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GEOSTATISTICAL VISUALIZATION AND COMPARISON OF COROMANDEL SHORELINE OF ANDHRAPRADESH, INDIA

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ABSTRACT
Shoreline change analysis is an important tool for understanding the dynamics of coastal environments, particularly in the face of climate change and increasing anthropogenic pressures. The North most Coromandel Coast of India is a densely populated and rapidly developing region that is particularly vulnerable to these challenges. In this study, a statistical approach was used to analyse shoreline changes along the Andhra based Coromandel Coast using GIS. The study analysed shoreline data from 1988 to 2021, which was obtained from satellite images and maps. The data was processed using GIS software to generate shoreline vectors, which were then used to calculate shoreline change rates. Statistical analysis was performed to identify significant trends and patterns in the data. The results of the study revealed that the northern line of Coromandel Coast has experienced significant shoreline changes over the past three decades, with the majority of the coast experiencing erosion. The study also identified several hotspots of shoreline erosion and accretion, which were associated with natural and anthropogenic factors such as river sedimentation, coastal infrastructure development, and climate change. The statistical approach used in this study provides a valuable tool for analysing and understanding shoreline changes in coastal environments. The results of this study can be used to inform management and conservation strategies for the Coromandel Coast, as well as other coastal regions facing similar challenges.
KEYWORDS: shoreline, coast, DSAS, Linear regression, Model, Statistics

1. INTRODUCTION

Natural calamities such as tsunamis, flooding, cyclones, storm surges, wave action, tide and wind variations, and sea level changes have caused coasts to erode and grow throughout history (Mukhopadhyay et al. 2011). Human activities such as port construction, beach sand mining, industry, rubbish dumps, urbanisation, recreation, the discharge of sewage and industrial waste, and the removal of silt from rivers have accelerated the process of change, including alterations to the shoreline. Dilara and Tarik 2019; Jayakumar and Malarvannan 2016). According to Salghuna and Bharathvaj (2015), the movement of the coast can be classified into three types: eroding (also known as "landward retreat"), equilibrium (commonly known as "stationary"), and accreting (seaward extension). These states were influenced by changes in sea level, the amount of sand on the beach, and the contour of the terrain. (2015) (Salghuna and Bharathvaj). Natural and man-made disturbances, according to To and Thao (2008), Saranathan et al. (2011), Mahapatra et al. (2014), Poornima et al. (2015), and Jayakumar and Malarvannan (2016), all play major roles in the erosion and deposition of the surrounding ecosystems, which affects the shorelines. The most strong processes in coastal environments include hydrodynamic, geomorphic, tectonic, and climatic forcings. These are the ones that alter the shoreline in both the long and short term. Bagli and Soille (2003), Sunarto and Scott (2004), Thom, Cowell, and Mills (2005), and Marfai et al. (2008). Global warming causes sea levels to rise, which has a significant impact on both the erosion and appearance of coasts (Mukhopadhyay et al. 2011). Similarly, constructing groynes, revetments, jetties, and seawalls can alter the movement of waves and the flow of coastal currents. This can wash away beach sand and shift the location of the shoreline (Masselink and Short 1993; Muthusankar et al. 2017).

Coastal zone research and analysis are vital not only to monitor how sensitive the coast is to things like bioresource loss, rising sea levels, coastal erosion, seawater intrusion, and coral bleaching, but also to predict how the coastline will change in the future. Remote sensing is a better way to monitor coastal and deltaic environments than more traditional ways (Muthusankar 2011; Saranathan et al. 2011). There has been a lot of emphasis in recent years on combining numerical models and data from remote sensing to investigate and anticipate the shoreline (Nithu Raj et al. 2020). Identifying the main changes is easier and more reliable with satellite data and GIS tools (Ciavola et al. 1999; Yang et al. 1999; Mujabar et al. 2007; Mujabar and Chandrasekar 2011a, b; Kaliraj et al. 2013). Classifications based on isodata clustering, Tasseled cap, Normalized Difference Vegetation Index (NDVI), Maximum Likelihood, and Principal Component Component Analysis (PCA) all aid in tracking changes along coastlines. (Mouat and Lancaster 1996, Reid and colleagues 2000, Chen 2002, Weng 2002, Siddiqui and Maajid 2004, and Mujabar and Chandrasekar 2011a, b) Linear Regression Rate (LRR), Least Median of Squares (LMS), Average of Rate (AOR), and Jack Knifing statistics have been used to estimate and predict rates of change in shoreline elevation (Deepika et al. 2013). Dolan and his colleagues believed that EPR was the most effective method for determining what alterations to the shoreline will mean in the long run. Similarly, the LRR is helpful for determining the shoreline since it reduces random error and short-term volatility (Douglas and Crowell, 2000; Allan et al., 2003; Maiti and Bhattacharya, 2009). The Digital Shoreline Analysis System, or DSAS, is a statistical programme that calculates how much the shoreline has changed over time using multi-temporal satellite data in the EPR, LRR, and LMS modules (Thieler et al. 2009; Mujabar and Chandrasekar 2011a, b). Karim Nassar et al. (2018) examined changes in the northern Sinai coast's shoreline using MSS satellite data from Landsat TM, ETM, and OLI images, as well as DSAS (Egypt).

India's coastline is 7517 kilometres long in total, with 2094 kilometres considered to be part of India's island possessions. People in this area fish and take tourists to mangrove forests, coral reefs, beaches, estuaries, and lagoons. Estuaries are another natural resource in the area (Jayakumar and Malarvannan, 2016). Nithu Raj and his colleagues employed Landsat TM, ETM +, and OLI data sets in a recent study (Raj et al., 2020) to investigate how changes to the shore near Chennai affect the environment. They were primarily concerned about how these changes might harm nature.

