Automated Extraction of Satellite-Derived Shoreline Changes along the Ongole Coast of Andhra Pradesh from 2000 to 2023 Using CoastSat

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Abstract: *This paper presents a fully automated methodology for extracting time-series of monthly shoreline changes along the sandy beaches of the Ongole coast in Andhra Pradesh, India, from 2000 to 2023 using publicly available satellite imagery. The methodology involves the identification of sandy coastline sections within the region of interest, creating cross shore transects automatically at each site, and utilizing the open-source global shoreline mapping toolbox called CoastSat. The CoastSat tool is employed to extract time-series of shoreline change at each transect. To account for variations in tide levels among satellite images, the final step includes tidally correcting the shoreline change time-series using predicted tide levels and an image-derived estimation of the average intertidal beach slope.*

Keywords: - *satellite imagery, shoreline change, Ongole coast, Andhra Pradesh, CoastSat, automated methodology, time- series analysis, and tide correction.*

1. Introduction:-

Coastal areas are dynamic environments that experience ongoing changes due to natural processes and human activities. Monitoring shoreline changes is essential for understanding coastal evolution and implementing effective management strategies. This paper presents a fully automated methodology for extracting time-series data of monthly shoreline changes along the sandy beaches of the Ongole coast in Andhra Pradesh, India, from 2000 to 2023. The study utilizes publicly available satellite imagery and leverages a novel open-source tool called CoastSat to analyse and interpret the shoreline dynamics. The methodology begins by identifying the sandy coastline sections within the region of interest. Advanced image processing techniques are employed to automatically detect these sections, ensuring accurate and consistent identification across the study area. Once the coastline sections are identified, cross shore transects are automatically generated at each site for detailed analysis. These transects serve as reference lines for monitoring the shoreline positions over time.

CoastSat, an open-source global shoreline mapping toolbox available on GitHub, is employed to extract time-series data of shoreline change at each cross shore transect. By utilizing satellite imagery from different time periods, CoastSat provides a reliable and efficient means of quantifying shoreline movements. The tool employs robust algorithms to determine shoreline positions, accounting for various factors such as image quality, shoreline complexity, and topographic variations. One of the challenges in analysing shoreline changes from satellite imagery is the influence of tidal fluctuations during image acquisition. To address this, the methodology incorporates a tidal correction process. Predicted tide levels and an image-derived estimation of the average intertidal beach slope are utilized to normalize the shoreline change time-series. This correction ensures that the extracted data accurately represents the underlying shoreline dynamics, independent of tidal conditions during image capture.

The availability of a growing archive of publicly accessible satellite imagery has provided researchers with valuable resources for studying shoreline dynamics. These medium-resolution multispectral images, with pixel sizes ranging from 10-30 meters, offer a high temporal frequency, typically between 5 days and 2 weeks, spanning from 2000 to the present day. Advancements in cloud computing tools, such as Google Earth Engine, and the development of sub- pixel resolution algorithms have significantly enhanced the efficiency of accessing satellite data and extracting shoreline positions. The combination of readily available satellite imagery, advanced image analysis methods, and the CoastSat toolbox presents an innovative and reliable approach for extracting detailed shoreline information. This methodology enables the capture of high-resolution temporal changes and provides valuable insights into coastal dynamics at various spatial and temporal scales.

The main purposes of this study are to (1) detect shoreline changes using 'CoastSat' software which is an open source and python-based program (Vos et al. 2019a), (2) The construction of ports influences changes in the shoreline along the study area and (3) A comparison between shoreline changes measured through field measurements and shoreline changes obtained using CoastSat software along the East coast of Andhra Pradesh.

2. Study Area:-

The study area for this research focuses on the sandy beaches along the Ongole coast of Andhra Pradesh, India. The Ongole coast is located on the eastern coast of India and stretches over a specific geographical region that encompasses several sandy beach sections. The Ongole coast is selected as the study area due to its significance in terms of coastal dynamics and the need for monitoring shoreline changes in this region. The coast is subjected to various environmental factors that drive both rapid advances and retreats of the shoreline, as well as longer- term erosion/accretion trends. Understanding the variability and evolution of the Ongole coast is crucial for coastal engineers, managers, and researchers involved in coastal management and policy-making.

By focusing on the sandy beaches of the Ongole coast (Kothapatnam Beach and Ramayapatnam Beach), this study aims to provide a comprehensive analysis of the shoreline changes that have occurred in the region from 2000 to the present day. The study area's specific location and characteristics make it an ideal case for investigating the applicability and effectiveness of the methodology outlined in the research.

