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Research Article

Analysis of shoreline changes in the severe storm surge region of upper Coromandel coast, India, using Remote sensing (RS) and Geographic information system (GIS)

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Abstract
Coastlines have been subject to ongoing vulnerability from natural disasters, resulting in erosion and accretion occurring at varying intervals. The impacts of human activities and alterations in natural processes, including those induced by climate change, exacerbate the existing challenges faced along coastal regions. The present study aimed to analyze the changing shoreline along the Bapatla coastal tract in the upper coromandel coast of Andhra Pradesh due to erosion and accretion using the DSAS toolbar in ArcGIS software. Multiple statistical methods are available in DSAS; the present study confined attention to the end point rate (EPR), linear regression rate (LRR), and net shoreline movement (NSM) for this investigation. The Nizampatnam Mandal had the greatest erosion rate (-16.8 m/yr) and accretion rate (10.5 m/yr), according to EPR, as well as the highest erosion rate (-16.7 m/yr) and accretion rate (10.4 m/yr) according to LRR. As per NSM, between 1990 and 2020, the highest erosion and accretion was seen again in Nizampatnam. The shoreline at Nizampatnam either retreated by as much as -285.2 meters or advanced by 211.1 meters. The research indicated that the Bapatla district's shoreline is susceptible to erosion and accretion. The present investigation revealed that the coastal region of Bapatla district exhibits susceptibility to both erosion and accretion phenomena. The findings of the present study hold significant implications for professionals in the fields of coastal science, engineering, and administration. The findings are of utmost importance in the development of sustainable approaches for coastal management.

Keywords: Bapatla District, Digital Shoreline Analysis System DSAS, Erosion and Accretion, Geographic Information System (GIS), Remote Sensing (RS), Shoreline change

INTRODUCTION

Coastal areas are one of the most susceptible regions, tend to be more heavily urbanized, and have larger densities of human populations (Brown *et al.,* 2018; Sahoo *et al.,* 2018). According to the United Nations Environment Programme (UNEP, 2012; Kneller, 2020), around 40% of the world's population lives within 100 kilometers of the coast, and 10% is located in places less than 10 meters above mean sea level. According to Vivek *et al.* (2016), more than 25 percent of India's population lives within 50 kilometers of the country's coastline. The intricate relationship between natural events, especially those driven by climate change, and anthropogenic activity is increasing the vulnerability of coastal areas. Rising sea levels are a major contributor to the increased vulnerability seen in India's coastal regions, increasing the likelihood of catastrophic occurrences like flash floods and storm surges brought on by cyclones (Arshid and Uma, 2023).
Shorelines are influenced by numerous variables, including sedimentation by longshore currents, wind and wave action, rainfall, changes in sea level, river discharge, and construction activities like building sea walls, ports, breakwaters, and shipyards (Selvan *et al.,* 2014). These variables have the potential to change the structure and geometry of the coastline in several different ways. Two instances include the possibility of coastal erosion, which is produced by sediment movement, and shoreline accretion,

caused by increased sediment deposits (Thakur *et al.,* 2018). Therefore, monitoring the changes along shorelines over time is imperative to identify patterns of shoreline disruptions (Arshid and Uma, 2022; Ayalke *et al.,* 2023 Due to morphological, climatological, or geological influences, shoreline boundaries constantly shift as the land meets the water (Mujabar and Chandrasekar, 2013). Due to their position as a transition zone between land and water and the inherent variability of their surrounding environment, shorelines are in constant flux (Mentaschi *et al.,* 2018). The research on shoreline change is an essential step in understanding the dynamics and development of coastal regions, and it may help stakeholders do a better job of decreasing the risk of coastal erosion and minimizing the associated economic, social, and physical losses (Fuad and Fais, 2017).

According to Williams (2013), one of the most critical components of managing coastal zones is researching how shorelines change over time and producing projections about these shifts. Coastal erosion is one of the most significant marine geological catastrophes, and the hazardous degree of coastal erosion indicates that coastal erosion range may also occur in the future (Wan *et al.,* 2019). Erosion makes the shore more dangerous for those who live and work there (Jayakumar and Malarvannan, 2016).. Anthropogenic activities like beach sand mining, port building, garbage dumps, industrialization, urbanization and recreation, decreased sediment supply from rivers, sewage, and industrial effluent discharge have all been shown to amplify the modification processes, including changes in the shoreline (Jayakumar and Malarvannan 2016; Dilara and Tarik, 2019).

Extraction of shorelines using conventional ground survey methods is laborious and time-consuming (Aedla *et al.,* 2015). Aerial photographs and satellite imagery have previously been used to evaluate coastline changes. The use of remote sensing is a huge help when it comes to the compilation of spatial data. The tools of remote sensing (RS) make the process of acquiring and analyzing satellite pictures relatively straightforward. Recent improvements in GIS and remote sensing are helping to overcome the difficulties of extracting data from coastlines (Mahapatra *et al.,* 2013) The latest technological advancements and the combination of GIS and remote sensing technologies have made it possible to offer extensive coverage and analysis of shoreline alterations using several methodologies (Mullick *et al.,* 2020). Using remote sensing and geographic information system approaches, several studies have been conducted to investigate changes to shorelines, including shoreline change monitoring in Atikhisar reservoir (Kale and Acarli, 2019), analysis of shorelines from Cuddalore to Nagapattinam (Sangavi and Roopa, 2020), extraction of shoreline changes in Selangor coastal area (Selamat *et al.,* 2017), monitoring shoreline change of Acigol and Burdur lakes (Sabuncu, 2020), Vishakhapatnam coast (Baig *et al.,* 2020), and Vizianagaram–Srikakulam coast (Rani *et al.,* 2018),

The Digital Shoreline Analysis System, often DSAS, is an extension program used with ArcGIS software. It primarily analyzes shoreline migration dynamics over short and long time scales (Himmelstoss *et al.,* 2018). Most studies estimated shoreline change rates from a time series of different coastal locations using the Digital Shoreline Analysis System (DSAS) extension tool (Thieler *et al.,* 2009: Natarajan *et al.,* 2021). The DSAS is a tool used extensively to evaluate shoreline changes worldwide (Duru, 2017; Emam and Soliman, 2020). Several studies on the determination of shoreline change have recently been undertaken using DSAS in combination with RS and GIS. For example, Shoreline changes analysis in Kuwaru coastal area (Mutaqin, 2017), coastline changes analysis for the Qingdao coastline (Yasir *et al.,* 2020), shoreline mapping and coastal change studies along Chennai Coast (Jose *et al.,* 2018), shoreline change monitoring in Nellore coast (Kannan *et al.,* 2016), assessment of shoreline change along Nagapattinam coast (Mageswaran *et al.,* 2015), assessment and forecast of shoreline change using geospatial techniques in the Gulf of California (Zambrano-Medina *et al.,* 2023). The present research uses multi-temporal Landsat satellite imageries and the DSAS extension of ArcGIS software to explore the change in the coastline of Bapatla that has occurred due to erosion and accretion. The research findings could benefit coastal hazard management in the Bapatla district of Andhra Pradesh, one of India's most susceptible coastal regions (Basheer Ahmad and Pandey, 2019). The present study aimed to assess coastline changes in one of the most susceptible coastal districts of Andhra Pradesh State, the upper Coromandel Coast of India.

