6 m	03:11 PM/1.1 m
Landsat 8 OLI/TIRS	20191119_010620	1.10 m	07:25 AM/0.5 m	12:42 AM/1.4 m
			07:10 PM/0.5 m	01:16 PM/1.2 m

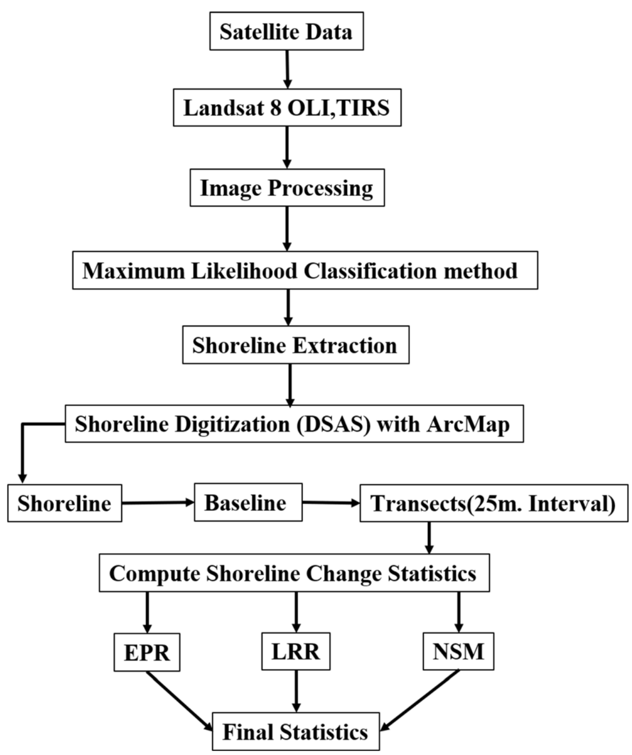

Figure 3. Flow chart of the methodology.

beach due to severe erosion where the sea has advanced considerably, engulfing the adjoining roads and a few buildings in the Uppada village. Whereas Kakinada beach is a fairly wide and flat beach located just to the north of the Kakinada port and lies in the sheltered area behind Kakinada Bay and the sand spit (a more general description of the study area is found in Baig *et al.* 2020).

3. Methodology

In the present study, the shoreline changes along the selected area for five years (2014, 2015, 2016, 2017, 2018 and 2019) utilizing satellite imagery Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) Level-1 Data Products with a spatial resolution of 30 m is used as shown in figure 2. The Landsat 8 OLI has covered the repetitive and synoptic data coverage and multi-spectral resolution capabilities to detect and calculate sea surface, and land geophysical characteristics and these are eminent and proven valuable for coastal zone management studies (Baig *et al.* 2020). The spectral bands of the Landsat 8 OLI sensor, similar to Landsat 7's ETM+ sensor, provide enhancement from prior Landsat instruments, while a deep blue visible channel (band 1) has been specifically designed for water resources and coastal zone investigation (Vaughn Ihlen and Karen Zanter 2019). Satellite data were taken from USGS (https://earthexplorer.usgs.gov/) and the tidal data was obtained from wxtide32 and the website of *tide-forcast.com.* Tide level falls or rises in the range of the beach face in the case of a small tidal range. Even the beach bottom in this zone may possess a sloping bottom with fewer variations. It is reasonable to assume that a beach face has an approximately uniform slope (Chen and Chang 2009). Then applying geometric, radiometric, and tidal corrections using ArcMap software & wxtide32 from www.pol.ac.uk, the website of Permanent Service for Mean Sea Level (PSMSL), the monthly mean sea level of Visakhapatnam is 45 m and Kakinada is 2 m. Visakhapatnam is vulnerable to

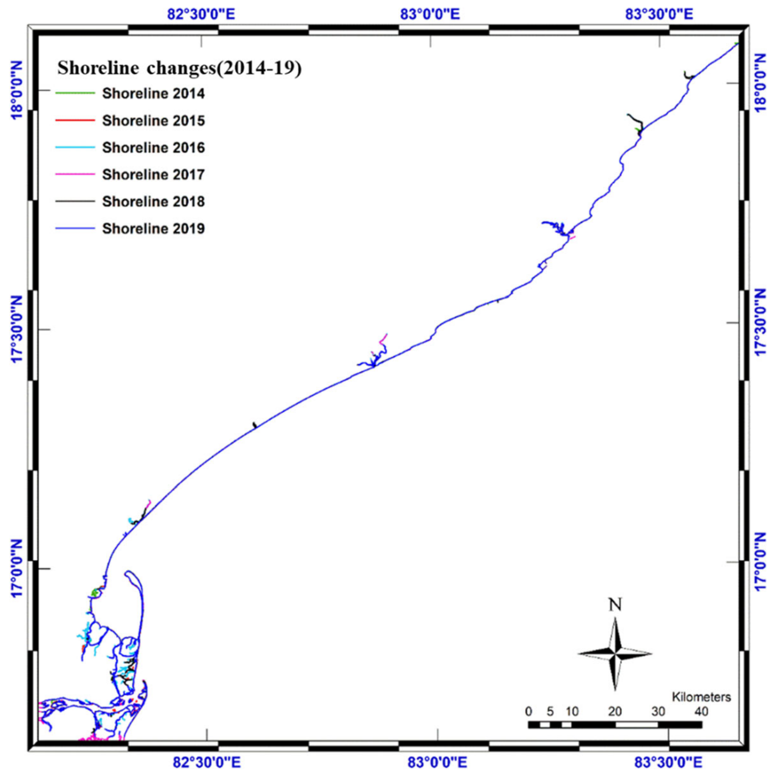

Figure 4. Extracted coastline using MLC method and converted to vector format during the period from 2014 to 2019.

extreme sea levels during storms (Prasad *et al.* 2010).

The selection of data was based on the clarity of the images from clouds. Table 1 gives Landsat OLI/TIRS imagery acquisition date and time with tidal height. It plays a vital role in investigating shoreline changes. It may be mentioned here that although the resolution is only 30 m, assuming that the resolution error is nearly constant throughout, then it could be possible that here obtain the relative changes in the shoreline positions with a better and desired accuracy to study the beach and shoreline changes.

Shoreline extraction from Landsat satellite images using image classification and the DSAS model developed by the USGS in ArcGIS software was used to measure the rate of shoreline change variability (Bama *et al.* 2020). In this study, the same methodology is applied to the shorelines extracted from the given satellite images (2014–2019) using maximum likelihood classification in the form of shape files as shown in figure 3, and given as input in DSAS tool.