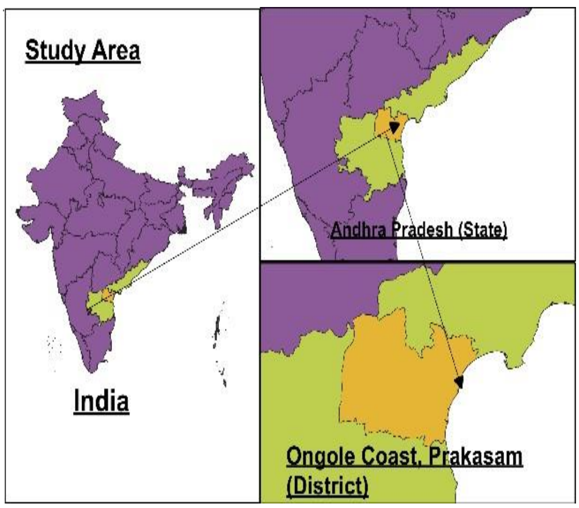


Figure 2.1 Location map of beaches along the Ongole coast **Figure** 2.2 Location map of Kothapatnam Beach

Figure 2.3 Location map of Ramayapatnam Beach

3. Methodology

For this study, three beaches, namely Kothapatnam Beach and Ramayapatnam Beach, were chosen on the Ongole coast of Andhra Pradesh, considering them as the most dynamic and widely used shorelines in the area (Fig 2.1, Fig 2.2 & Fig 2.3).

3.1 Shoreline Change Detection

In this analysis, the open-source software 'CoastSat' toolkit was utilized to extract shoreline positions for the study areas, namely Kothapatnam Beach and Ramayapatnam Beach. 'CoastSat' is a Python-based program capable of obtaining time-series of shoreline positions (with a horizontal accuracy of approximately 10 m) in any coastal zone worldwide. It does so by using publicly available satellite images archived in Google Earth Engine (GEE) over a span of more than 30 years (Vos et al., 2019a, b).

To derive shoreline positions from the 'CoastSat' software in the coastal zones, the following satellite images were used: Landsat-5, Landsat-7, Landsat-8, Landsat-9, and Sentinel-2. These images are archived in the GEE (Table 1). Particularly, Sentinel-2 satellite images, available since 2015, offer a spatial resolution of 10 m in the Red, Green, Blue, Near Infra-Red (NIR) bands, and 20 m in the Short Wave Infra-Red 1 (SWIR1) band. These images were chosen for this study because of their enhanced spatial resolution compared to Landsat images (30 m), making them most suitable for accurate shoreline detection and extraction.

Previous studies have shown that traditional medium spatial resolution satellite images, like Landsat-8 with 30 m spatial resolution, are effective for mapping regional-scale landscape elements (Amaro et al., 2015; Goncalves and Awange, 2017; Parrish et al., 2005; Saleem and Awange, 2019; Yu et al., 2011). However, for more precise coastline information and a better understanding of shoreline changes, European Sentinel-2 satellite data with higher temporal resolution (5 days) and spatial resolution (10 m) have been utilized (Immitzer et al., 2018; Saleem and Awange, 2019; Topouzelis et al., 2016; Yang and Li, 2012). Research based on the analysis of shoreline changes using Sentinel-2 satellite images from 2015 to 2020 in various locations has demonstrated that the average shoreline changes are comparable to actual field-based measurements (Astiti et al., 2019; Cabezas-Rabadán et al., 2019; Mitri et al., 2020; Saleem and

Awange, 2019). This highlights the reliability and accuracy of using Sentinel- 2 data for studying shoreline dynamics.