MATERIALS AND METHODS

Description of the Study area

The coastal region of Andhra Pradesh, particularly susceptible to natural disasters, includes the Bapatla district. This region is part of the Coromandel Coast. The Coromandel Coast is the coastal line from Kanyakumari in Tamil Nadu state to the Bapatla (earlier Guntur District) in Andhra Pradesh state. The present study was focused on the newly formed district of Andhra Pradesh State, i.e., Bapatla district, which has a coastline of about 91 km approximately, as it comes under the highly vulnerable coastal stretch of Andhra Coast. The global location of Bapatla district is between 79^{o} 51' 12 ″to 80^{o} 54' 46″N Latitude and 15^{o} 36' 23 ″to 16^{o} 16' 19 ″of E Longitude. Bapatla, Chirala, and Repalle are the district's three revenue divisions, and each has its sub-collector. The Bapatla revenue division consists of 6 mandals, the Chirala revenue division has ten, and the Repalle revenue division has 9 Mandals (Fig. 1). Each Mandal contains various village and town settlements.

The current investigation demonstrates an effective method for determining a change in the coastline and comprehending accretion and erosion in the coast of Bapatla district by using satellite imagery integrated with remote sensing and GIS. As satellite imagery is easily accessible, it is possible to determine the changes in shoreline patterns for different spatial and temporal time frames (Nikolakopoulos *et al.,* 2019). The present research was carried out by analyzing the satellite data and using the many different ArcMap software applications available. The flow chart provides an overview of the methodology applied during this study (Fig. 2).

To help resource management and essential coastal planning and development operations, DSAS have been extensively adopted by national and regional governments (Himmelstoss *et al.,* 2018). Moreover, the DSAS extension tool is used to calculate the statistics of change in shoreline from a series of coastal sites over time. Therefore, in the present analysis, an extension of ArcGIS called the DSAS toolbar v5.0 from the US Geological Survey was employed to evaluate the alterations that have taken place along the coastline. Three different statistical techniques were applied in the present investigation to evaluate the shoreline changes along the Bapatla coastal tract. The statistical techniques include, "Linear Regression Rate" (LRR), "Net Shoreline Movement" (NSM), and "End Point Rate" (EPR). The measurements were generated from an analysis of the locations of the coastline at a variety of different times throughout history. The current research region was split into five sections (Zone I to Zone V) based on the locations of the mandals that run parallel to the Bapatla Coast. Chinaganjam, Vetapalem, Chirala, Bapatla, and Nizampatnam mandals were the five divisions that make up this area (Fig. 3). The digital shoreline

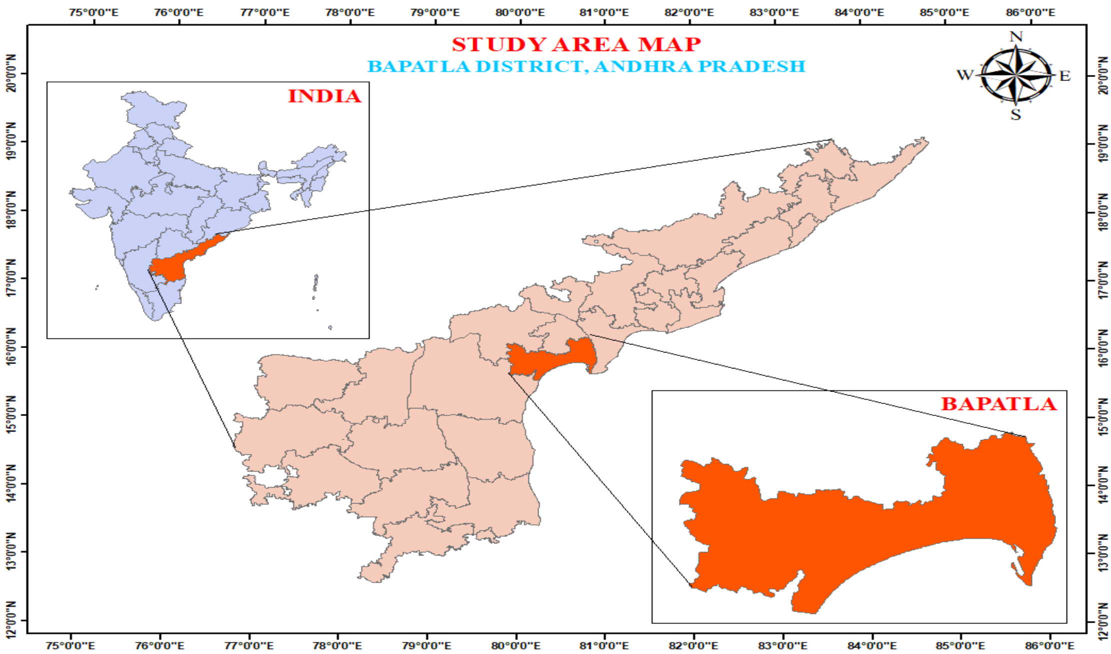

Fig. 1. *Map of the study area*

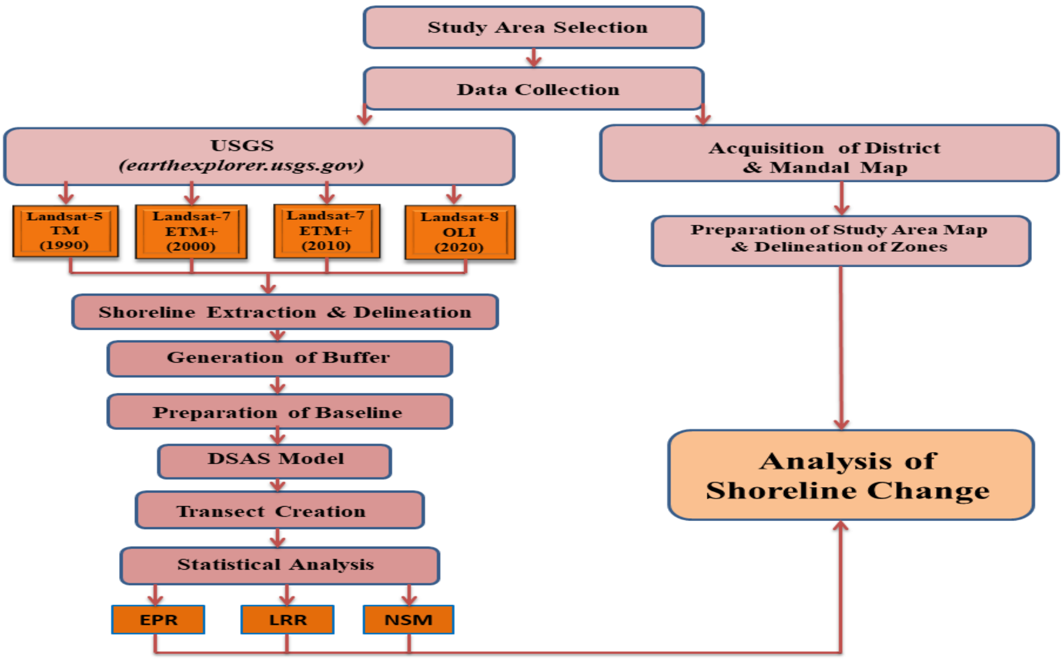

Fig. 2. *Flow diagram of methodology for assessment of shoreline change*

analysis system calculated 452 transects for the whole Bapatla coast. According to the DSAS's computed transects, Zone 1 had a length of 15 km and 72 transects. Zone 2 had a total coastline length of 13 km and a total of 68 DSAS transacts. Comparatively, Zone 3 extended along roughly 6 kilometers of coastline and had just 30 DSAS transects, whereas Zone 4 extended along approximately 10 kilometers of coastline and had 47 transects. Zone 5 had roughly a shoreline of 47 km with 235 transects.