Using DSAS's EPR and LRR analyses, they were able to determine the rates of erosion and accumulation. Similarly, Kumaravel et al. (2012), Sriganesh et al. (2015), and Gurugnanam (2020) used DSAS to analyse changes along the Cuddalore coastal. They discovered the risky sites by examining erosion and accumulation ranges from 1991 and 2012, 1972 and 2012, and

1971 and 2013. Using remote sensing, GIS techniques, and DSAS, we investigated how the Cuddalore coast altered through time and place. This was done in areas that have been devastated by natural disasters over the last 20 years. Cuddalore, in southern India, is one of these locations. We looked at how erosion and building up altered over a 50-year period, from 1972 to 2020. The Kalman filter model was then used to forecast what would happen to the shoreline over the next 20 years. Scientists must put in a lot of effort to figure out how to predict coastal erosion (e.g., Nithu Raj et al. 2020).

According to Zhang (2011), more work has been done to quantify, monitor, and mitigate coastal stressors since people have realized that a variety of factors are degrading the quality of coastal ecosystems worldwide. This occurs immediately following the realization. By monitoring how coastal environments change over time and place, we may learn how erosion hazards are distributed, estimate how those risks will vary over time, and do additional study on how to prevent coastal erosion. Monitoring coastal zones entails locating the shorelines and determining how quickly they change over time.

According to Genz et al. (2007), the coastline is where the line between land and sea lies at any given time. The coastline is a constantly changing section of the land that illustrates how the coast is shrinking or expanding. Changes to the shoreline can occur at various time frames, ranging from long-term geological processes to short-term, dramatic catastrophes. Changes in sea level, waves, tides, winds, storms, geomorphic processes such as erosion and deposition, and human activity all contribute to these changes (Van and Binh, 2008).

Several foreign studies have looked at the quality of education (Addo and Kufogbe, 2011; abuth et al., 2013; Thi et al., 2014; Murali et al., 2015; Elsharnouby et al., 2015; Masria et al., 2015; Anand et al., 2016; Nandi et al., 2016; and Kermani et al., 2016).

People, on the other hand, attempted to predict where the shoreline would be in the future in order to mitigate the effects of the projected erosion. This was done to prevent the beach from becoming too far away. Furthermore, in order to create forecasts about how the coast will change in the future, accurate and full information regarding how the coast used to be and how it is today is required. If the correct modelling tools are available, a GIS system can help predict where shorelines will be.

Several statistical models, including the End Point Rate (EPR) model, the Average of Rates (AOR) model, the Least Median of Squares (LMS) model, the Linear Regression Rate (LRR) model, and the Jackknife model (JK), were tested using historical data (Burgess et al. 2004; Kuleli 2010; Chand and Acharya 2010; Mukhopadhyay 2010).

There hasn't been a lot of useful research done on Egypt's North Sinai coast. Frihy and Lotfy (1997) used a 1955 aerial shot, a 1992 topographic map, and a 1922 admiralty chart to depict how the northern shore of Sinai has altered over time. These three maps were all utilised. Even still, the surveying tools they utilised were incapable of determining how much the shoreline had shifted.

In 2002, Badr and Frihy conducted a hydrographic investigation to determine how the El Arish power station, located west of the coast of the El Arish valley, affected the area immediately adjacent to it on Sinai's Mediterranean coast. According to the authors, the coast moved 5.5 metres away from the barrier of the El Arish power station per year. Azab and Noor (2003) compared topographic maps from 1973 with satellite pictures from 1984 and 1996 to examine how the shoreline evolved along the western half of the North Sinai coast, from El Tinah Bay to El Bardawil Lake. The majority of their research was conducted between El Bardawil Lake and El Tinah Bay. They also discovered how much Lake El Barawil's size had altered throughout time. Between 1973 and 1984, the size of El Bardawil Lake shrank by an average of 128 km2. However, between 1984 and 1996, the size decline slowed to just 5 km2. El Banna (2009) examined TM and ETM true colour Landsat images from 1986 to 2001 to determine how the North Sinai coast (from El Bardawil Lake to Rafh) altered over 15 years. They discovered that erosion was occurring at a rate of 0.123 km2 per year and accretion was occurring at a rate of +0.076 km2 per year.

Finally, the extensive literature investigation conducted on the Godavari coast revealed that the data that has already been published in this area needs to be updated or revised. Furthermore, there are no methodologies that can be utilised to calculate the rates of change in shorelines with great accuracy.

In addition, the current study aims to: (1) apply three different semi-automated shoreline extraction techniques; (2) map and quantify the shoreline erosion/accretion rates using several statistical approaches that are functionalized in DSAS, such as EPR, LRR, NSM, and LMS; and (3) set up a decision-support-algorithm that can dynamically assist in developing plans to deal with circumstantial coastal issues. All of these objectives will be met with the assistance of DSAS.

2. PRIMARY BACKGROUND AND DATA

The section of coast located to the north of the Godavari River will be the focus of this investigation. Within the scope of this investigation, the districts of Kakinada and Visakhapatnam can be found along the coastline. The overall length of the coastline is 253 kilometres when ports and artificial sand bars are not included in the calculation.

Figure 1: The full length of the coast taken for the current study.