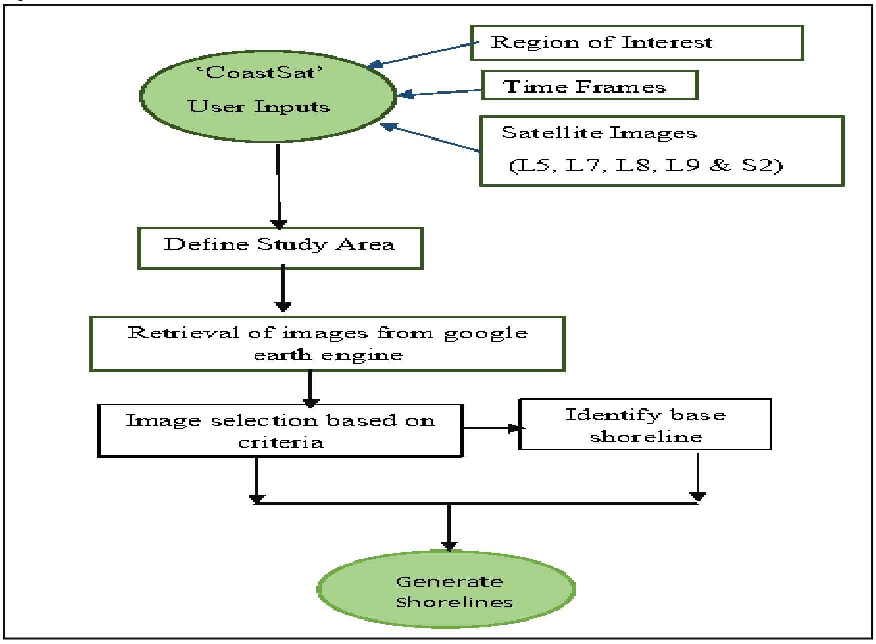


Figure .3.1 Flow chart outlining the functionalities of Coastsat.

Figure 3.1 illustrates the flowchart depicting the step-by-step process of obtaining a satellite-derived shoreline for a user-defined region of interest (ROI) using the 'CoastSat' toolkit. The process begins with the user inputting necessary information into 'CoastSat,' including the ROI, desired dates for satellite image retrieval (start date and end date), and the choice of satellite mission (Landsat and/or Sentinel-2).

Next, the toolkit retrieves and downloads a time-series of satellite images from Google Earth Engine (GEE) along with their metadata. These downloaded images undergo pre-processing to eliminate cloud pixels and enhance spatial resolution through cloud masking and panchromatic image sharpening and down-sampling methods, respectively. After pre-processing, the shoreline positions are extracted from the images. The pre-processed images are then classified into four spatial classes: sand, water, white-water, and other land features, using a supervised classification method. Subsequently, sub-pixel resolution border segmentation is performed to extract the boundary between sand and water (also known as the instantaneous shoreline). This step utilizes the Modified Normalized Difference Water Index (MNDWI) applied to each classified image.

To establish the reference shoreline, one of the cloud-free, pre-processed, and classified images is selected. The user has the option to manually digitize the reference shoreline in 'CoastSat,' and the coordinates of this reference shoreline serve as a basis for subsequent shoreline demarcation and assist in identifying outliers and false detections. Following the establishment of the reference shoreline, the shoreline detection process commences within the defined ROI. Shore-normal transects are created on the extracted shorelines to determine the time- series of cross-shore distance, which is saved as a *.csv file. In the analysis, a tidal correction was applied to all extracted shorelines using a time-series of water-level data obtained from the University of Hawaii Sea Level Centre (http://www.ioc-sealevelmonitoring.org/map.php). The sand-water boundary of the classified satellite image extracted at a specific tidal stage is treated as the instantaneous shoreline position, as described by Vos et al. (2019a). However, using the instantaneous shoreline positions directly for inter-comparison of shorelines is not suitable due to variations in tidal stages.

After the pre-processing and classification steps, 85 images were selected for shoreline analysis in Kothapatnam Beach, 72 images in Ramayapatnam Beach. The time gap between selected images was approximately 30 days, maintaining a constant interval for accurate shoreline change analysis in each location. Within the 1 km-long coastline of each study area, four shore-normal transects were defined at approximately equal distances (as shown in Fig. 3). Tidal corrections were applied to the extracted shorelines in each location. Subsequently, time-series of cross-shore distances along the shore-normal transects, from landward to seaward, were determined. The resulting data files were saved in MS-Excel *.csv format through 'CoastSat.' Finally, the time-series of shoreline changes along each transect were plotted on a graph using the MS-Excel *.csv data files for analysis. The accuracy of shoreline position extracted by ‘Coast-Sat’ was verified by comparing it with the shoreline field survey data.

4.0 Results and Discussion

4.1 Comparison of Shoreline Positions: 'CoastSat' vs. Field Observations

The average horizontal difference between shoreline positions extracted by 'CoastSat' and field observations was found to be 7.5 ± 1 meters in Kothapatnam Beach on 20 August 2022 and 8.3 ± 1 meters on 10 July 2023 (Fig. 4). It is important to note that the obtained error margin (6-9 meters) was less than the horizontal accuracy of coastline positions provided by 'CoastSat' (approximately 10 meters). As a result, the horizontal difference of shoreline positions between 'CoastSat' and field observations falls within an acceptable range.