Data acquisition

The current research used multi-temporal Landsat data (for 1990, 2000, 2010, and 2020) to evaluate the erosion and deposition responsible for shoreline movement in the Krishna district of Andhra Pradesh. The USGS Earth Explorer website (https://earthexplorer.usgs.gov) was utilized to retrieve satellite data for the different periods of the location that were being investigated. For the year 1990, thematic mapper (TM) sensor data was employed, while enhanced thematic mapper (ETM) data was utilized for 2000 and 2010 (Table 1). And the data for the year 2020 was obtained from an operational land imager (OLI) sensor. The district and mandal maps acquired from the local administrative departments were used to prepare the location map. The information obtained from Google Earth also has an application in this research.

Digitization and extraction of shorelines

The shapefile with the name of shoreline was prepared in ArcMap software to extract and digitized for different years. The shoreline for other years was extracted by manually digitizing multi-temporal satellite imagery in ArcMap 10.8 software. After collecting data on coastlines from a wide range of periods, it was imported into DSAS so that it could be used to analyze the change in shorelines from 1990 to 2020. In order to continue with the processing, it was necessary to complete all of the steps described in the DASA guide version 5.0. These procedures were followed one after the other. Tonal distinctions between land and water were used to map the coastline's characteristics. Band ratio analysis was performed to distinguish between land and water pixels. An additional vectorization approach was employed to acquire the shoreline details in ArcGis software. The visual interpretation was used to adjust the shoreline elements such that they were under the high tide line (HTL) (Misra and Balaji, 2015).

Preparation of baseline

ArcMap software's buffering technique was used to create the baseline. Creating a baseline is one of the steps involved in depicting shoreline changes (Natarajan *et al.,* 2021). Extracted shorelines from several periods were merged into a single feature, and a 1000m buffer was set up around it. The "Baseline Shapefile" was used to digitize the buffer from the landward side, creating the baseline.

Generation of transects

The shoreline change rate was determined by entering digitized coastline for different years (1990, 2000, 2010 and 2020) into the DSAS in vector format. Transects were placed at 100-meter intervals along the coastline to gather the data needed for the study. Digitized coastlines from several periods were integrated into a single shapefile in a personal geodatabase. To estimate the rates of change, the DSAS required baseline measurements of shorelines throughout the time, which demands the storage of a different shapefile inside the same personalized geodatabase (Leatherman and Clow, 1983). Creating transects begins with selecting the personal geodatabase, where the user selects the given default parameters, such as shoreline and baseline configurations. The cast transects option was

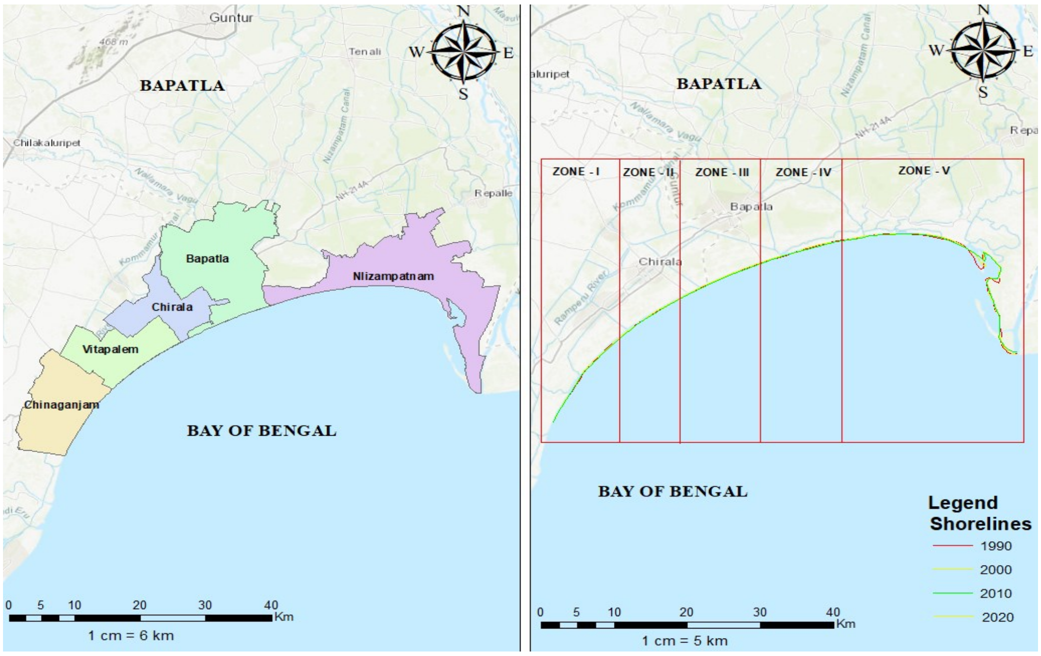

Fig. 3. *Mndals and zones of the study area along the Bapatla coast*

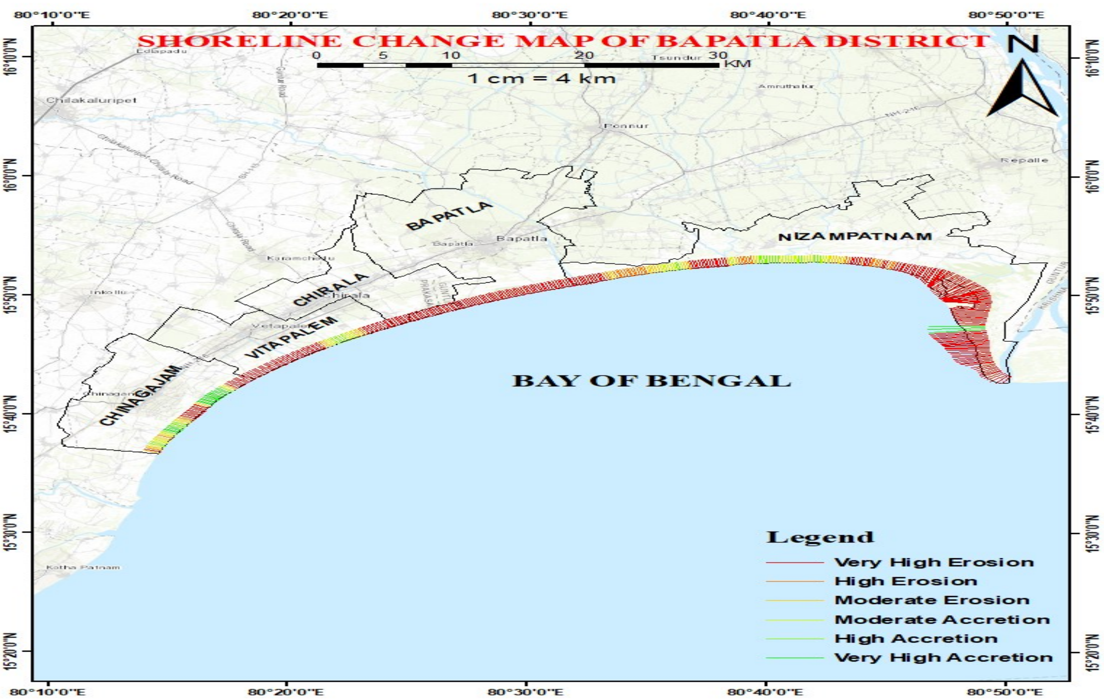

Fig. 4. *Map presenting the variations in shoreline of Bapatla district from 1990-2020*