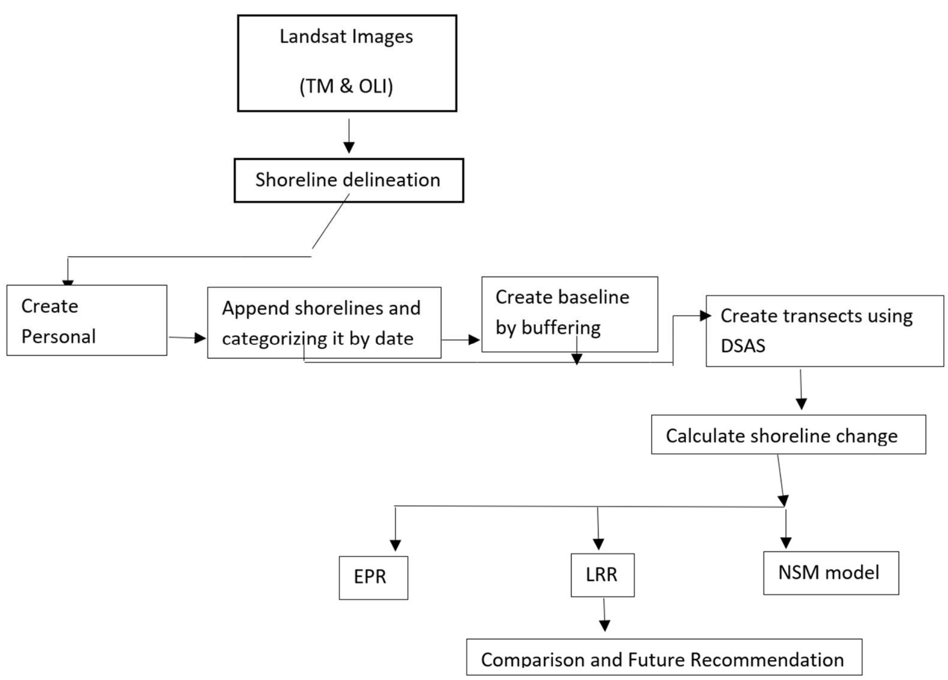
Data from the Landsat TM and OLI/TIRS satellites were used in this work to provide a multi-resolution and multi-temporal perspective. These datasets were collected on days with few or no clouds, at a variety of different times, throughout the period of time that was provided (1988 to 2021). The methodology of this study is broken down into sections that each describe the methods and procedures that were used for a certain type of data. Both LANDSAT 5 and LANDSAT 8 are capable of collecting data, however the methods they use to do so differ. Seven distinct spectral bands make up the image data that comes from the Landsat 4-4 TM satellite. The resolution for bands 1–7 is 30 metres, with the exception of band 6, which initially had a resolution of 120 metres but was later resampled to 30 metres (references). Landsat 8 OLI/TIRS image data files have eleven spectral bands. Bands 1 through 7 have a resolution of 30 metres, bands 8 through 10 have a resolution of 15 metres, and bands 10 and 11 (the thermal infrared band) have a resolution of 100 metres. From the USGS website, LANDSAT 4-5 TM Level-1 photographs were gathered between the years 1988 and 2011, while LANDSAT 8 OLI/TIRS C1 Level-1 photographs were gathered between the years 2014 and 2021.

The process of data selection is an essential part of change detection investigations, particularly those that focus on changes to the shoreline. Because of sea surge and down welling, seasonal variations in the shoreline may be caused by the time (season, month) in which multiple-date photographs were taken. This could result in the shoreline seeming different from one season to the next. The shoreline is affected not only by high tide and low tide but also by the phase of the moon. In contrast, data availability frequently imposes restrictions on data selection, and the option that is ultimately chosen is typically a trade-off between the targeted timeframe, the capture interval, and the data availability. Moon tide impacts, on the other hand, are not well understood despite the abundance of information that is accessible for each season. It is vital to have a broad selection of images that spans multiple dates in order to reduce the impact of climatic factors on specific seasons. Because changes in the earth's surface must induce detectable fluctuations in brightness, the amount of time that passes between the capture of many dates' worth of images is of the utmost importance. The date range of the datasets used in this investigation is 1988 to 2021, with the majority of the data being collected in March. This was done to avoid the seasonal influence by retaining the same month or season for the entirety of the investigation. In addition, the amount of time spent monitoring should be anywhere between three and four years so that the trend of the change can be easily identified.

Table 1: Table depicting the year, month and sensor of the datasets used for the study.

Sensor	Year	Month
Landsat 5 TM	1988	March
	1992	
	1996	
	2001	February
	2005	April
	2008	
	2011	March
Landsat 8 OLI/TIRS	2014	
	2018	
	2021	

3. METHODOLOGY AND ANALYSIS



3.1 Procedure

Using multitemporal Landsat (MSS, TM, ETM+, and OLI) images from a variety of years, we conducted a quantitative analysis of the changes that occurred along the coastline between 1988 and 2022. (Table). Each of these photos was obtained by downloading separate bands from the Earth Explorer archives that were given by the USGS. Only one band of the image, such as band 5 for TM imagery, which can differentiate between land and water, is used for the digitization of the shorelines. This helps ensure that the data is accurate. A further benefit of the land-water boundary was that it made it easier to track changes in the FCC's shoreline.