4.2 Kothapatnam Beach: Seasonal Morphological Variations

The shoreline change analysis was conducted by comparing the shorelines of Kothapatnam Beach between March 2000 and March 2023, using two sets of satellite images with different spatial resolutions: Sentinel-2 Multi- Spectral Instrument (MSI) images with a high resolution of 10 meters and Landsat 5, 7, 8, and 9 satellite images with a coarser resolution of 30 meters. The Sentinel-2 MSI images provided a detailed and precise view of shoreline changes over the 23-year period, identifying small-scale coastal processes. On the other hand, Landsat images, with their coarser resolution, captured large-scale coastal features and changes during the same period.

4.2.1 Field Measurement:-

The field survey during the Monsoon season reveals significant volume variations along the beach transects. The maximum erosion is observed at beach transect point 06–07, with a volumetric loss of approximately -3887.44 m3 per month. On the other hand, the maximum deposition is observed at beach transect point 08–09, with a volumetric gain of approximately +5242.68 m3 per month. These observations indicate the dynamic nature of sediment movement and the contrasting processes of erosion and deposition during the Monsoon season.

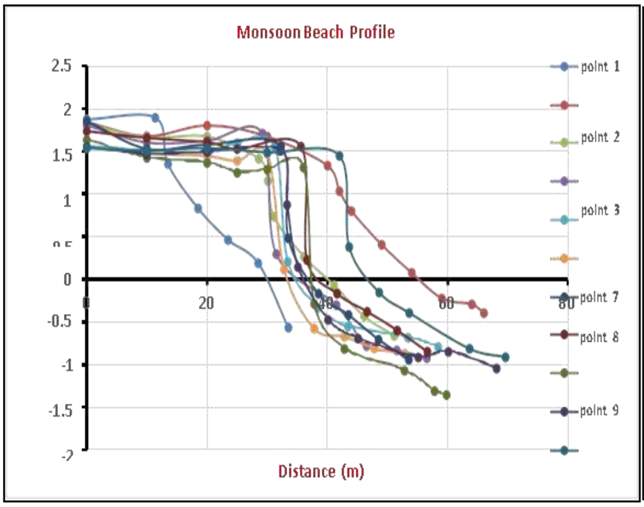
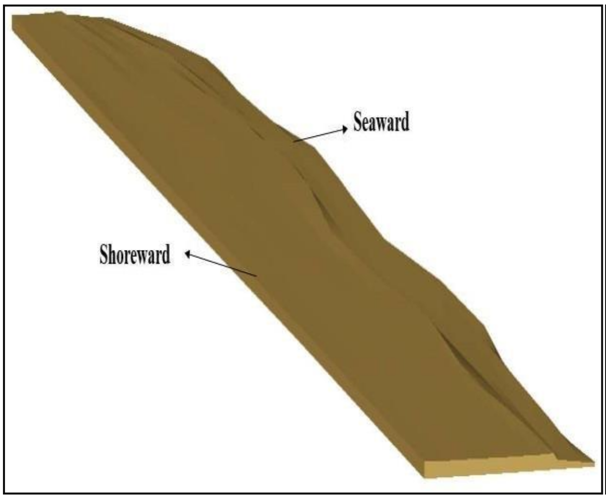


Figure .4.1 Monsoon Beach Profile at Kothapatnam Beach **Figure** .4.2 Beach survey at Kothapatnam coastline

In the figure 4.5, positive values above the X-axis indicate accretion, meaning that during this time, the beach experienced sediment deposition and shoreline advancement seaward. On the other hand, negative values below the X-axis indicate erosion, indicating that the beach experienced a retreat landward and loss of sand and sediment during this period. The 3D model presented in Figure 4.3 provides visualization of the coastal changes.



