

Spatio-Temporal Analysis of Shoreline Change Along the Machilipatnam Coast Using Landsat Imagery and QGIS

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ABSTRACT

Shoreline analysis is an important aspect of coastal studies, as coastlines are continuously influenced by natural processes such as waves, tides, currents, and human activities. Monitoring these changes is essential for effective coastal management, environmental protection and sustainable development. This research work focuses on the analysis of shoreline characteristics along the Machilipatnam coast in Krishna District, Andhra Pradesh, using geospatial techniques. Landsat ETM + satellite imagery for the period 2018 to 2022 was used as the primary data source. The satellite data provides multispectral information with moderate spatial resolution, making it suitable for coastal analysis. The images were processed using QGIS software, where band combination and colour composite techniques were applied to enhance the visual distinction between land and water features. A layer stack approach was used to organize raster data for better interpretation. The shoreline was identified based on textural variations and digitized as a vector line layer. Additionally, the land and water regions were digitized as polygon layers to enable spatial analysis. Various GIS tools were used to calculate shoreline length and area measurements, allowing for systematic comparison across multiple years. This study demonstrates the effectiveness of integrating remote sensing and GIS techniques for shoreline mapping and analysis.

1. Introduction

A shoreline is the boundary where land meets water, such as oceans, seas and rivers. It is one of the most dynamic features of the Earth's surface, continuously changing due to natural processes like waves, tides, currents, and sediment transport. In addition to natural forces, human activities such as coastal development, urbanization, port construction and resource utilization also influence the shoreline behaviour. These interactions result in two major processes: erosion, which causes loss of land, and accretion, which leads to the deposition of sediments and formation of new land [1-2]. Coastal regions are highly significant as they support biodiversity, fisheries, tourism, and human settlements. However, they are also highly vulnerable to environmental changes such as sea-level

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rise, storms and climate change. Monitoring the shoreline changes is therefore essential for understanding coastal dynamics and ensuring sustainable coastal management [3-4]. It helps in identifying vulnerable areas, assessing risks and planning effective coastal protection measures. The analysis of shoreline changes is carried out to understand how coastal regions evolve over time and to identify the patterns of erosion and accretion. This is especially important for regions like Machilipatnam, which are low-lying and prone to coastal hazards such as flooding and sediment shifts. By studying shoreline position, land area and water extent over multiple years, this project provides useful information for disaster management, environmental protection and coastal zone planning. It also supports the decision-making for infrastructure development and conservation of coastal ecosystems [5-6]. In this research work, the study area is the Machilipatnam coast, located in Krishna District, Andhra Pradesh, India, along the Bay of Bengal. This region is characterized by flat coastal terrain, river mouths and sediment deposition zones, making it highly dynamic and suitable for shoreline change analysis. The coastline in this area undergoes continuous changes due to natural coastal processes and environmental conditions. The data used for this study was obtained from Landsat ETM+ (Enhanced Thematic Mapper Plus) satellite imagery for the years 2018 to 2022. These images were collected from publicly available sources such as the United States Geological Survey (USGS). Landsat ETM+ provides multispectral data with a spatial resolution of 30 meters, which is suitable for identifying and analysing land and water features [7-8].

The satellite images were processed using QGIS software, an open-source Geographic Information System. Image preprocessing techniques such as band combination and colour composition were applied to enhance the visual distinction between land and water areas. A layer stack approach was used to manage raster data efficiently. The shoreline was then detected based on the tonal variations and digitized as a line layer. Similarly, land and water areas were digitized as polygon layers to enable spatial analysis. Further, GIS tools were used to calculate shoreline length, land area, and water area for each year. These measurements help in understanding spatial changes and trends over time. The use of Remote Sensing and GIS techniques provides an accurate, efficient, and cost-effective method for analysing large coastal regions compared to traditional field-based methods [9-10]. Thus, this project demonstrates the effective use of geospatial technologies for shoreline analysis. It provides valuable insights into coastal changes and supports better planning, management, and conservation of coastal environments. Coastal regions are highly dynamic and continuously influenced by natural processes such as waves, tides, and sediment movement, as well as human activities. These changes can lead to shoreline erosion and accretion, affecting coastal ecosystems, infrastructure, and nearby communities. Understanding these changes is essential for protecting coastal areas and ensuring sustainable development. The Machilipatnam coast, being a low-lying and sensitive region along the Bay of Bengal, is particularly vulnerable to coastal changes such as flooding, land loss, and sediment deposition. However, the continuous monitoring of such changes is often limited due to lack of data and resources. With the availability of satellite imagery and open-source of GIS tools like QGIS, it has become possible to analyse the shoreline changes efficiently and accurately [11-12].

This research is motivated by the need to utilize these technologies to study coastal dynamics, identify patterns of change, and provide useful information for coastal management and planning. The study also aims to demonstrate how Remote Sensing and GIS can be effectively used by students and researchers to analyse real-world environmental problems in a cost-effective and systematic manner. The main objectives of this research works are study and understand the concept of shoreline and its dynamic nature [13-14]. To collect and utilize Landsat ETM + satellite data for the years 2018 to 2022 and process the satellite images using QGIS software through the band