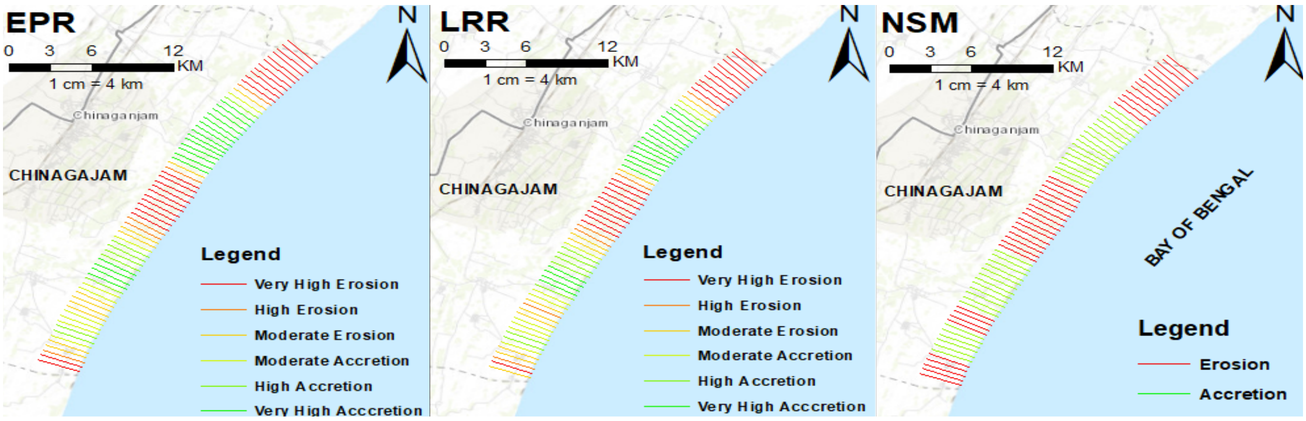

Fig. 5. *Variability in erosion and accretion from LRR, EPR and NSM at Chinagajam (Zone - I) for the time period of 1990-2020*

utilized in DSAS to establish transects that were 1500 meters long and perpendicular to the coast. These transects were spaced at 200-meter intervals throughout the coastline, and the smoothing distance was set at 50 meters. Changes were calculated by utilizing data from the transect feature class collected from 452 transects. When calculating the statistical rate of change of the coastline, the intersections of transects with the coastline situated along the baseline were considered (Saranathan *et al.,* 2011).

Statistical analysis in DSAS tool bar

In the course of this inquiry, a variety of statistical methods drawn from the DSAS toolbar were used. These methodologies included the linear regression rate (LRR), the net shoreline movement (NSM), and the end point rate (EPR). The statistical analysis of the coastline change rate provided negative and positive findings; negative values reflect erosion, while positive values represented accretion (Nithu Raj *et al.,* 2020).

Linear Regression Rate (LRR)

The linear regression rate is one of the statistical technique that was applied in the current study. The linear regression rate-of-change statistics can be calculated using a least-squares regression line to match all coastline points for a particular transect. By squaring the difference between each data point and the regression line and putting the results together, we can get the optimal location for the regression line. The slope of the line represents the linear regression rate (DSAS 5.0 user guide, 2018).

End Point Rate (EPR)

According to Sebat and Salloum, (2018), calculating and analyzing shoreline change using the end point rate (EPR) approach in conjunction with satellite imagery is an accurate and trustworthy method. To get EPR, the shoreline displacement distance is divided by the elapsed time between the oldest and youngest shoreline. The EPR's primary advantages lie in its requiring little information (only two shoreline data) and can be calculated quickly and easily. The drawback is that when new information is provided, it is often disregarded, such as signs (from accretion to erosion), size, or cyclical changes that may go undetected (Dolan *et al.,* 1991; Crowell *et al.,* 1997).

$$EPR = (Dy - Do / Ty - To)\ m/yr \quad \text{Eq.1}$$

Where,

$D_y – D_o$ represents the distance between the youngest and oldest shoreline (e.g. 1990-2020 for our study) in metre per year.

$Ty – To$ represents the time elapsed between the oldest and the youngest shoreline.

Net Shoreline Movement (NSM)

NSM is another statistical parameter that enumerates the distance between the oldest and the youngest shoreline for each transect laid perpendicular to the shorelines (DSAS 5.0 user guide, 2018). The NSM can be calculated as follows;

$$NSM = (Dy—Do)\ m \quad \text{Eq. 2}$$

Where,

$D_o–D_y$ represents the distance between the youngest and oldest shoreline in meters. For this study, D_y is 1990 and D_O is 2020.

For identifying areas of erosion and accretion along the Bapatla coast, the rate of shoreline changes was computed using the end point rate (EPR) and linear regression rate (LRR) technique in ArcGIS software. These methods were used to quantify the rate of coastline variations. Based on EPR and LRR, the shoreline of the Bapatla coast was categorized into seven classes ranging from very high erosion to very high accretion (Natesan *et al.,* 2015; Nitu Raj *et al.,* 2019). The classes are shown in Table 2:

RESULTS AND DISCUSSION

The coastal zone is vulnerable to the impacts of a diverse range of variables and occurrences because it is integrated into the larger system of the globe. Two processes that threaten coastal communities are erosion brought on by storm surges and the influence of unmanaged groins created for coastal management efforts (Nitu Raj *et al.,* 2020). The fact that coasts are subjected to a wide array of dynamic natural processes causes them to often undergo both long-term and short-term changes (Bouchahman and Yan, 2014). According to research done by Mukhopadhyay *et al.* (2018), erosion not only causes the loss of a sizeable amount of resources each year but also results in the forced displacement of significant portions of the population residing in coastal communities. Therefore, to explore the temporal variations of coastal sites, many previous studies have made considerable use of the data gathered by remote sensing (Fletcher *et al.,* 2003). In the present study, the change in the coastline was calculated for the Bapatla district coast with the help of the DSAS tool included in ArcGIS softwar,. The DSAS approach gives excellent qualitative estimates to comprehend the dynamics in a particular location. The study demonstrated the value of using GIS tools while doing coastline research. The amount to which the coastline has been accreting or eroding between 1990 and 2020 is shown in Fig. 4 over a length of approximately 91 km.