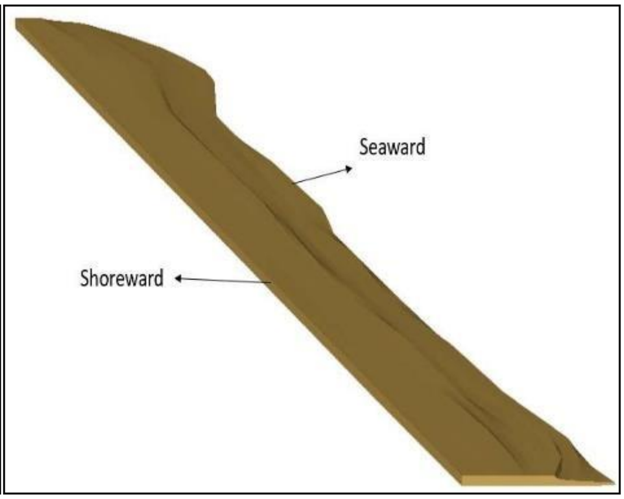


Figure .4.3 3D Beach Transect model Pre-monsoon Period

Figure .4.4 3D Beach Transect model Monsoon Period

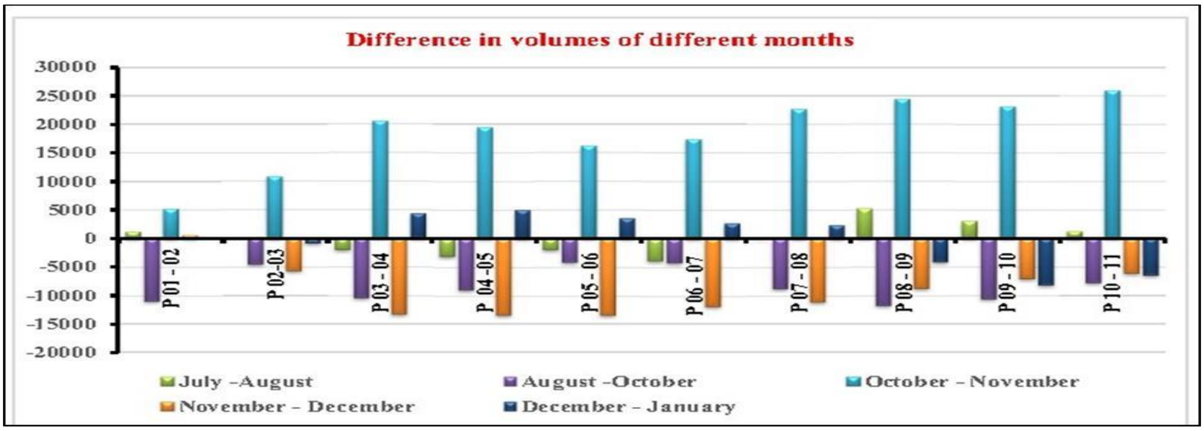


Figure .4.5 Difference in Volume of Monsoon and Post Monsoon

Based on the above figure, the comparison results of beach shoreline erosion and accretion are depicted for two time periods: July 2022 to August 2022 and October 2022 to January 2023. The figure illustrates the changes in shoreline position over these respective periods.