For shoreline change monitoring, identification of the boundary between land and water must be necessary. For this purpose, the method of MLC employs the basic method of parametric maximum likelihood classification. The maximum likelihood classification (MLC) methods have a high accuracy in separating the boundary between water and land (Bamdadinejad *et al.* 2021). Due to the use of statistical parameters involving basic probability, variance, covariance, and average classes, this method is supposed to be the best method compared to algorithms (Tamassoki *et al.* 2014). It assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless there selects a probability threshold, all pixels are classified. Each pixel is assigned to a class that has the highest probability. If the highest probability is smaller than the threshold you specify, the pixel remains unclassified (Ahmad and Quegan 2012). More details on the MLC are available in Tamassoki *et al.* (2014). For coastline detection using the feature extraction of the MLC method in ArcMap, generating a land–water classification map around the study area and extraction of both land and water by raster format is required. The boundary between these two areas can be regarded as the shoreline. It has been converted into vector polyline format for easy shoreline identification and the shoreline is carefully digitized and exported to a shape file. Similar analyses carried out for the remaining years separately are shown in figure 4. The resulting vector

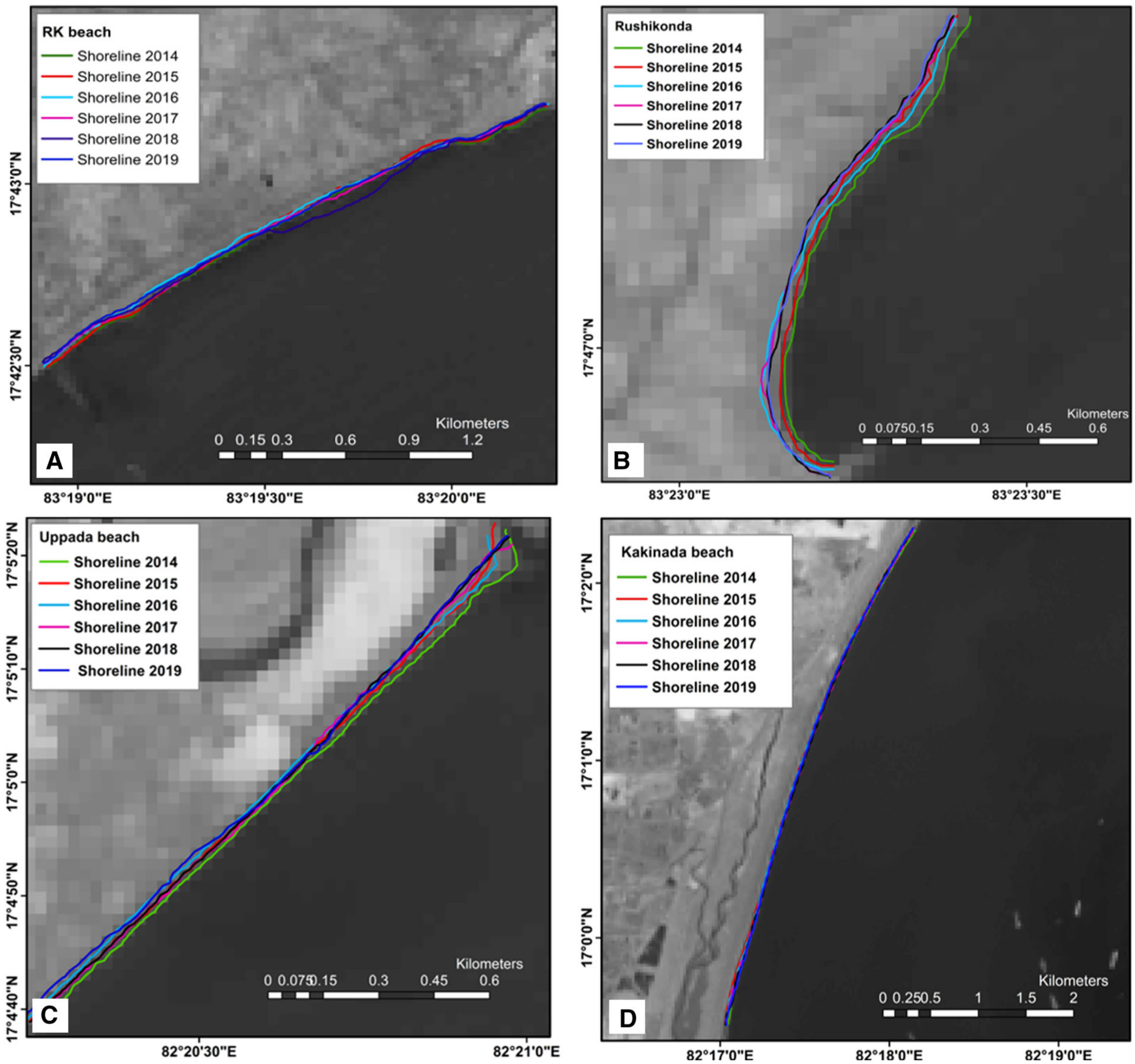

Figure 5. Extracted shorelines of selected areas **(A)** RK beach, **(B)** Rushikonda beach, **(C)** Uppada, and **(D)** Kakinada over Landsat 8 OLI band1.

polyline is smoothened for every 100 m of the shoreline for geo-referencing of the shoreline in the study area. All the image sets are projected in UTM (Universal Transverse Mercator) projection with zone number UTM44N and world geodetic system (WGS1984) datum using ArcMap software.

Extracted shorelines from 2014 to 2019 are shown in figure 5 and some areas of accretion and erosion zones are identified. During the study period, a significant rate of changes in the beach was observed from year to year for RK Beach, Rushikonda Beach, Uppada, and Kakinada beaches.

During this period, some erosion and deposition changes were observed. The shoreline change is mainly associated with waves, tides, winds, sea level change, periodic storms, the geomorphic processes of erosion and accretion, and human activities (Himmelstoss *et al.* 2018). The period of simulation studies corresponds to the winter monsoon period along the east coast of India, where waves are predominantly from the east (Ramakrishnan *et al.* 2018). Field observations were conducted to study the erosion and accretion aspects of the specified beaches in the region. As shown in figure 6, the RTK-GPS data was collected by walking along the shoreline of the study area for the same period of the acquired Landsat image in 2019 at low tide time.

3.1 *Digital Shoreline Analysis System (DSAS)*

DSAS is used to calculate the statistical methods such as EPR (end-point rate), LRR (linear

Figure 6. Tracking of shoreline position using the Emlid Reach RTK-GPS at selected areas.

regression rate), and NSM (net shoreline movement), which are used for calculating the rate of shoreline change. Here a baseline (300 m) is established parallel to the seashore and transects were generated using DSAS with 25 m spacing to study the changes that occurred along the study region.

4. Results

In order to validate the extracted shoreline from the Landsat imageries, it was compared with the shoreline identified by the Emlid reach RTK GPS surveyed data, as shown in figure 7. The correlation coefficient between Landsat and field data is 0.8, justifying the validity of Landsat images to detect shoreline changes.

The main purpose of this study is to extract and investigate the shoreline changes from satellite imagery (Landsat 8 OLI) using ArcMap along the coastal strip of Visakhapatnam–Kakinada. This coastal strip experiences some significant change due to natural and anthropogenic changes like local drainage systems, solid waste disposal, concrete constructions, etc. The shoreline position changes continually through time due to cross-shore and alongshore sediment movement in the littoral zone driven by the dynamic nature of water levels at the coastal boundary like waves, tides, groundwater, storm surge, setup, run-up, etc. (Boak and Turner 2005). Years of maximum coastal movement are shown in figure 8.