The study region was divided into five zones: Chinaganjam, Vetapalem, Chirala, Bapatla, and Nizampatnam. This was done so that the data collected could be correctly interpreted and so that proper data could be obtained for coastal erosion and accretion. These processes are responsible for changes to the coastline. The LRR, the NSM, and EPR are three separate statistical approaches used to ascertain the shoreline change rate using the DSAS toolbar in ArcGIS. Because of this, it was feasible to compute the pace at which the coastline was shifting. As a result of accretion and erosion, the coastline is in a state of perpetual change. Figs. 5 to 9 depict the estimated varying degrees of accretion and erosion for LRR, EPR, and NSM for all four zones between the years 1990 to 2020.

According to Sebat and Salloum (2018), the end point rate (EPR) methodology is a precise and credible way of calculating and assessing changes in the shoreline. This approach is best used in conjunction with satellite images. EPR indicated that the maximum erosion rate in Zone–I, i.e. Chinaganjam was -8.9 meters per year, while the highest accretion rate was 6.9 meters per year. In Zone-II, i.e. Vetapalem, the highest accretion and erosion rates were -9.7 and 1.7 meters per year, respectively. In Zone-III and Zone-IV, i.e. Chirala and Bapatla mandals, it was observed that the erosion occurs only throughout three decades. Chirala and Bapatla mandals highest erosion rates were -9.7 and -8.9 m/yr, respectively. For Zone-V, i.e. Nizampatnam mandal, the maximum erosion and accretion rates were -16.8 and 10.5 meters per year, respectively (Table 3).

Many methods exist for studying coastline shifts, but only the LRR allows for the utilization of data from multiple coastlines simultaneously (Burningham and French, 2017; Sheikh and Chandrasekar, 2011). Based on LRR, for the period 1990-2020, the highest erosion rate in Zone–I (Chinaganjam) was -9.1 meters per year, while the maximum accretion rate was 6.9 meters per year. In Zone-II, Vetapalem Mandal, the maximum erosion and accretion rates were recorded as -9.7 meters per year and 1.7 meters per year, respectively. According to the analysis done through LRR, it was recorded that the shoreline has continuously receded at the places of the Chirala and Bapatla mandals. The maximum rates of erosion observed in these two places i.e. Zone-III and Zone-IV, are -9.7 and -8.9 m/yr, respectively. In Zone-V i.e. the Nizampatnam mandal, the maximum erosion rate was -16.7 m/yr, while the maximum accretion rate was 10.4 m/yr (Table 4).

According to the digital shoreline analysis system's 5.0 user guide 2018, another statistical measure called net shoreline movement (NSM) counts the distance between the oldest and youngest shorelines along each transect placed perpendicular to the shorelines. The results of the

Table 1. Data used for evaluation of erosion and accretion in the coast of Bapatla district

Year	Satellite	Sensor	Date of acquisition (DD/MM/ YYYY)	Source
1990	Landsat - 5	TM	19-02-1990	*earthexplorer.usgs.gov*
2000	Landsat - 7	ETM+	30-01-2000	*earthexplorer.usgs.gov*
2010	Landsat - 7	ETM+	02-06-2010	*earthexplorer.usgs.gov*
2020	Landsat - 8	OLI/TIRS	02-04-2020	*earthexplorer.usgs.gov*

Table 2. Classification of shoreline based on the value of erosion and accretion

S/No.	Value (m/yr.)	Class
1	>-2	Very High Erosion
2	>- 1 to <-2	High Erosion
3	>- 1 to < 0	Moderate Erosion
4	0	Stable
5	>0 to < 1	Moderate Accretion
6	>1 to < 2	High Accretion
7	>2	Very High Accretion

NSM over the period spanning 1990-2020 indicated that the coastline at Chinaganjam (Zone-I) receded by 105.4 m (Maximum) and advanced by a distance of 98.9m (Maximum). In Vetapalem (Zone-II), the maximum erosion and accretion were 344.63m and 104.1m, respectively. The coastline at Chirala and Bapatla (Zone-iii and Zone-iv) has receded regularly, with the maximum values recorded as -97.1 and -81.7, respectively; there was no sign of accretion in the coastline at these two places. At Zone-V, the Nizampatnam Mandal, it was observed that there occurred an erosion of -285.2m and an accretion of 211.1m from 1990 to 2020 (Table 5).

The coastlines are one of the most vulnerable regions on the earth's surface, and they have always been prone to both erosion and accretion as a consequence of natural catastrophes such as floods, tsunamis, storm surges, cyclones, fluctuations in sea level, and changes in tide and wind. According to Mukhopadhyay *et al.* (2011), natural calamities of this kind have always been a factor in the shifting of coastlines. As per the statistical analysis (EPR, LRR, and NSM) conducted from 1990-2020, shoreline alterations were observed in all five zones of the research area. The highest rate of erosion and accretion was observed in Nizampatnam, which is Zone-V (Figs. 9 to 11).

The erosion rate was at its worst in the region close to the point where the tributaries of the Krishna River emptied into the Bay of Bengal from False Divi Point to Adavuladheevi Sea Point View. Because of the swift current of the Krishna River and the movement of the waves, the sediments get dislodged and are either carried away or washed away, causing the coastline to recede. It may be deduced from the flow of the Krishna River that the locations at which the Krishna River discharges into the Bay of Bengal will tend to shift toward the landward side. The fact that the Krishna River empties into the Bay of Bengal is the foundation for this forecast and prognosis. The part of the Andhra Pradesh coastline, situated in the middle, has a somewhat dynamic characteristic due to the effect of the Krishna River (Basheer Ahammed and Pandey, 2022). The waves generated due to a cyclone storm are strong and lively. These waves can potentially wreak havoc on beaches by taking sediments from the region and depositing them farther out to sea, making the coastline recede (Saxena *et al.,* 2013). Storm surges, including high water levels and enormous waves, greatly increase the chance of shoreline erosion during a hurricane. Due to their erosive power, storm surges are the most deadly kind of natural catastrophe (Kumar *et al.,* 2010; Rani *et al.,* 2015). The coastal region of Andhra Pradesh, of which the Bapatla district is a part, is very vulnerable to the effects of natural disasters, particularly typhoons and storm surges (Basheer Ahammed and Pandey, 2019). Larger storm surges caused by more violent cyclones can cause significantly more extensive harm along coastlines in the form of coastal erosion (Kommireddi *et al.,* 2015).