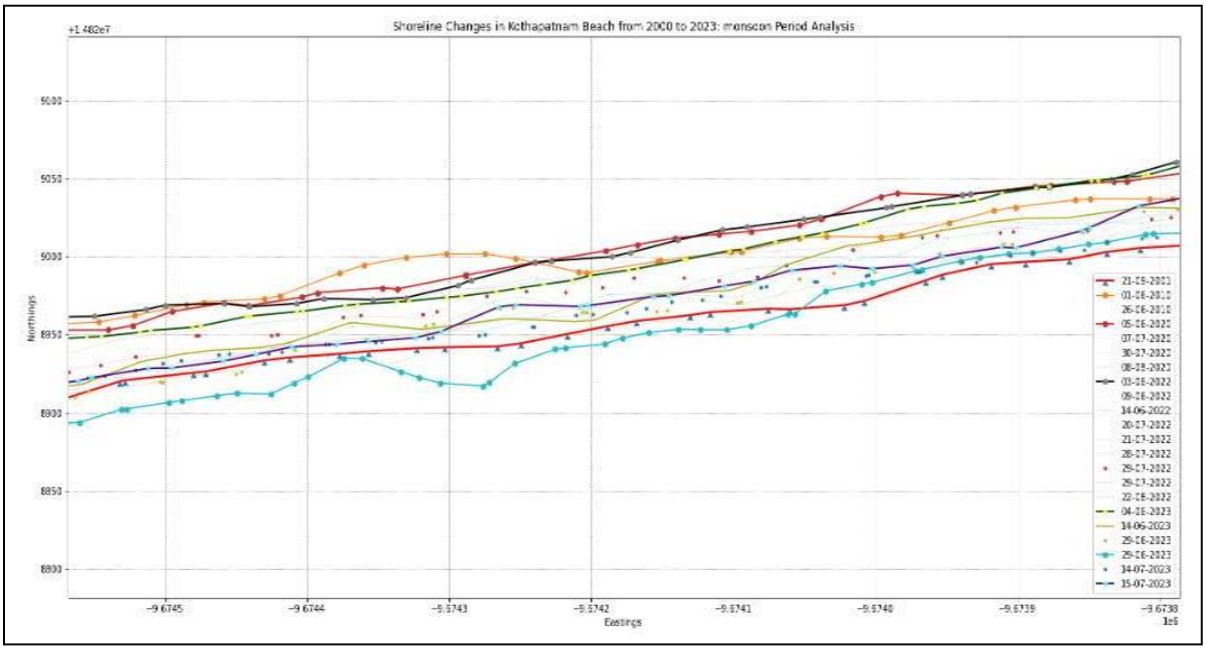


Figure .4.6 Shoreline Changes in Kothapatnam Beach from 2000 to 2023. (Coast Sat)

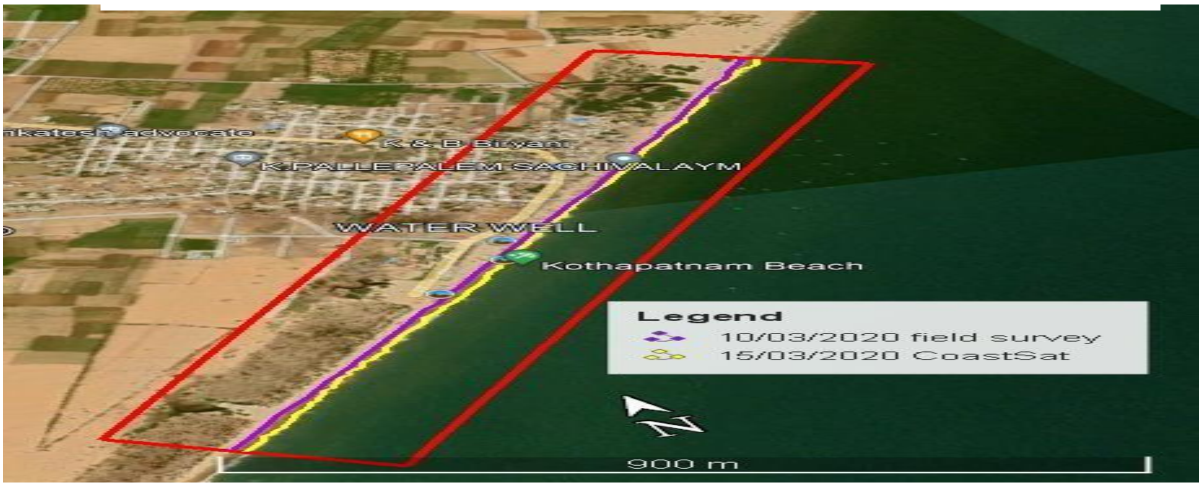


Figure .4.7 Comparison of Shoreline Positions: 'CoastSat' vs. Field Observations

During the pre-monsoon period, the shoreline changes that occurred in Kothapatnam Beach over the last three decades, showing a total shoreline change of 42 meters. During the pre-monsoon period, the maximum points of accretion was observed. Upon comparing the shoreline positions using CoastSat, it was observed that the same trends were followed as observed in the field observations.

4.2 Ramayapatnam Beach: *Influence of Port Construction on Shoreline Variation*

The analysis of shorelines extracted for the years 2000, 2010, 2020, and 2023, using CoastSat software, has revealed interesting patterns of shoreline changes near the port area at Ramayapatnam Beach. The study indicates that the coastline in this region has experienced both erosion and accretion over the years. The shoreline change rate for the Ramayapatnam coastline is estimated to be -3.2354 meters per year. This negative value suggests an overall trend of shoreline retreat or erosion during the study period.