The coastline curvature at RK beach shows the maximum change in the year 2016–2017. The entire coastline slightly developed in 2017 as compared to 2016 and it indicates accretion. The maximum coastline movement towards the sea was over 28.2 m in 2017 as compared to 2016 on the north side. In Rushikonda, the maximum observed erosion of –0.043 km^2 during the year 2015–2016, a slight coastline erosion was observed and when compared to last year, it has gone back by 25 m along the south side. The Uppada beach had severely eroded during the year 2014–2015 and when compared to the last year, it has gone back by 40 m along the north side and moderate erosion was noticed in the south as well. The Kakinada coastal area, especially the southern side, saw a deposition of 18 m in 2017 when compared to 2016. On the south side adjacent to Kakinada port, the wave effect is less on the south side of the beach due to the effect of the island. Maximal changes in beach areas and values of shoreline advancement or recession along selected areas as computed by using the georeferenced satellite data are shown in table 2. The changes in beach areas differed widely in spatial and temporal scales.

Overall, severe erosion and significant shoreward movement of the coastline along the Uppada region, moderate erosion and accretion along other regions. There is moderate erosion on the southern side and a certain amount of accretion on the northern side. The shoreline changes fluctuate from south to north for each station. Continued monitoring of the shoreline is of utmost importance to understand further changes in the selected areas. These studies have to be continued by researchers since they play a vital role in coastal management and public safety and are highly useful for policymakers in the present-day scenario (Ghaderi and Rahbani 2020).

5. Discussion

Since random fluctuations in shoreline changes are observed concerning time and also the region, it is worthwhile to apply statistical methods to better understand the resulting shoreline changes for the

6 years (2014–2019). After considering all the statistical methods (Selvan and Vipin 2016), it is observed that the amalgamated use of satellite imagery could be a reliable method for shoreline change analysis for such coastal conditions. Accordingly, various transects were set up along the shoreline with a spacing of 25 m in between the adjacent transects with the numbering of the transects increasing from north to south as shown in figure 9. The baseline was set up onshore parallel to the shoreline and the orthogonal transects extended seaward up to 300 m at 25 m intervals. Shoreline variations in the selected areas are calculated for 115 transects along RK Beach, 75 along Rushikonda Beach, 135 along Uppada, and 280 transects along Kakinada. It is found that the LRR (m/year) index is the most suitable index for describing the erosion and accretion processes of the selected areas. The LRR for each transect is determined by fitting the least-squares regression line to all shoreline points. Figure 9 shows the rate of change of coastline, as well as the amount of erosion or accretion for each section, and the transects, are depicted in different colours depending on the degree of high-rate erosion, moderate erosion, moderate accretion, high accretion, or very high accretion along each transect based on the LRR value from the selected areas of RK beach, Rushikonda, Uppada, and Kakinada. The linear regression rate (m/year) along the RK beach indicates that much of the coastline shows high accretion, i.e., 2.20–3.68 m/year while on the south side, high erosion is –3.68 to –2.20 m/year. Severe erosion of –3.04 to –1.98 m/year and moderate erosion of –1.9 to –0.9 m/year were observed along the Rushikonda beach. The high rate of erosion is about –6.7 to –4.6 m/year along the north Uppada coastal region. Moderate erosion of –4.6 to –2.5 m/year was noticed along southern Uppada beach and a high rate of accretion of about 1.7–3.8 m/year was observed in central Uppada beach. Finally, a high accretion rate of 3.3–7.3

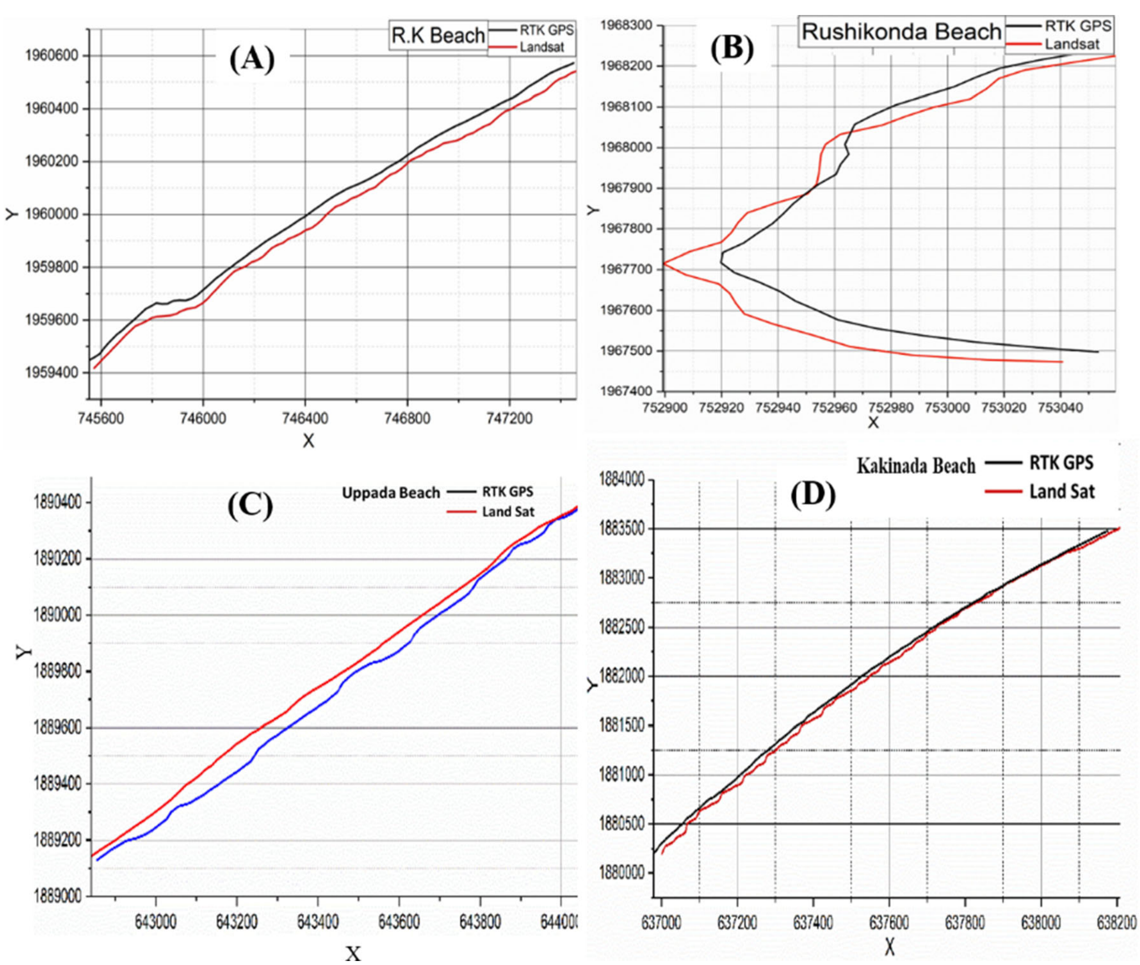

Figure 7. Extracted shorelines from GPS field data and Landsat image of the selected areas for the year 2019.