The accretion was observed because of the curvilinear pattern of the coast. The accumulation of sediment in a curved pattern in this region leads to the development of a beach. The littoral drift during the southwest monsoon is responsible for the movement and deposition of sediments, leading to the coastline's advancement in this area due to accretion (Samarasekara *et al.,* 2023). Sediment movement down the coast, maybe pushed by cyclone waves, is called longshore drift. The size and shape of

Table 3. Statistical data of shoreline change from 1990-2020 using EPR

ZONE NAME	EPR				
	Transect count	Max. Erosion (m/yr.)	Max. Accretion (m/yr.)	Mean	Standard deviation
CHINAGANJAM	72	-8.9	6.9	-0.01	3.31
VETAPALEM	68	-9.7	1.7	-5.05	3.21
CHIRALA	30	-9.7	NA	-7.72	1.42
BAPATLA	47	-8.9	NA	-6.95	1.39
NIZAMPATNAM	235	-16.8	10.5	-4.57	5.03

Table 4. Statistical data of shoreline change from 1990-2020 using LRR

ZONE NAME	LRR				
	Transect count	Max. Erosion (m/yr.)	Max. Accretion (m/yr.)	Mean	Standard deviation
CHINAGANJAM	72	-9.1	6.9	-0.005	3.13
VETAPALEM	68	-9.7	1.7	-5.12	3.13
CHIRALA	30	-9.7	NA	-7.61	1.48
BAPATLA	47	-8.9	NA	-6.98	1.39
NIZAMPATNAM	235	-16.7	10.4	-4.56	5.03

Table 5. Statistical data of shoreline change from 1990-2020 using LRR

ZONE NAME	NSM				
	Transect count	Max. Erosion (m)	Max. Accretion (m)	Mean	Standard deviation
CHINAGANJAM	72	-105.4	88.9	-4.18	55.18
VETAPALEM	68	-88.8	38.4	-42.68	34.71
CHIRALA	30	-97.1	NA	-77.25	12.42
BAPATLA	47	-81.7	NA	-63.19	8.71
NIZAMPATNAM	235	-285.2	211.1	-86.65	91.04

beaches and other shoreline features may be altered by the sand deposition caused by this sediment flow. When waves come in at an angle, sediment is more often pushed along the coast in the direction from where the waves are coming in (Kafoor *et al.,* 2023). According to the Coastal Engineering Manual-2002, in addition to natural phenomena, anthropogenic factors like water extraction, mining, dredging, dams or reservoirs, etc., among other things, are also accountable for accretion and erosion. Based on the sediment budget, the coastline has a pattern of altering its form to arrive at a point of stability, which can be seen over time (Pandian *et al.,* 2004).

As per the findings of the present investigation, it is abundantly apparent that the net erosion rate is far higher than the net accretion rate. The shoreline that undergoes accre-

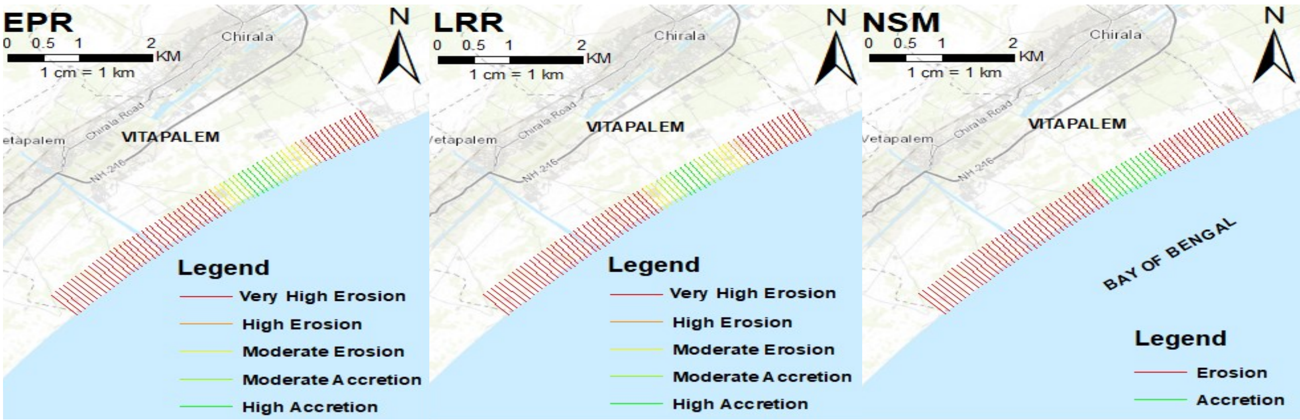

Fig. 6. *Variability in erosion and accretion from LRR, EPR and NSM at Vitapalem (Zone - II) for the time period of 1990-2020*

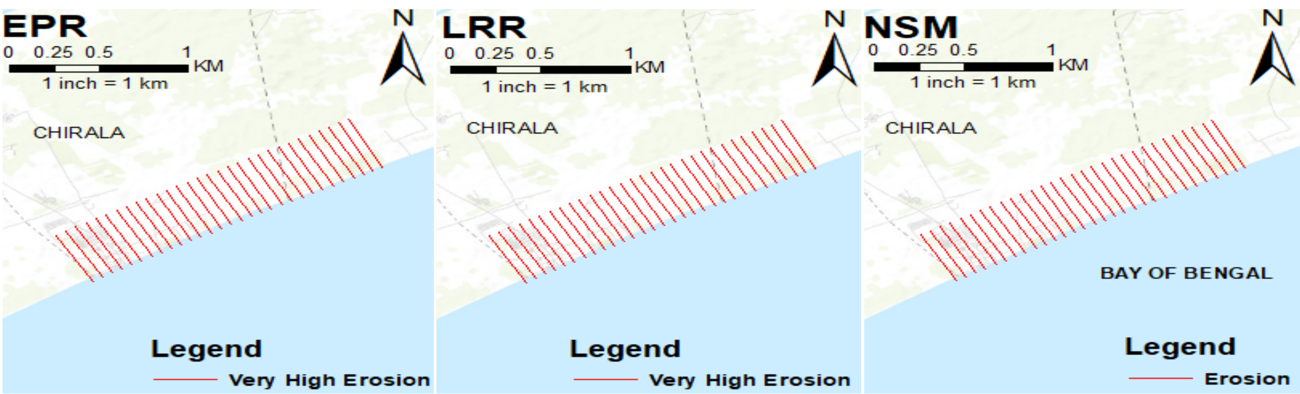

Fig. 7. *Variability in erosion and accretion from LRR, EPR and NSM at Chirala (Zone - III) for the time period of 1990-2020*

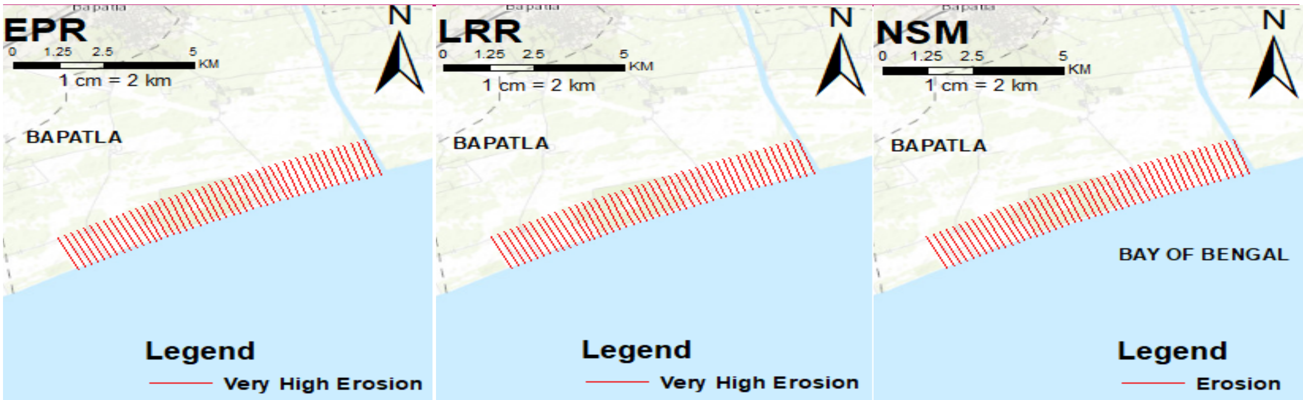

Fig. 8. *Variability in erosion and accretion from LRR, EPR and NSM at Bapatla (Zone - IV) for the period of 1990-2020*