3.2 Shoreline analysis in DSAS

The USGS estimates shoreline changes using the digital shoreline analysis system (DSAS) version 5.0, an ArcGIS extension. The procedures included prepping the beach, creating a baseline, constructing a transect, and determining how quickly the shoreline was changing (Nithu Raj et al. 2020). A personal geodatabase has a single shapefile including digitalized shorelines from various years. The coast image has been modified so that the date is displayed in the format MM/DD/YYYY and the baseline is displayed in the metre coordinate system. DSAS employed baseline measurements of a time series of shorelines to estimate rates of change and required an additional shapefile in the same personal geodatabase (Leatherman and Clow 1983). The most basic tool was the default parameter, and the process of creating a transect began with selecting the preferred default parameters from the personal geodatabase. The baseline and shoreline settings, for example, were chosen as default parameters. We used DSAS's cast transects tool to place 1000-meter transects parallel to the beach every 100 metres along the whole shoreline, with a 50-meter smoothing space in between. The data from the transect feature class's 4,774 transects was utilised to determine the changes. In this study, we used the linear regression rate (LRR), the end point rate (EPR), and the net shoreline movement (NSM). Positive values for accretion and negative values for erosion were observed in the rates of coastline change (e.g. Nithu Raj et al. 2020).

3.3 Statistical analysis

The linear regression rate (LRR) is an estimation of the rate of variation that is obtained by applying the least-squares regression line to each point that is located along the shoreline of a transect (DSAS 5.0 user guide 2018). This method takes into account all of the data, regardless of whether the trend or the precision shifts. The recognised and proven statistical ideas of Dolan et al. (1991) and Crowell et alwidely. were applied to all of the computer calculations (1997). It is the most accurate method for estimating the future position of the shoreline and the confidence intervals that go along with it (Crowell et al. 1997; Douglas and Crowell 2000).

The term "net shoreline movement," or NSM for short, is a statistical metric that measures the actual distance between the shorelines that are considered to be the oldest and the shorelines that are considered to be the youngest along each transect that is placed perpendicular to the shorelines (DSAS 5.0 user guide 2018). It is possible to ascertain this by:

$$\mathbf{NSM = \{d_{2022} - d_{1988}\}m}$$

The end point rate (EPR) was calculated by dividing the total number of shoreline metres (NSM) by the amount of time that had passed since the oldest and most recent shoreline measurement (DSAS 5.0 user guide 2018). It requires the minimum values of two shoreline dates as well as additional information, such as erosion and accretion rates, magnitude, and cyclical trends, if these data are available. Additionally, it requires the minimum values of two shoreline dates (e.g., Dolan et al. 1991; Crowell et al. 1997). It is determined by the following formula:

$$\mathbf{EPR = \{d_{2022} - d_{1988} / t_{2022} - t_{1988}\} m/year}$$

4 RESULTS AND DISCUSSION

4.1 Statistical Analysis of Shoreline:

The statistical analysis of the Godavari shoreline can provide valuable information for understanding the behavior and changes in the coastline over time. The analysis can be carried out using various statistical techniques such as regression analysis, trend analysis, and change point analysis. Here are some possible steps that can be taken to conduct a statistical analysis of the Godavari shoreline:

4.1.1 Data collection

Collect and compile data on the position of the shoreline at different points in time. The data can be obtained from satellite images, aerial photographs, or field surveys.

4.1.2 Data preprocessing

Clean and preprocess the data to remove any outliers, errors, or gaps. This can be done using various techniques such as interpolation, smoothing, and filtering.

4.1.3 Trend analysis

Analyze the trend in the shoreline position over time using techniques such as linear regression, polynomial regression, or moving averages. This can help identify long-term trends in the shoreline position and the rate of change.

4.1.4 Change point analysis

Identify any significant changes in the trend of the shoreline using change point analysis techniques such as the Pettitt test or the Mann-Kendall test. This can help identify periods of stability or instability in the shoreline position.

4.1.5 Spatial analysis

Analyze the spatial distribution of the shoreline position to identify any spatial patterns or trends. This can be done using techniques such as spatial autocorrelation analysis or hotspot analysis.

4.1.6 Visualization

Present the results of the statistical analysis using various visualization techniques such as maps, charts, or graphs. This can help communicate the findings to stakeholders and decision-makers.

The statistical analysis of the Godavari shoreline can provide valuable insights into the behavior and changes of the coastline over time, which can inform coastal management and planning decisions. It is important to choose appropriate statistical techniques based on the research question and data availability and to interpret the results in the context of the specific coastal system being analyzed.

4.2 End Point Rate:

By dividing the distance of shoreline movement by the amount of time between the oldest and most recent shoreline, the end point rate (EPR) is determined. The simplicity of computation and the EPR's modest demand of just two shoreline dates are its main features. The drawback is that more information is frequently ignored when more data are available. Changes in sign (in other words, accretion to erosion), magnitude, or cyclical trends may be missed (Dolan and others, 1991; Crowell and others, 1997).

4.3 Linear Regression Rate:

A least-squares regression line can be fitted to all shoreline sites in a transect to produce a linear regression rate-of-change statistic. The offset distance of each data point from the regression line is squared, and the squared residuals are added to find the sum of the squared residuals, which is minimized. The slope of the line is the linear regression rate. The linear regression approach has the following characteristics: (1) it uses all the data, regardless of changes in trend or accuracy; (2) it is entirely computational; (3) the calculation is based on recognised statistical ideas; and (4) it is simple to apply (Dolan and others, 1991; Crowell and others, 1997).

4.4 Net Shoreline Movement:

Units are in metres because the net shoreline movement (NSM) is the separation between the oldest and youngest shorelines for each transect. The end point rate is obtained by dividing this distance by the interval between the two coastline location measurements.

Hence the Study area is divided into 6 different sectors so that the statistical analysis was studied in a detailed manner.