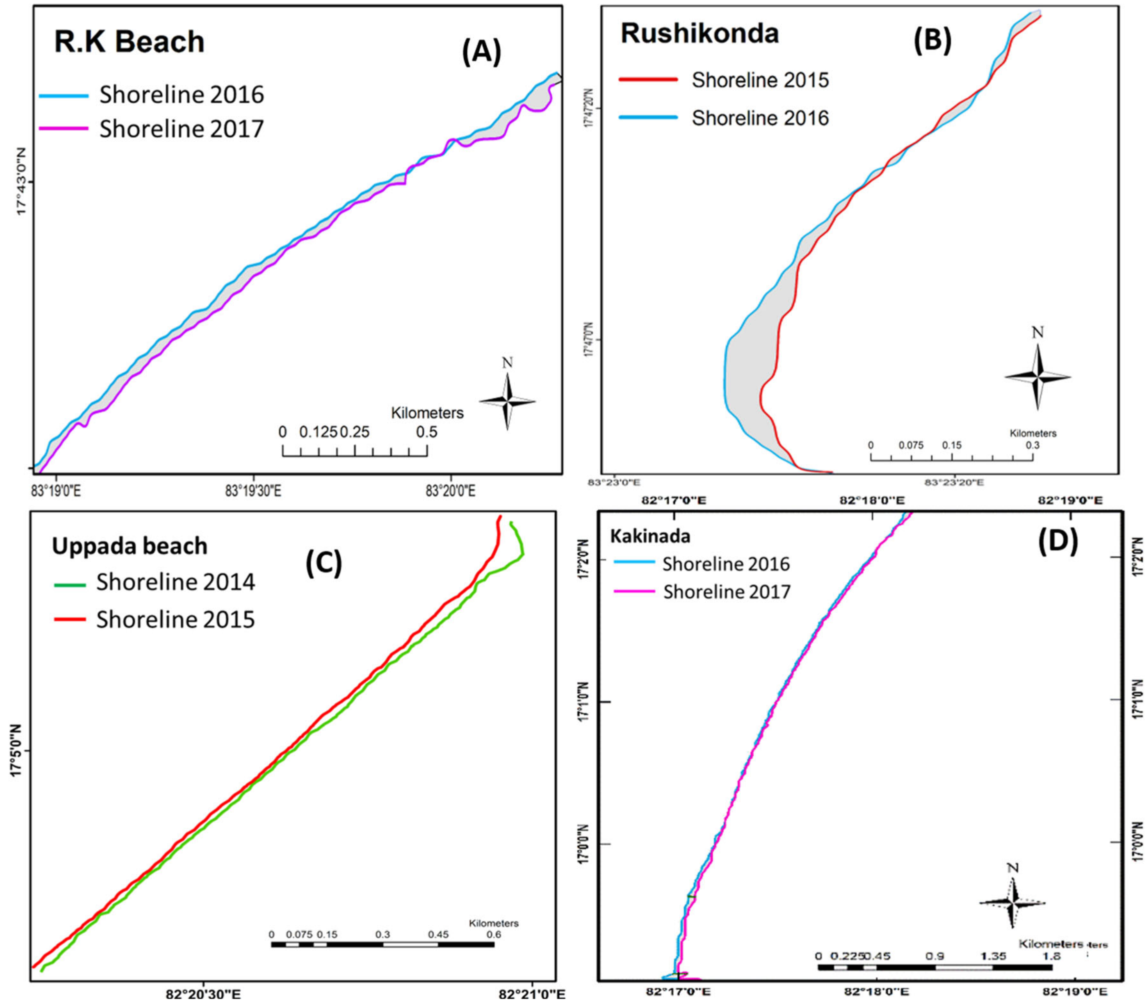

Figure 8. Maximum coastline changed years at selected areas **(A)** RK Beach, **(B)** Rushikonda Beach, **(C)** Uppada Beach, and **(D)** Kakinada Beach.

Table 2. *Maximal changes in beach areas and values of shoreline advancement or recession along selected areas.*

Study region	Max. changing years (b/w)	Total beach area change (km^2)	Maximum distance (m) observed b/w shorelines
RK (2.8 km)	2016–2017	+0.089	28.2
Rushikonda (1.8 km)	2015–2016	–0.043	25
Uppada (3.3 km)	2017–2018	–0.11	40
Kakinada (7 km)	2016–2017	+0.14	18

m/year was observed along south Kakinada beach, which is adjacent to the Kakinada port and moderate accretion of 0.2–3.2 m/year was observed along the central Kakinada beach, while –4.3 to 2.4 m/year moderate erosion along the northern side of Kakinada beach observed. Kakinada beach was observed to show a high rate of accretion to moderate erosion from south to north.

The EPR and LRR indices for all the transects are presented in figure 10. The LRR index can be used to obtain the rate of shoreline changes between the transects during the selected period. Here the Endpoint rate is directly related to the leaner regression rate. At RK beach, the high EPR is 2 m along the northern side while the low EPR is –5 m on the south side of RK beach 2.4 m