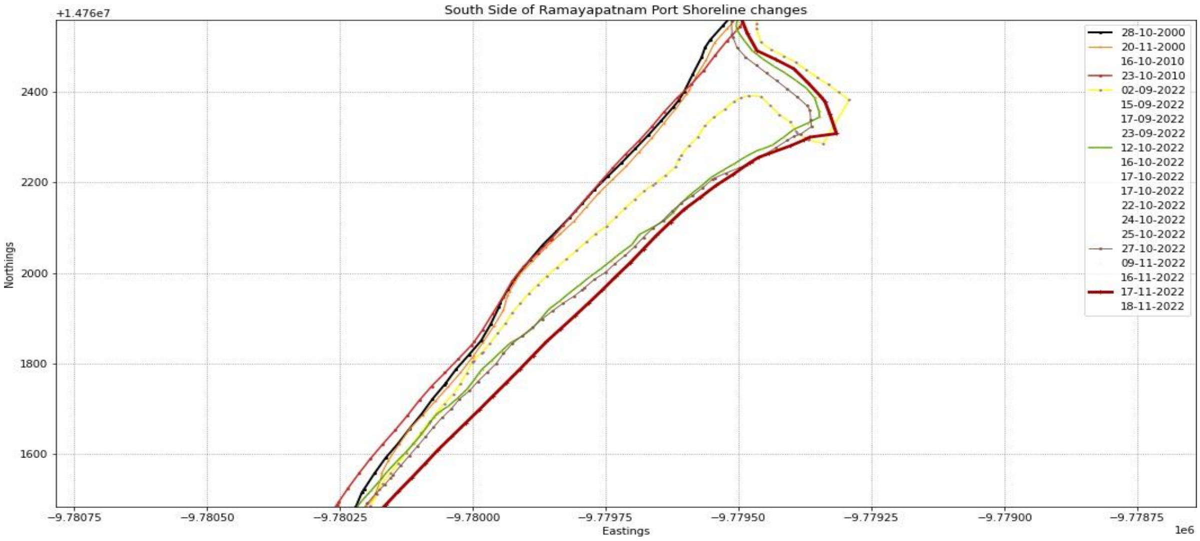


Figure .4.5 South Side of Ramayapatnam Port Shoreline changes

Despite the dynamic nature of sediment transport along the Ramayapatnam coast, the coastal area near the port has shown a net loss of land over time. The study further reveals that the coastal region is in a state of dynamic equilibrium, where both erosion and accretion processes are observed along the coast.

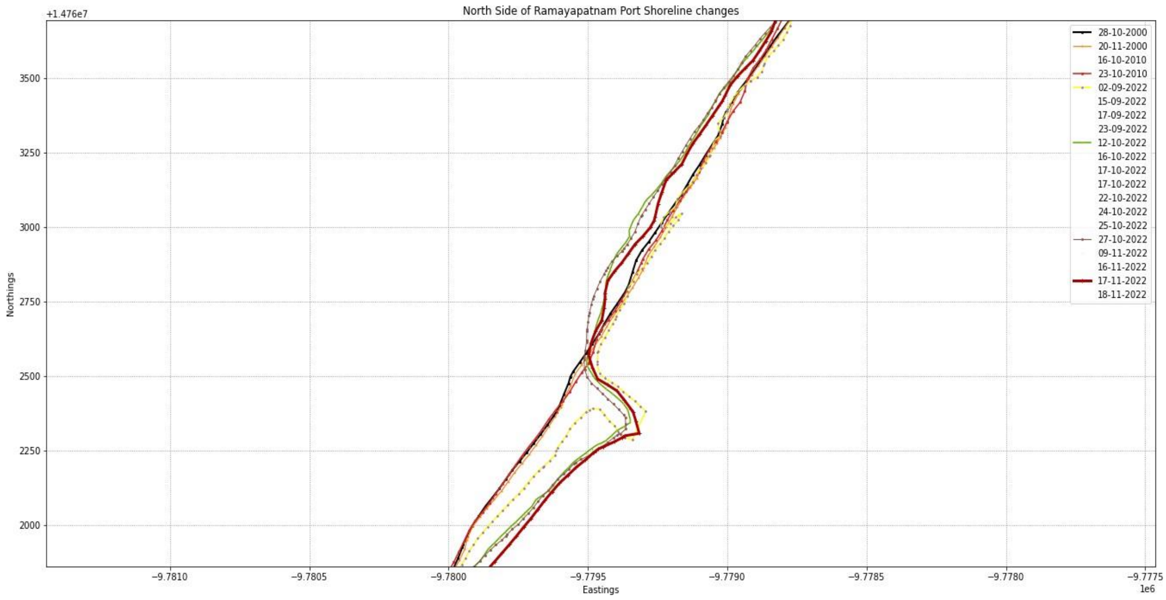


Figure .4.6 North Side of Ramayapatnam Port Shoreline changes

During the construction of the port and the completion of both breakwaters at Ramayapatnam, a significant pattern of shoreline changes was observed. Specifically, the northern side of the port experienced maximum erosion, while the southern side showed maximum accretion it show in fig 4.7.