Table 2: Rate of change of shoreline

Category	Rate of shoreline change (m/year)	Shoreline classification
1	>-2	Very high erosion
2	>-1 and <-2	High erosion
3	>0 and <-1	Moderate erosion
4	0	Stable
5	>0 and <+1	Moderate accretion
6	>+1 and <+2	High accretion
7	>+2	Very high accretion

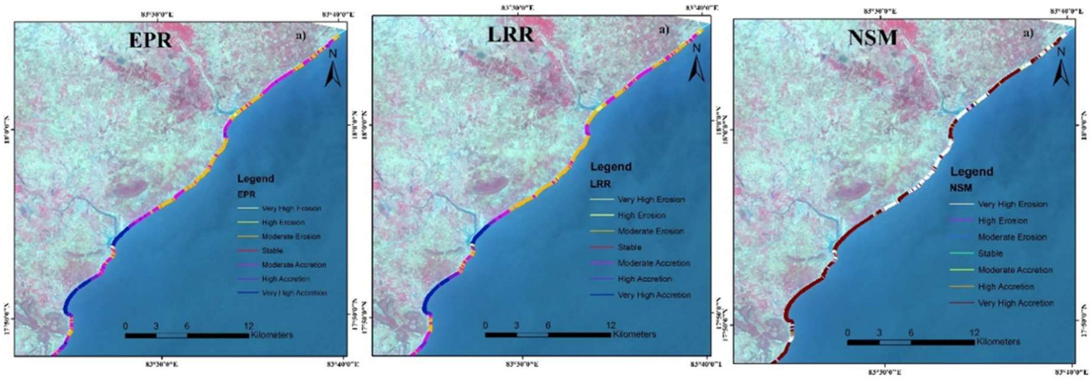


Figure 2 : Northern most part of the study region in which the EPR shows it covers with the Moderate Erosion & Moderate to Very High Accretions. The LRR also shows the similar trend as of EPR but the NSM shows that maximum of Very High Erosion & Very High accretion.

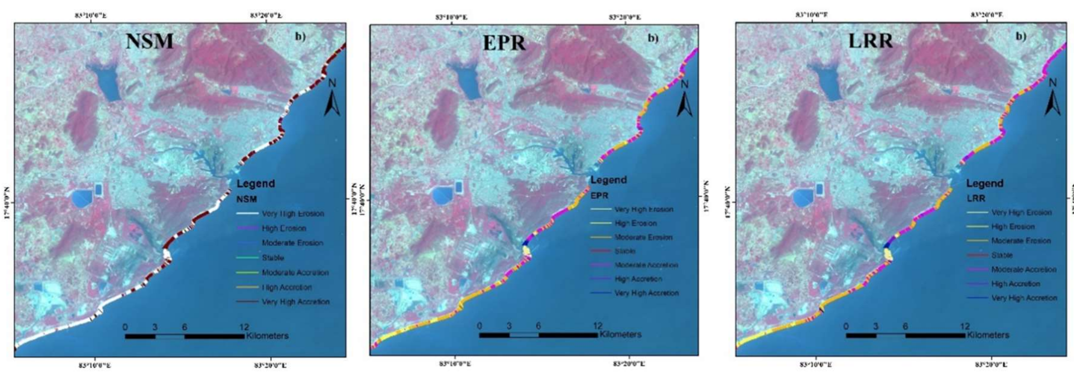


Figure 3 : The part next to the Northern most part of the study region in which the EPR shows it covers mostly with the Moderate Erosion & some with Moderate Accretions and few with High & Very High Accretions, the opening in this region shows Very Erosion due to its dynamic nature. The LRR also shows the similar trend as of EPR but the NSM shows that maximum of Very High Erosion & Very High accretion, very few regions with Moderate Erosion to High Accretion.

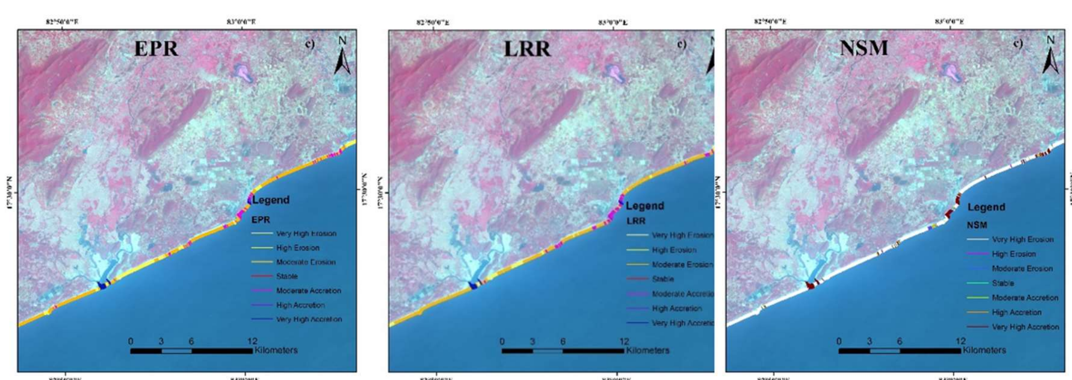


Figure 4 : In this part of the study region in which the EPR shows it covers with themostly with High & Moderate Erosion & some with Moderate Accretion and the opening of river area shows Very High Accretions since it is dynamic. The LRR also shows the similar trend as of

EPR but the NSM shows that maximum of Very High Erosion and few with Moderate Erosion to High Accretion & some with Very High accretion and also the opening of river in this shows Very High Accretion.