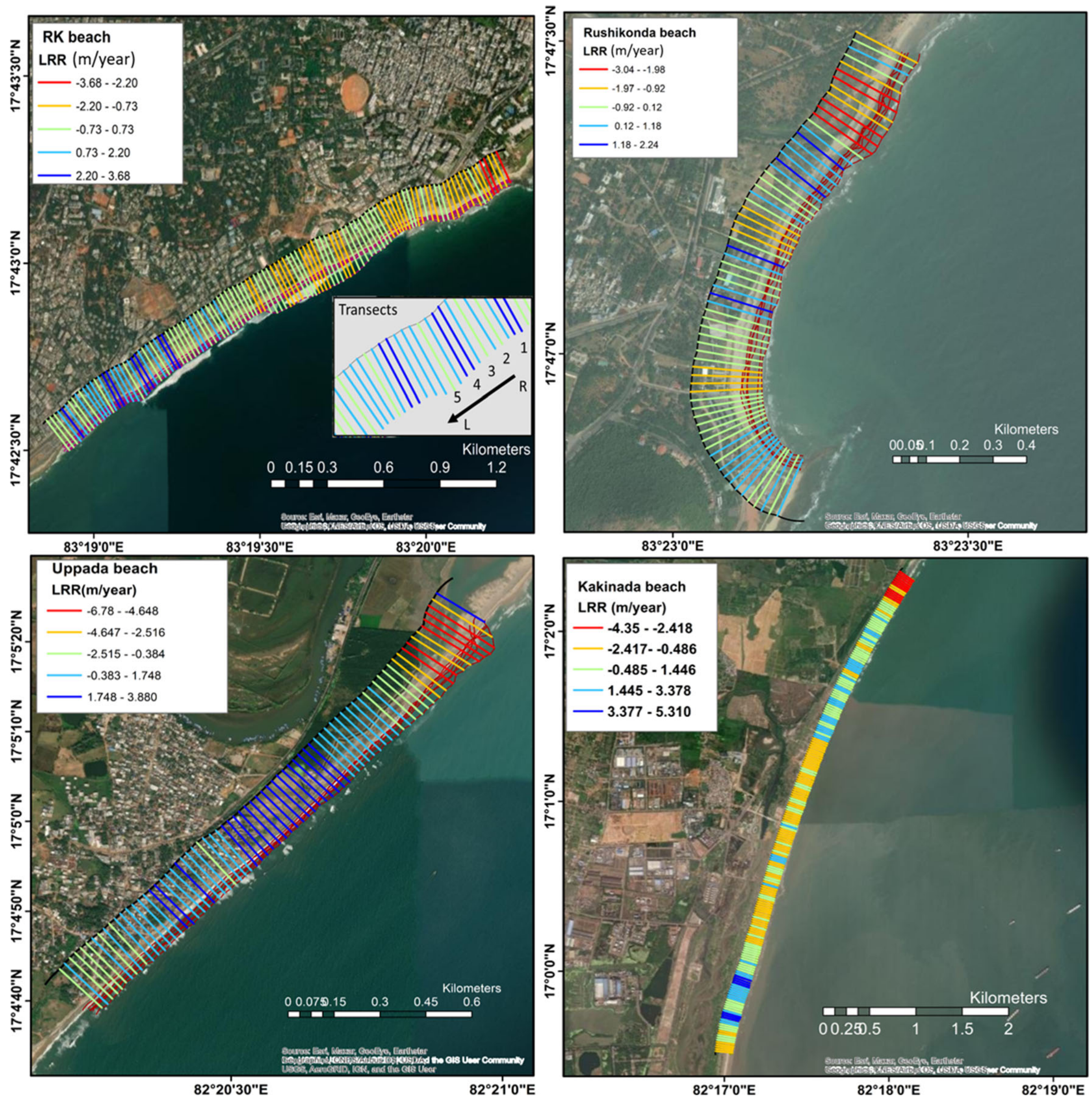

Figure 9. Evolution of the shoreline between 2014 and 2019 by LRR (m/year) in selected areas (RK beach, Rushikonda, Uppada, and Kakinada) using DSAS.

and –4.8 m of EPR along southern Rushikonda beach. At central Uppada Beach, 2.8 m of High EPR are observed, and –7.8 m of low EPR from south of the beach. EPR of 4.2 m peaks at the north side of Kakinada beach while –5.2 m of the lowest EPR is noticed at the south. Other than the Uppada beach, moderate EPR values have been noticed.

As described by Ghaderi and Rahbani (2020), the shape of the coastline in any area gives a clue about the rate of shoreline changes in that area. The linear regression rate of change can be determined by fitting the least-squares regression line to all shoreline points across different transects. The LRR method is used to define shoreline position change rate and eliminates short-term variability and potential random error by using a statistical approach (Tuan Vu *et al.* 2020). Figure 11 shows a good positive correlation between EPR and LRR along with all the selected areas. A strong positive correlation is observed at the Uppada coast ($R^2 = 0.89$) and a good correlation is observed at RK beach, Kakinada Beach and Rushikonda Beach, where R^2 is 0.81, 0.80, and 0.78, respectively.

Finally, net shoreline movement (NSM) is another statistical parameter that can effectively be used to study the overall trends of erosion and deposition and the consequent net movement of the shoreline over longer periods. The NSM

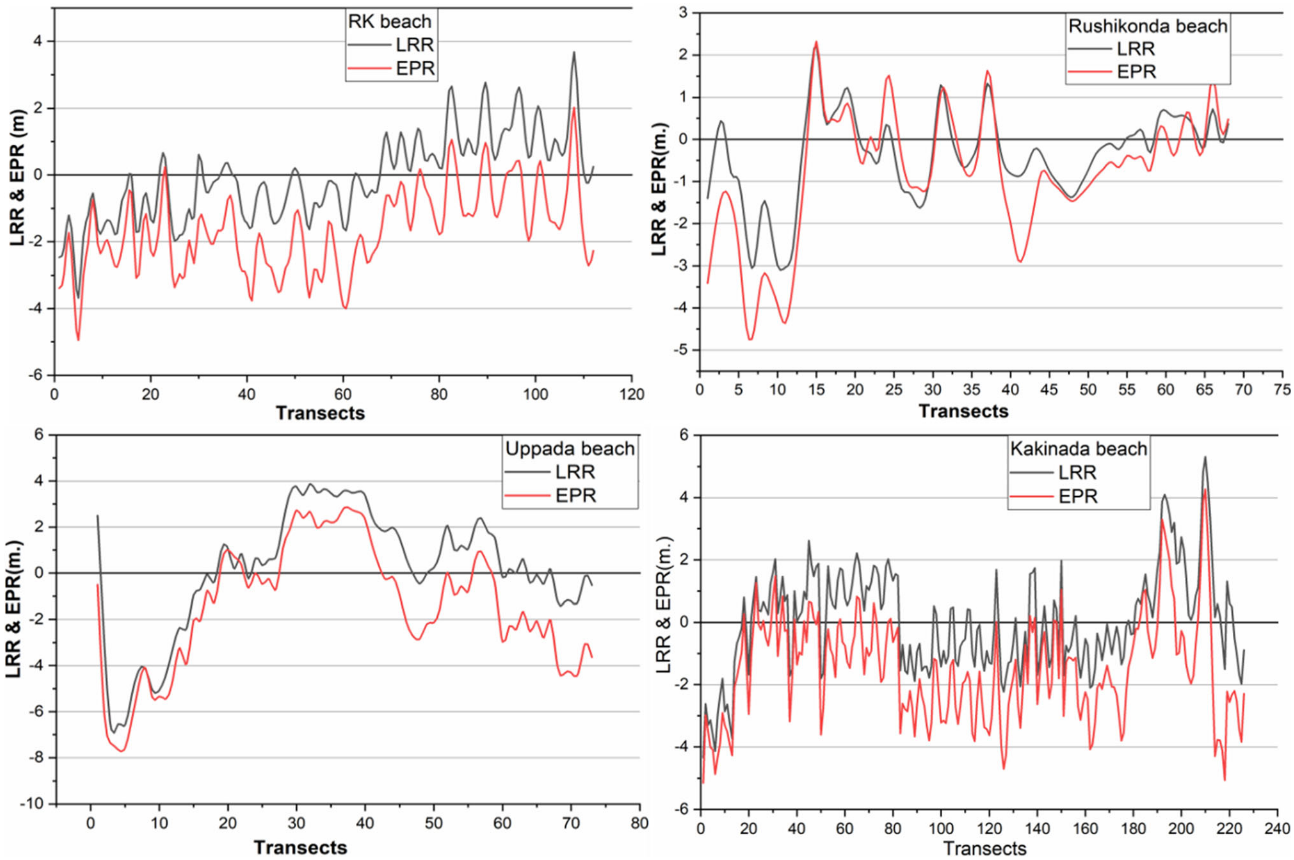

Figure 10. Shoreline change rates in LRR and EPR index at selected areas during 2014–2019.

indices for the 6 years from 2014–2019 are evaluated for different stations and are presented in figure 12.