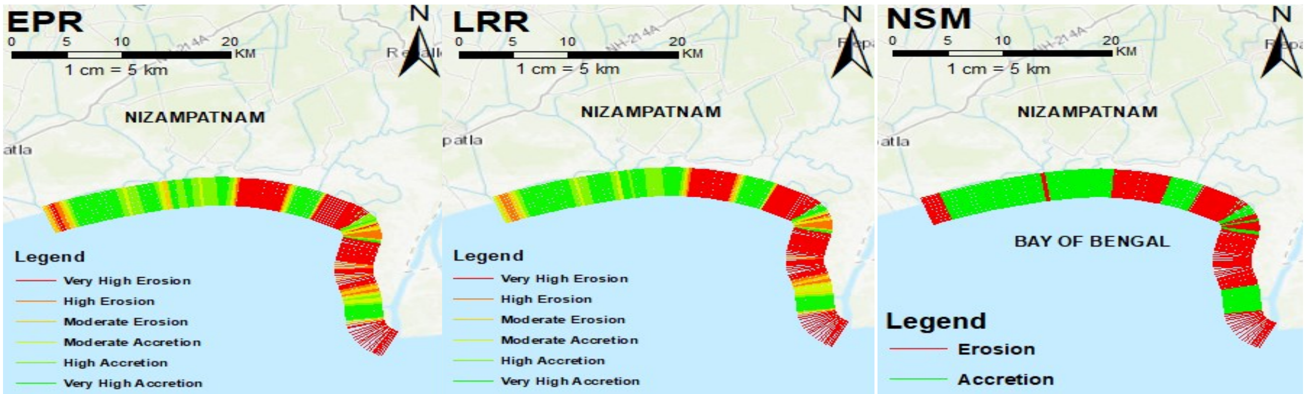

Fig. 9. *Variability in erosion and accretion from LRR, EPR and NSM at Nizampatnam (Zone - V) for the period of 1990-2020*

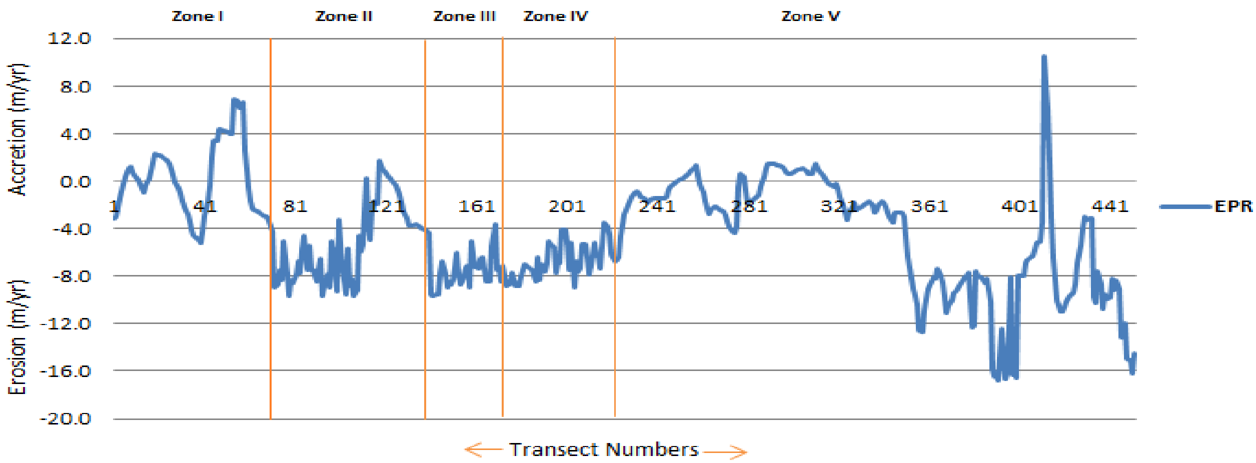

Fig. 9. *Estimation of Erosion and Accretion from EPR for all the five Zones (1990-2020)*

tion will be seen as more secure than the coast prone to erosion. Because regions with an accretion tendency migrate toward the ocean, creating new land areas, while areas with an erosion trend cause the coastline to recede, raising the risk that people may be exposed to coastal threats (Jana and Hegde, 2016). Because of its position and geographical distribution along the ocean, the coastal Andhra Pradesh (CAP) area is especially susceptible to erosion (Kantamaneni *et al.,* 2019). According to (Babu and Narayana, 2016), tides, waves, and wind are all examples of natural factors that can quickly move unconsolidated sand and soils in coastal areas, which may lead to significant shifts in the location of the coastline along the Andhra coast. Erosion and accretion are natural processes that occur over various time scales and are responsible for altering coastlines. In the wake of temporary phenomena like wave action, storms, winds, and normal tides, or the wake of permanent phenomena like glaciations, this may drastically change sea levels (Nikolakopoulos *et al.,* 2019). Storms are an excellent example of an event that occurs on a smaller scale and over a shorter period. Consequently, most coastlines are naturally dynamic, and the cycles of erosion that occur along these beaches are often a crucial part of the ecological makeup of these places (Kannan *et al.,* 2016). According to Kankara *et al.* (2018), the shoreline is prone to change due to natural and anthropogenic

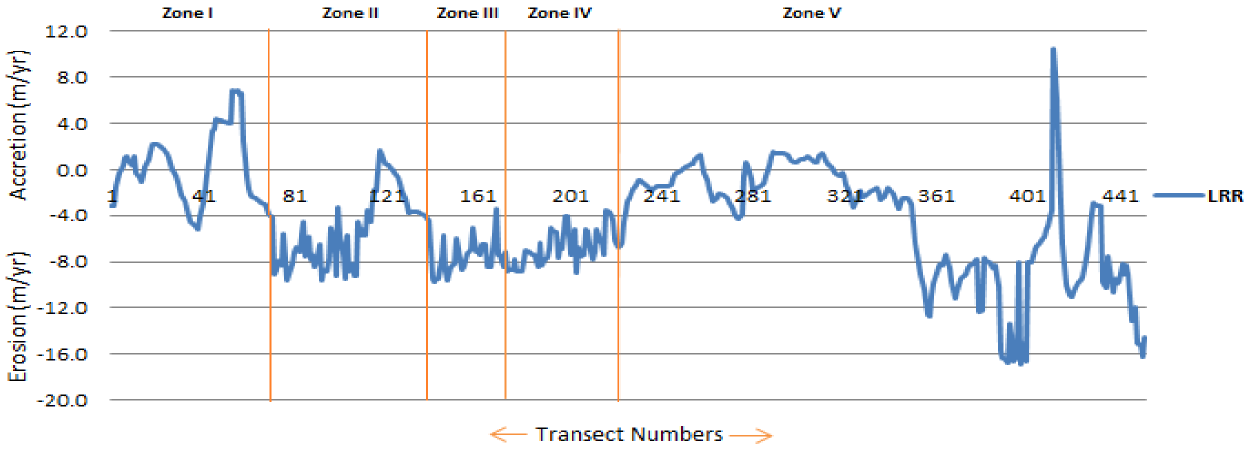

Fig. 10. *Estimation of Erosion and Accretion from LRR for all the five Zones (1990-2020)*