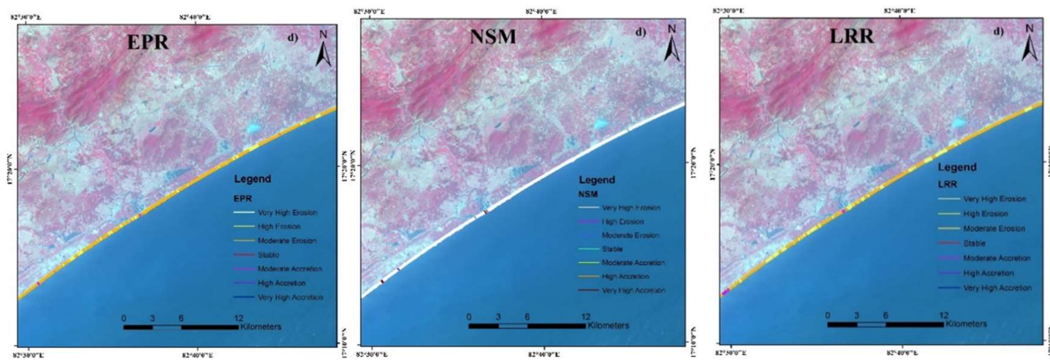


Figure 5: In this part of the study region in which the EPR shows it covers mostly with High & Moderate Erosion & very few with Moderate Accretion and the opening of river area shows Moderate Accretion since it is dynamic. The LRR also shows the similar trend as of EPR but the NSM shows that maximum of Very High Erosion and few with Very High accretion and also the opening of river in this shows both High Erosion & Very High Accretion.

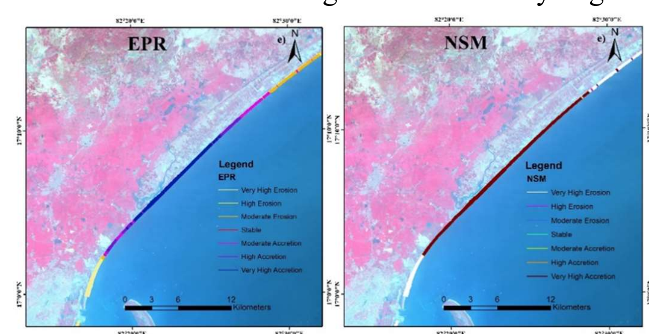


Figure 6: The part upper to the southern most part of the study region in which the EPR shows it covers mostly with Moderate to Very High Accretion next to that with the High to Moderate Erosion and the opening of river area shows Very High Accretions since it is dynamic. The LRR also shows the similar trend as of EPR but the NSM shows that maximum of Very High Accretion with Very High Erosion and also the opening of river in this shows Very High Accretion.

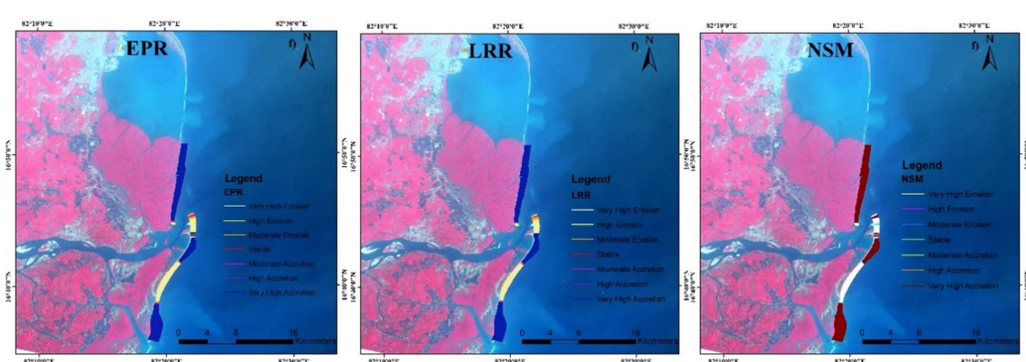


Figure 7 : The southernmost part of the study region in which all the EPR, LRR & NSM shows of the similar results with most of Very High Accretion and next to that with the Very High Erosion since it is a portion of land formed covering the Marshy area and is more dynamic in nature.

With all this from Figure 2 to Figure 7, it is observed that the EPR & LRR shows of the similar trend from Figure 2 to Figure 6 and only in the Figure 7 the same trend is seen merging with all the EPR, LRR & NSM. Hence it is observed that the region with similar slope variations the EPR & LRR shows of similar trend and in the dynamic regions all the three may results as like. Whereas in the river opening regions the Erosion and Accretion may varies because of its characters Wind, Wave currents, tides etc.

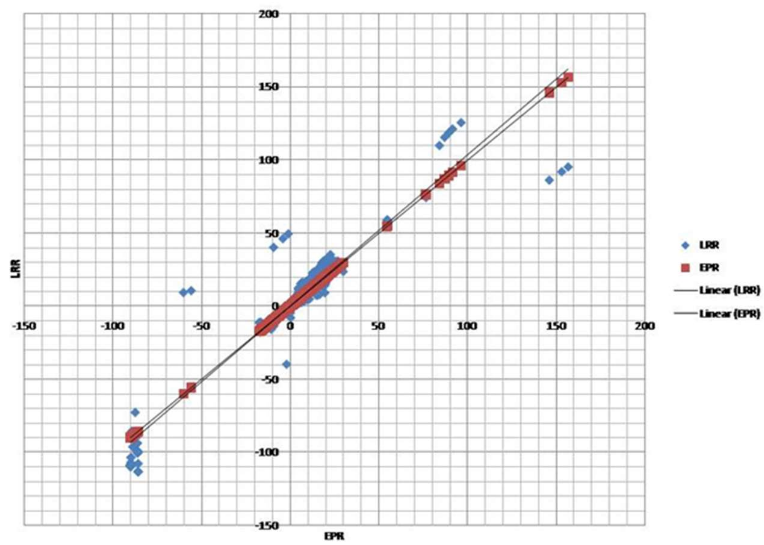


Figure 8 : Comparison between EPR vs LRR

EPR and LRR are two commonly used methods to calculate the rate of shoreline change. The main differences between EPR and LRR are the following