At RK Beach, the net shoreline movement increases slightly from north to south. Here negative sign indicates erosion of the coast and shoreline moves towards land and the positive sign belongs to the accretion of the coast and shoreline moving toward the sea. The high and low NSM at RK beach is 10 m and –25 m, respectively. At Rushikonda Beach, there was complete erosion from north to south. Here there was –11.9 m of maximum coastline erosion along the north. At Uppada, severe erosion of –37 m along the north and 14 m of maximum accretion along the centre of the beach. According to NSM maximum erosion noticed between the oldest and youngest shorelines in a given period at Kakinada beach is –25 and –26 m along north and south and 22 m of maximum accretion close to the south. The overall beach changes between the oldest and youngest shorelines for the 5 years (2014–2019) appear to be quite different from that noticed for single specific years, as discussed earlier. Randomly distributed erosion and accretion zones were noticed all along the study area. It may be due to ever-changing local topographic features like rocky outcrops, local wind waves, bathymetry, etc., which cause variations in wave convergence and wave divergence zones.

On the Visakhapatnam coast, due to the sediment cut-off from the south, erosion in the northern parts is inevitable. Beach erosion at RK Beach during recent years may be due to the inefficient beach nourishment due to sediment cut-off at Gangavaram Port (Rao *et al.* 2014). The overall study shows that data derived from Landsat 8 during the period (2014–2019) was used to assess the rate of erosion/accretion along the coastline of selected areas, i.e., RK Beach, Rushikonda Beach, Uppada, and Kakinada beach. The GPS land survey measurements are used to affirm the proposed method. Uninterrupted shoreline monitoring is a requirement for the coastal areas of the coastal zone management because the entire coastal region is facing severe erosions by

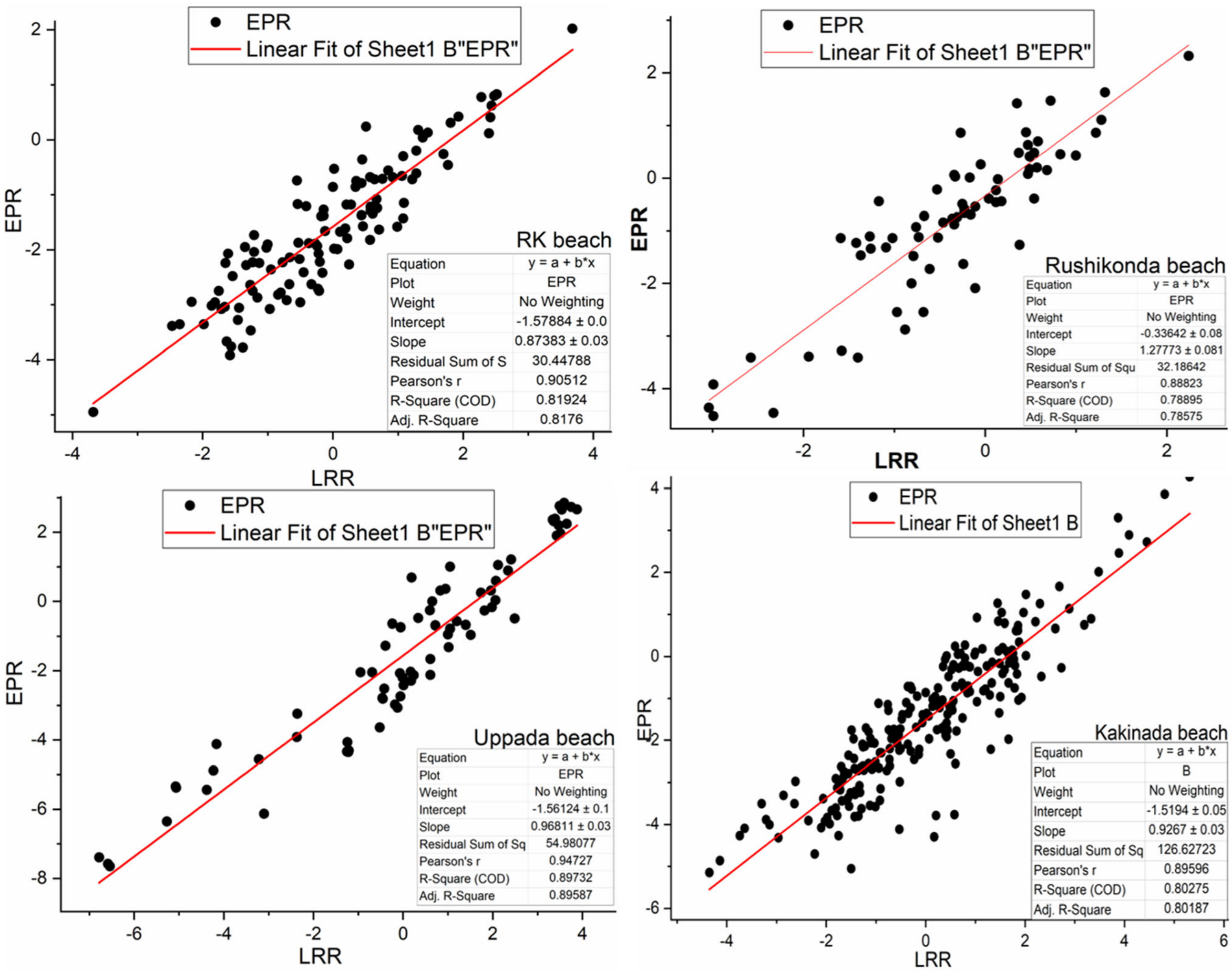

Figure 11. Comparison of the rates of change in shoreline (m/year) obtained by common statistical methods (EPR and LRR) in selected areas during the period.

the influence of natural and human activities (Himmelstoss *et al.* 2018).