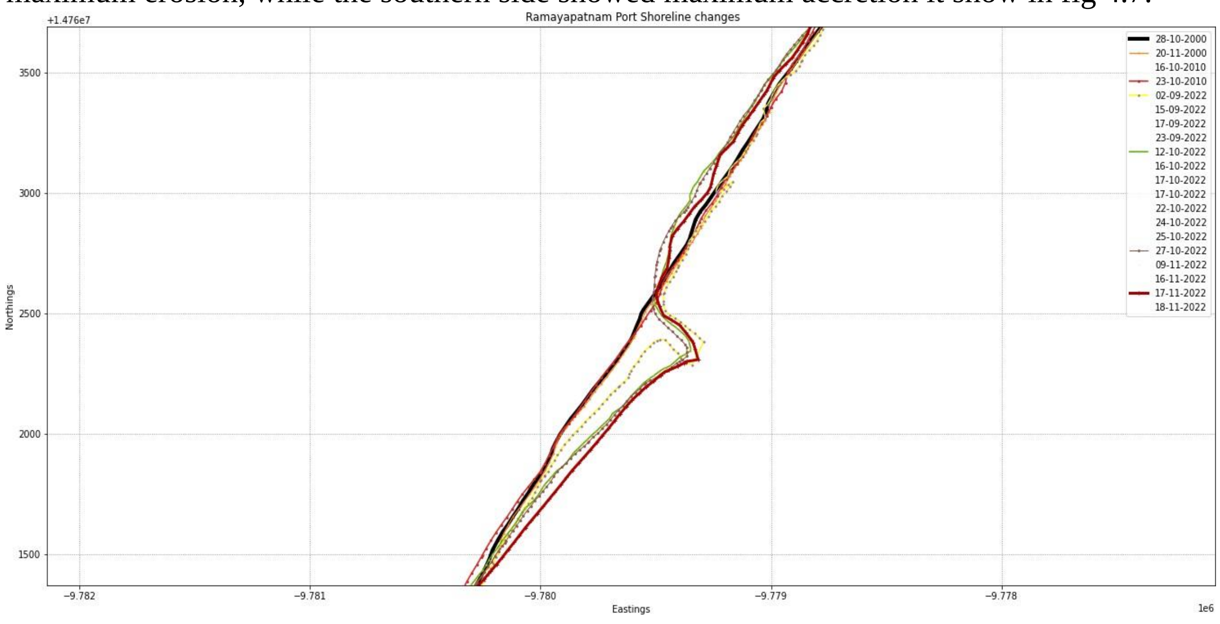


Figure .4.7 Ramayapatnam Port Area Shoreline changes

5. Conclusion

The time-series of shoreline positions extracted using 'CoastSat' software (v1.1.1) were utilized to investigate shoreline changes in three well-known beaches on the Ongole coast of Andhra Pradesh: Kothapatnam Beach and Ramayapatnam Beach. The study led to the following conclusions:

1. The average difference between shoreline positions obtained by 'CoastSat' and field observations was found to be 6-9 meters.
2. In the absence of long-term field measurements for coastal data, 'CoastSat' proved to be a valuable alternative method. This Google Earth Engine-enabled Python toolkit allowed for the extraction of shoreline positions and the detection of coastline changes, with proper tidal corrections. It can be applied to any coastal area worldwide for shoreline change detection.
3. The overall beach condition in the study area exhibited erosional and accretional trends of more than 12 meters, influenced by both monsoon seasonality and anthropogenic factors. Upon comparing the shoreline positions using CoastSat, it was observed that the same trends were followed as observed in the field observations.

4. Coastal erosion was particularly noticeable during the monsoon due to high-energy wave action, resulting in significant wave heights.
5. On the other hand, coastal accretion was evident during the Pre-monsoon characterized by calmer wave conditions and lower significant wave heights.
6. The construction of ports has had a significant impact on shoreline changes at Ramayapatnam Beach. As a result, the north side of the port experienced maximum erosion, while the south side of the port showed maximum accretion. The estimated shoreline change rate for the Ramayapatnam coastline is approximately
-3.2354 meters per year.

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