Calculation Method: EPR calculates the rate of change between two specific endpoints in time, while LRR calculates the average rate of change over a linear segment of shoreline over a given period.

Sensitivity to data: EPR is more sensitive to data outliers and variability, while LRR is more stable and less sensitive to short-term fluctuations in the shoreline.

Data requirements: EPR requires data for two specific points in time, while LRR requires data for a continuous linear segment of shoreline over a given time period.

Spatial scale: EPR is better suited for analyzing short-term shoreline changes at a local scale, while LRR is better suited for analyzing long-term shoreline changes at a regional scale.

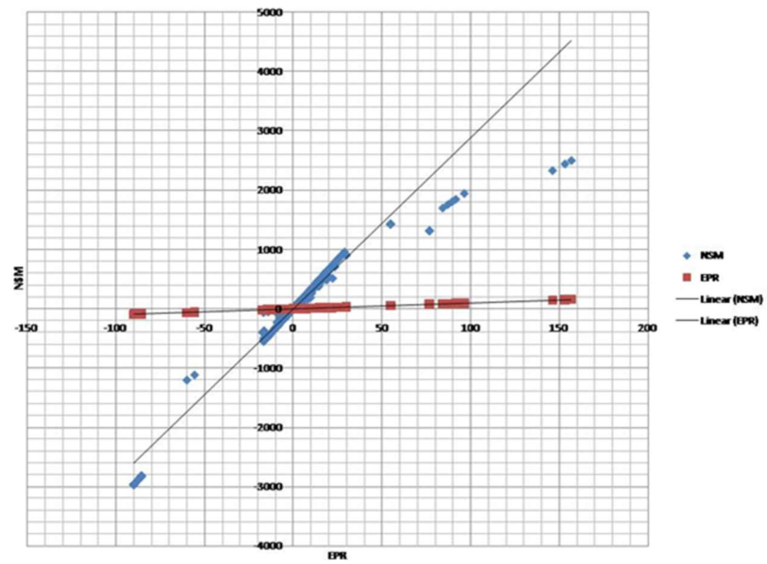


Figure 9 : Comparison between EPR vs NSM

EPR and NSM are two different methods to calculate shoreline change rates. The main differences between EPR and NSM are:

Calculation Method: EPR calculates the rate of change between two specific endpoints in time, while NSM calculates the difference between the average position of the shoreline in two different time periods.

Sensitivity to data: EPR is more sensitive to short-term fluctuations and variability in shoreline position, while NSM is less sensitive to short-term changes but can capture longer-term trends.

Data requirements: EPR requires data for two specific points in time, while NSM requires data for two longer periods of time.

Spatial scale: EPR is better suited for analyzing short-term shoreline changes at a local scale, while NSM is better suited for analyzing longer-term changes at a regional scale.

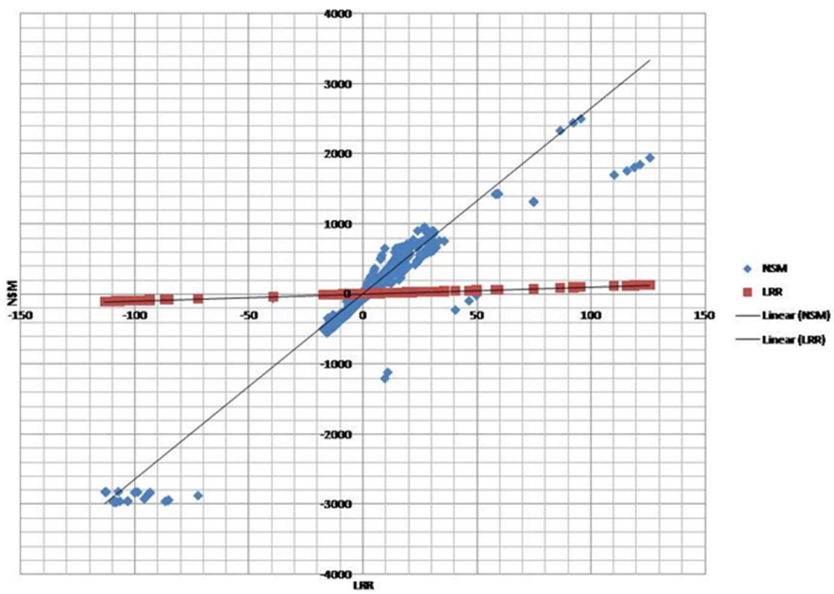


Figure 10 : Comparison between LRR vs NSM

LRR and NSM are two commonly used methods to calculate the rate of shoreline change. The main differences between LRR and NSM are:

Calculation method: LRR calculates the average rate of change over a linear segment of shoreline, while NSM calculates the difference between the average position of the shoreline in two different time periods.