6. Conclusions

Shoreline change analysis and prediction are important for integrated coastal zone management. The continuous shoreline monitoring outcomes allow a local, regional and national comparison that may assist to understand and monitor the coastal erosion or accretion vulnerability and strategies (Kantamaneni *et al.* 2022). In this study, the primary objective is to detect and extract the shoreline from Landsat-8 imageries along the central east coast of India comprising the Visakhapatnam–Kakinada coasts using an object-based approach. This is an object-based approach for the automatic detection of coastline from Landsat imagery using the Feature Extraction Workflow by Maximum Likelihood implemented by the classification method (MLC). For shoreline change monitoring, identification of the boundary between land and water must be necessary. For this purpose, the method of MLC employs the basic method of parametric maximum likelihood classification. The MLC methods have a high accuracy in separating the boundary between water and land (Bamdadinejad *et al.* 2021). Due to the use of statistical parameters involving basic probability, variance, covariance, and average classes, this method is supposed to be the best method compared to algorithms (Tamassoki *et al.* 2014). This method gives a resulting vector polyline, which is smoothened for every 100 m using ArcGIS software for the present study. Later, the delineation of multi-temporal satellite images was performed by visual interpretation from 2014 to 2019 to detect the shoreline changes. This detection and extraction

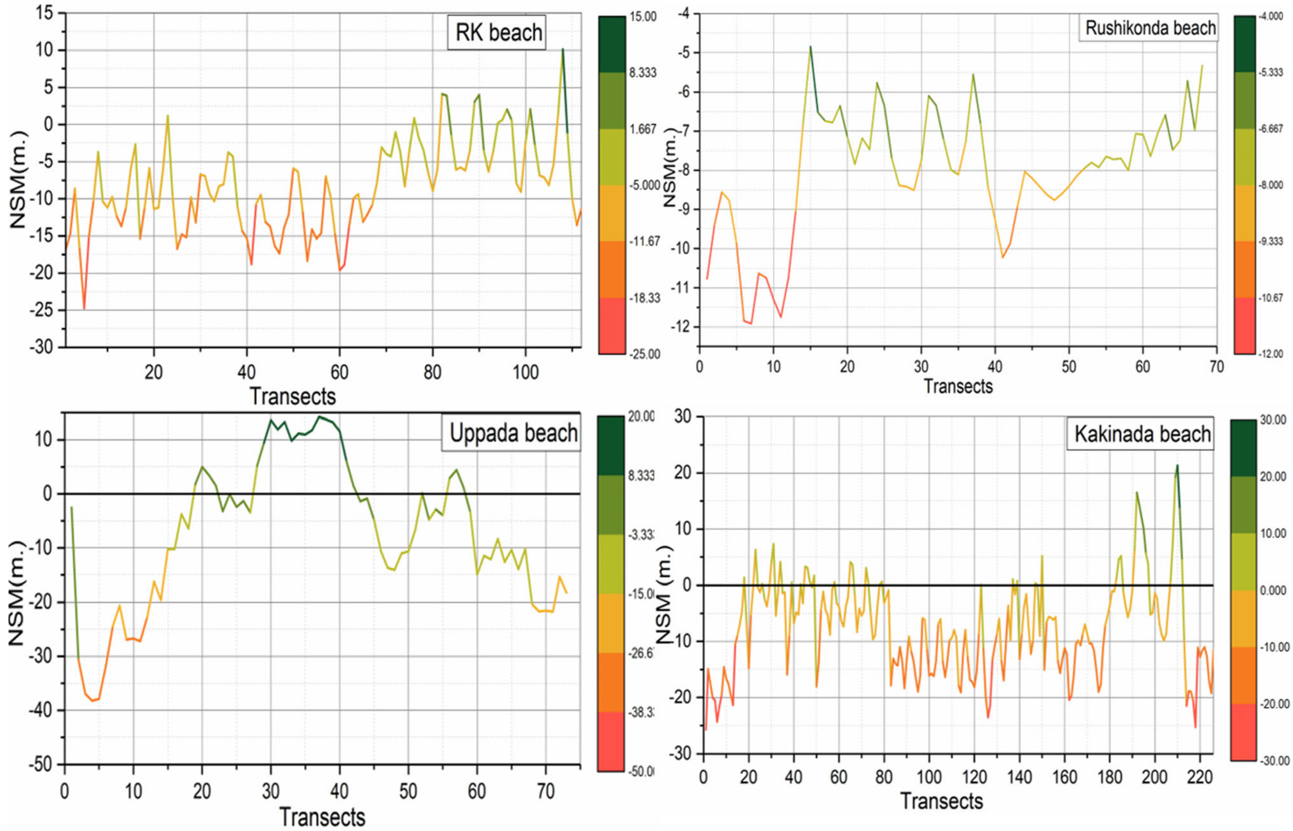

Figure 12. Shoreline evolution (accretion and erosion) in selected areas as computed by net shoreline movement (NSM).

of shoreline from the georeferenced Landsat satellite data using the MLC method show promising results. Since this method is automatic detection of shorelines, it has an advantage over conventional or manual digitization methods, which are tedious and requires operator skill to yield the best results. Different available techniques and methods are employed to observe shoreline changes. The data derived from Landsat 8 during the period (2014–2019) was used to assess the rate of erosion/accretion along the coastline of selected areas, i.e., RK Beach, Rushikonda Beach, Uppada, and Kakinada beach. In addition to this, *in-situ* shoreline measurements were carried out using RTK GPS and the detected shoreline positions are found to correlate well with RTK GPS measurements. The observed and remote sensing shoreline changes help to identify the areas of accretion and eroding zones over the long term. The spatial variation rates were calculated using the statistical methods of the DSAS from 2014 to 2019. The maximum observed shoreline accretion and erosion rates at Kakinada are 5.3 and –4.35 m/year indicating slight accretion. The maximum observed accretion and erosion rates at Uppada beach are 3.8 and –6.78 m/year, respectively indicating erosion. Similarly, at RK Beach the maximum observed shoreline accretion and erosion rates are 3.68 and –3.68 m/year, respectively indicating the beach is in a stable state. At Rushikonda beach, the maximum observed shoreline accretion and erosion rates are 2.24 and –3.04 m/year, respectively indicating erosion.

In the present study, image-processing techniques are found to be beneficial for detecting and predicting shoreline changes. Uninterrupted shoreline monitoring is a requirement for the coastal areas of the coastal zone management because the entire coastal region is facing severe erosions by the influence of natural and human activities. This study indicates that regular monitoring of the shoreline is crucial for proper planning and management of the coast. One limitation of the MLC is the classification of pixels depends on each cover type with known properties but generates statistically inseparable classes and another one is the classification accuracy of ML depends on the separation between the mean of the classes in the decision space (Ahmad and Quegan 2012).

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Author statement

Gireesh B has reviewed the literature, adopted and implemented the MLC method, executed the DSAS using ArcGIS and prepared the original manuscript. Acharyulu P S N has revised the manuscript and shared the knowledge in implementing this work. Venkateswarlu Ch provided inputs on satellite image analysis. Sivaiah B and Venkateswararao K revised the manuscript and suggested minor changes. Prasad K V S R shared his experience and provided guidance. C V Naidu has provided overall support and guidance.

References

Ahmad A and Quegan S 2012 Analysis of maximum likelihood classification on multi-spectral data; *Appl. Math. Sci.* **6(129–132)** 6425–6436.

Anand R, Chandrasekar B N and Magesh S K N S 2016 Shoreline change rate and erosion risk assessment along the Trou Aux Biches-Mont Choisy beach on the northwest coast of Mauritius using GIS-DSAS technique; *Environ. Earth Sci.* **75** 1–12, https://doi.org/10.1007/s12665-016-5311-4.

Baig M R I, Ahmad I A, Shahfahad Tayyab M and Rahman A 2020 Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: An application of digital shoreline analysis system (DSAS); *Ann. GIS* **26(4)** 361–376, https://doi.org/10.1080/19475683.2020.1815839.