activities. The natural causes include the action of nearshore currents and tides, waves, sea level rise, and storms. The development of offshore dredging, the damming of rivers, and sand mining are all examples of anthropogenic influences that may cause alterations to the coastline. According to Mukhopadhyay *et al.* (2011), one of the impacts of global warming is an increase in sea level. This rise in sea level has a substantial role in the erosion of coasts and the shifting of shorelines.

Mitigation strategies for change in coastline

The coastal administration of Andhra Pradesh has implemented several adaptive strategies in response to stress, including the construction of cyclone shelters, the formation of a disaster response force to take reactive steps, and the establishment of tsunami and cyclone warning ceers (Topno, 2018). In the same way, flood-prevention measures were taken along rivers and coastlines for better resistance to floods (National Disaster Management Authority, 2016). According to Bhattacharyya *et al.* (2016), the principal way coastal land degradation caused by erosion may be minimized is by implementing complicated engineering interventions. These interventions include the construction of dykes, seacoasts, and groins. Sand mining, urban development, and dredging are all human activities that contribute to coastal erosion; however, revetments, groins, and seawalls may help mitigate the problem (Linham and Nicholls, 2012). According to Linham and Nicholls (2012), sea dyke construction, beach nourishment, coastal setbacks, wetland restoration, and detached breakwaters are all realistic and successful adaptation measures that might be adopted in ecologically vulnerable regions. With the aid of constructed structures, longshore drift erosion may be temporarily alleviated, but in the long term, these interventions may exacerbate erosion rates further down the coast. In addition, the costs associated with maintaining these artificial innovations are rather significant (FAOUN, 2016). As a result, there is need to find a more effective and affordable solution, like geotubes or the creation of a green belt.

The utilization of a geotube structure would be highly appropriate for safeguarding the Bapatla coast. The presence of indigenous vegetation and intentionally planted trees in certain areas necessitates the provision of water to support their growth, as geotextile used in the construction of geotubes can allow water and soil to pass through them (Shin *et al*., 2002). The implementation of geotubes is expected to serve as a protective measure against erosion along the Bapatla coast while also facilitating the deposition of fresh sediments in the area. Furthermore, implementing geotubes will not disrupt the runoff patterns during the monsoon season, hence mitigating the issue of inundation in the low-lying coastal areas of Bapatla district. Moreover, the geotubes protect the coastline of marine embankments and dikes at a cheaper cost than rock or precast concrete block units (Kim *et al.,* 2013). Whereas, Green belts are strategically positioned rows of trees that serve as a protective barrier along coastal areas, mitigating storm surges' impact. Establishing a green belt is expected to contribute to the preservation of the Bapatla coast by virtue of the robust root systems of plants, which serve as a stabilizing agent in the soil. This, in turn, mitigates the potential for soil erosion and promotes the maintenance of coastal integrity. The Bapatla Coast has many beaches, and a green belt plantation would improve its recreational and scenic value. This enhancement will attract people to these beaches. According to Hegde (2010), a method for integrating green belts into regions near river estuaries involves the implementation of tree-lined strips that serve many objectives, such as fruit production, timber resources, floral cultivation, and commercial utilization. The implementation of the green belt may be expected to yield favourable economic outcomes for the residents of Bapatla Coast.

Conclusion

The present study assessed the shoreline change rates along the Bapatla coastal tract by applying remote sensing and Geographic Information System (GIS) applications. Using geospatial methods and automated calculations, the newly updated tool, the Digital Shoreline Analysis System (DSAS), included within ArcGIS, made locating and evaluating the shoreline changes along the Bapatla coast sim-

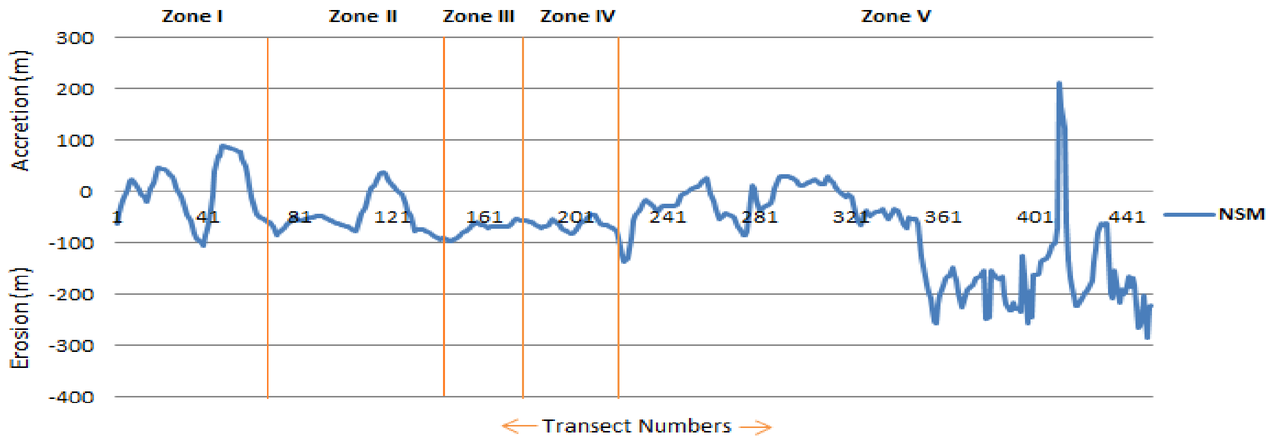

Fig. 11. *Estimation of Erosion and Accretion from LRR for all the five Zones (1990-2020)*

ple. Based on the findings of this inquiry, it can be deduced that the coastline has gradually shifted along the Bapatla coast between the years 1990 and 2020. As per the outcomes of the current research it indicates that the Bapatla district's shoreline is constantly susceptible to erosion and accretion. The Nizampatnam Mandal of the study region has the highest impact erosion in all three decades. The analysis found that more than 67% of the shoreline along the Bapatla coast has receded, more than the length (37%) of the coastline that has been advanced. This presents a significant challenge when the erosion rate exceeds the accretion rate. Coastal erosion is a big concern, especially for a nation like India that is seeing a massive expansion in the population of its coastal districts. Therefore, constant shoreline monitoring is vital for managing the Bapatla coastal zone as it is badly eroding owing to the combined impacts of natural and human-caused causes. Creating a green belt and installing geotubes along the Bapatla coastal tract would play a crucial role in mitigating shoreline alterations.

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Conflict of interest

The authors declare that they have no conflict of interest.

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