Sensitivity to data: LRR is more sensitive to short-term fluctuations and variability in shoreline position, while NSM is less sensitive to short-term changes but can capture longer-term trends.

Data requirements: LRR requires data for a continuous linear segment of shoreline over a given time period, while NSM requires data for two longer periods of time.

Spatial scale: LRR is better suited for analyzing short-term shoreline changes at a local scale, while NSM is better suited for analyzing longer-term changes at a regional scale.

In this comparison it is observed that the EPR & LRR correlates with each other but the NSM doesn't correlates with both EPR & LRR.

5 CONCLUSION

Shoreline analysis in the Digital Shoreline Analysis System (DSAS) of Godavari would involve using remotely sensed data such as satellite imagery to measure changes in the shoreline over time. This analysis can help to identify areas of erosion or accretion, which can be useful for coastal management and planning. The DSAS software can be used to extract the shoreline from the imagery and then calculate the rates of shoreline change. This information can be used to identify areas of vulnerability and inform decisions about how to manage and protect the coastline.

EPR involves measuring the change in the position of the shoreline between two points in time and calculating the average rate of change. LRR involves fitting a straight line to the shoreline positions at multiple points in time and calculating the rate of change over the entire time period. NSM involves calculating the difference between the endpoints of the shoreline at different points in time. LMS is a statistical method that involves identifying the median of the differences between the shoreline positions at different points in time.

There is no one "best" method for shoreline analysis as each method has its own strengths and limitations. Here is a comparison of the four methods you mentioned:

EPR is a simple and straightforward method that is easy to calculate and interpret. It provides a good estimate of the average rate of shoreline change between two points in time. However, it assumes that shoreline change is linear and may not capture short-term fluctuations or non-linear trends.

LRR is also a simple method that fits a straight line to the shoreline positions at multiple points in time, providing an estimate of the average rate of change over the entire time period. It is more robust than EPR and can capture longer-term trends. However, like EPR, it may not capture short-term fluctuations or non-linear trends.

NSM is more sensitive to short-term changes than EPR and LRR, making it a useful method for identifying areas of high erosion or accretion. It provides a good estimate of the net change in the shoreline position between two points in time, but may not capture longer-term trends or non-linear changes.

LMS is a statistical method that can handle outliers and is more robust than EPR, LRR, and NSM. It provides a good estimate of the median change in shoreline position between two points in time, making it useful for identifying trends and patterns in the data. However, it is more complex to calculate and may not be necessary for all types of shoreline analysis.

Based on the findings of shoreline analysis using DSAS, the following protection strategies can be considered for the Godavari coast:

Beach nourishment: This involves adding sand to eroded beaches to restore or enhance their width and volume. DSAS can help identify areas that require beach nourishment.

Living shorelines: This approach involves using natural materials, such as vegetation and shells, to stabilize shorelines and promote natural processes of accretion. DSAS can help identify areas where living shorelines may be appropriate.

Hard infrastructure: Structures such as sea walls, groins, and breakwaters can be used to protect shorelines from erosion. However, these approaches may have negative impacts on natural processes and habitats.

Managed retreat: In some cases, it may be necessary to move infrastructure and development away from vulnerable areas. DSAS can help identify areas where managed retreat may be appropriate.

Coastal regulations and zoning: Regulations and zoning can be put in place to limit development in vulnerable areas and promote sustainable use of coastal resources. DSAS can help identify areas where regulations and zoning may be appropriate.

It is important to note that protection strategies should be tailored to the specific conditions and needs of the Godavari coast, and should involve collaboration between stakeholders and communities.

Declaration of interest: none

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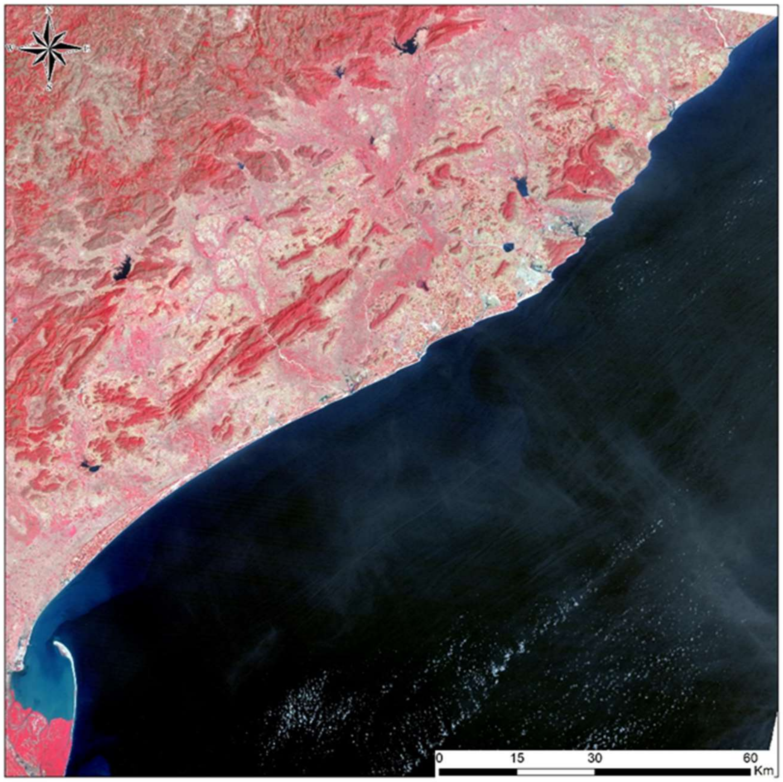

Figure 1: The full length of the coast taken for the current study.