Bamdadinejad M, Ketabdari M J and Chavooshi S M H 2021 Shoreline extraction using image processing of satellite imageries; *J. Indian Soc. Remote Sen.* **49(10)** 2365–2375, https://doi.org/10.1007/s12524-021-01398-3.

Barnhardt W A 2009 Coastal change along the shore of northeastern South Carolina–South Carolina Coastal erosion study; *US Geol. Surv. Circular* **1339** 1–87, https://agris.fao.org/agris-search/search.do?recordID=US201300143056.

Basheer Ahammed K K and Pandey A C 2019 Shoreline morphology changes along the Eastern Coast of India, Andhra Pradesh by using geospatial technology; *J. Coastal Conserv.* **23(2)** 331–353, https://doi.org/10.1007/S11852-018-0662-5/FIGURES/18.

Basheer Ahammed K K and Pandey A C 2022 Assessment and prediction of shoreline change using multi-temporal satellite data and geostatistics: A case study on the eastern coast of India; *J. Water Clim. Change* **13(3)** 1477–1493, https://doi.org/10.2166/wcc.2022.270.

Boak E H and Turner I L 2005 Shoreline definition and detection: A review; *J. Coast. Res.* **214** 688–703, https://doi.org/10.2112/03-0071.1.

Chenthamil Selvan S, Kankara R S and Rajan B 2014 Assessment of shoreline changes along Karnataka coast, India using GIS & remote sensing techniques; *Indian J. Geo-Mar. Sci.* **43** 1286–1291.

Chen W W and Chang H K 2009 Estimation of shoreline position and change from satellite images considering tidal variation; *Estuar. Coast. Shelf Sci.* **84** 54–60, https://doi.org/10.1016/j.ecss.2009.06.002.

Elnabwy M T, Elbeltagi E, Banna M M E l and Elshikh M M Y 2020 An approach based on landsat images for shoreline monitoring to support integrated coastal management – A case study, Ezbet Elborg, Nile Delta, Egypt; *Int. J. Geo-Inform.,* https://doi.org/10.3390/ijgi9040199.

Emily A Himmelstoss, Rachel E Henderson, Meredith G Kratzmann and Amy S Farris 2018 Digital Shoreline Analysis System (DSAS), Version 5.0, User Guide; U.S. Geological Survey, Open-File Report 2018–1179, 110p, https://doi.org/10.3133/ofr20181179.

Ghaderi D and Rahbani M 2020 Detecting shoreline change employing remote sensing images (Case study: Beris Port – east of Chabahar, Iran); *Int. J. Coast. Offshore Eng.* **3(4)** 1–8.

Kakani N R, Subraelu P and Ramakrishnan R 2008 Sea-level rise and coastal vulnerability: An assessment of Andhra Pradesh Sea-level rise and coastal vulnerability: An assessment of Andhra Pradesh coast; *India through Remote Sensing and GIS*, https://doi.org/10.1007/s11852-009-0042-2.

Kantamaneni K, Phillips M, Thomas T and Jenkins R 2018 Assessing coastal vulnerability: Development of a combined physical and economic index; *Ocean Coast. Manage.* **158** 164–175, https://doi.org/10.1016/j.ocecoaman.2018.03.039.

Kantamaneni K, Rice L, Du X, Allali B and Yenneti K 2022 Are current UK coastal defences good enough for tomorrow? An assessment of vulnerability to coastal erosion; *Coast. Manage.* **50(2)** 142–159, https://doi.org/10.1080/08920753.2022.2022971.

Karsten Mangor, Nils K, Drønen K H K and Sten E K 2017 *Shoreline management guidelines*; 4th edn, DHI.

Lipakis M, Chtysoulakis N and Kamarianakis Y 2008 Shoreline extraction using satellite imagery; *BEACHMED-e/OpTIMAL* **81–95**.

Mahendra R S, Mohanty P C, Bisoyi H, Kumar T S and Nayak S 2011 Assessment and management of coastal multi-hazard vulnerability along the Cuddalore-Villupuram, east coast of India using geospatial techniques; *Ocean Coast. Manag.* **54(4)** 302–311, https://doi.org/10.1016/j.ocecoaman.2010.12.008.

Prasad K V S R, Sreenivas P and Patnaik K V K R K 2010 Contribution of tides to sea level variations along Visakhapatnam, India; *Mar. Geodesy* **33** 282–289, https://doi.org/10.1080/01490419.2010.495301.

Raj N, Gurugnanam B, Sudhakar V and Francis P G 2019 Estuarine shoreline change analysis along the Ennore river mouth, southeast coast of India, using digital shoreline analysis system; *Geod. Geodyn.* **10** 205–212, https://doi.org/10.1016/j.geog.2019.04.002.

Ramakrishnan R, Agrawal R, Remya P G and Nagakumar K Ch V *et al.* 2018 Modelling coastal erosion: A case study of Yarada beach near Visakhapatnam, east coast of India; *Ocean Coast. Manage.* **156** 239–248, https://doi.org/10.1016/j.ocecoaman.2017.08.013.

Rao V R, Prasad K, Ramu V, Acharyulu P S N, Mohan R and Dhamodarrao V 2014 Nearshore circulation and sediment transport pattern along Gangavaram-Visakhapatnam coast, east coast of India; *Int. J. Earth Sci. Eng.* **2014** 5–7.

Sathiya Bama V P, Rajakumari S and Ramesh R 2020 Coastal vulnerability assessment of Vedaranyam swamp coast based on land use and shoreline dynamics; *Nat. Hazards* **100(2)** 829–842, https://doi.org/10.1007/s11069-019-03844-5.

Selvan S C and Vipin R S K 2016 Shoreline change and impacts of coastal protection structures on Puducherry, SE coast of India; *Nat. Hazards* **83** 293–308, https://doi.org/10.1007/s11069-016-2332-y.

Tamassoki E, Amiri H and Soleymani Z 2014 Monitoring of shoreline changes using remote sensing (case study: Coastal city of Bandar Abbas); In: *IOP Conference Series: Earth and Environmental Science,* Institute of Physics Publishing, https://doi.org/10.1088/1755-1315/20/1/012023.

Toure S, Diop O, Kpalma K and Maiga A S 2019 Shoreline detection using optical remote sensing: A review; *ISPRS Int. J. Geo-Information* **8(2)**, https://doi.org/10.3390/IJGI8020075.

Vaughn Ihlen and Karen Zanter 2019 Landsat 8 Data Users Handbook; *US Geol. Surv.*, *Nasa* **8** 114, https://landsat.usgs.gov/documents.

Tuan Vu M, Lacroix Y, Van Than V and Thanh N V 2020 Prediction of shoreline changes in Almanarre beach using geospatial techniques; *Indian J. Geo-Mar. Sci.* **49(2)** 207–217.

Warnasuriya T W S, Gunaalan K and Gunasekara S S 2018 Google Earth: A new resource for shoreline change estimation – case study from Jaffna Peninsula, Sri Lanka; *Mar. Geodesy* **41** 546–580, https://doi.org/10.1080/01490419.2018.1509160.

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