combination and colour composition techniques. To identify and detect the shoreline along the Machilipatnam coast and digitize the shoreline as a line layer and land and water areas as polygon layers to calculate the shoreline length for each year. To estimate the land area and water area using GIS tools and analyse changes in shoreline position, land and water extent over multiple years. To identify coastal processes such as erosion and accretion and demonstrate the application of Remote Sensing and GIS in coastal monitoring and management. A shoreline is the boundary between land and water, such as oceans, seas, rivers, or lakes. It represents one of the most dynamic and constantly changing natural features on the Earth's surface. Shorelines are continuously modified by natural processes such as wave action, tidal variations, ocean currents, and sediment transport. In addition to these natural forces, human activities such as coastal development, urbanization, construction of ports, and other infrastructure also influence shoreline behaviour. Shoreline changes occur in the form of erosion and accretion [15-16]. Erosion refers to the removal or loss of land due to the action of waves and currents, while accretion refers to the deposition of sediments that results in the formation or expansion of land. These processes are influenced by the balance between sediment supply and energy of coastal forces, making shorelines highly sensitive to environmental changes. Shorelines play a vital role in supporting ecological, economic and social systems. They provide habitats for a wide variety of plant and animal species and support activities such as fishing, tourism, and transportation. Coastal regions are also densely populated, making shoreline stability important for protecting human settlements and infrastructure. However, shorelines are highly vulnerable to natural hazards such as storms, cyclones, flooding, and sea-level rise caused by climate change. These factors can lead to significant and sometimes rapid changes in shoreline position, increasing the risk to coastal communities and ecosystems [17-18].

Shoreline changes occur due to a complex interaction of natural processes and human-induced activities that continuously modify the coastal environment. The shoreline is not a fixed boundary; rather, it is dynamic and responds to various physical, environmental, and anthropogenic factors over time. Natural factors play a major role in shaping the coastline. Wave action is one of the primary forces responsible for erosion and deposition along the shore. Waves continuously strike the coastline, removing sediments from some areas and depositing them in others [19-20]. Tidal variations also influence shoreline position by causing periodic rise and fall in sea levels, which affects the extent of coastal inundation. Ocean currents contribute to the movement of sediments along the coast, a process known as longshore drift, which leads to the redistribution of materials and changes in shoreline configuration. Sediment transport is another key factor that controls shoreline stability. The availability and movement of sediments determine whether a coastline experiences erosion or accretion. Areas with high sediment supply tend to show land formation, while areas with limited sediment supply are more prone to erosion [21-22].

Climatic conditions further influence these processes, as seasonal changes and weather patterns can alter wave intensity and sediment movement. Extreme natural events such as cyclones, storms, and storm surges can cause sudden and significant changes in the shoreline. These events can lead to rapid erosion, flooding, and displacement of sediments, resulting in noticeable shifts in coastal boundaries within a short period. Additionally, long-term changes such as sea level rise due to global warming contribute to gradual shoreline retreat and increased vulnerability of coastal areas. Human activities also have a significant impact on shoreline changes [23-24]. Coastal development, including the construction of ports, harbours, seawalls, and other structures, can disrupt natural coastal processes and alter sediment flow. Sand mining and dredging reduce sediment availability, leading to increased erosion in certain regions. Urbanization and deforestation further disturb the natural balance of coastal ecosystems, making shorelines more susceptible to change [25-26]. In many cases,

the human interventions can either accelerate erosion or cause excessive sediment deposition, leading to accretion in some areas. The combined effect of natural and human factors results in continuous modification of the coastline, making it essential to monitor and analyse shoreline changes regularly understanding the causes of shoreline change is crucial for effective coastal zone management. It helps in identifying vulnerable areas, predicting future changes, and implementing appropriate measures for coastal protection, environmental conservation and sustainable development. The use of Remote Sensing and GIS techniques provides a reliable approach for studying these changes and supports informed decision-making in coastal planning [27-28].

2. Literature study of shorelines analysis

Shoreline change analysis is an essential aspect of coastal studies, as coastlines are highly dynamic and continuously influenced by both natural processes and human activities. The integration of Remote Sensing and Geographic Information Systems (GIS) has significantly improved the accuracy and efficiency of monitoring shoreline variations over time. Many researchers have used satellite data and geospatial tools to analyse the shoreline changes, identify erosion and accretion patterns, and support coastal management. Natarajan et al. conducted a detailed study on shoreline changes along the Cuddalore coast over the last five decades. The study utilized multi-temporal satellite imagery to analyse the long-term shoreline variations and employed statistical methods to predict future shoreline positions for the years 2030 and 2040. The research highlighted the importance of long-term monitoring in understanding coastal evolution and emphasized the need for proper coastal management strategies to minimize risks associated with shoreline changes [1, 29-30]. Gunasekaran et al. performed shoreline change analysis from Pondicherry to Point Calimere using the Digital Shoreline Analysis System (DSAS 5.0). The study used GIS-based tools to calculate shoreline movement rates and provided quantitative measures of erosion and accretion. The use of DSAS enabled accurate comparison of shoreline positions over time, demonstrating the effectiveness of combining statistical analysis with GIS for coastal studies. The Landsat 7 ETM + Data Users Handbook published by the U.S. Geological Survey (USGS) provides comprehensive information about Landsat satellite data, including spectral characteristics, spatial resolution, and radiometric properties. It also explains the processing and interpretation of satellite images for environmental applications. This reference is crucial for understanding how Landsat data can be effectively used for shoreline detection, land-water discrimination and temporal analysis [2, 31-32].

Reddy and Kumar presented a study on digital shoreline analysis using GIS techniques, focusing on extracting shoreline features from satellite imagery. The study explains the importance of accurate digitization, proper projection systems, and the use of GIS tools for calculating shoreline length and detecting changes over time. It highlights how spatial analysis can be used to compare shoreline positions across multiple years [4, 33-34]. Murthy and Nagarajan from NRSC and ISRO discussed the application of GIS and remote sensing in coastal zone management. Their study emphasizes the role of satellite data in monitoring environmental changes, assessing coastal vulnerability and supporting the sustainable development. It also highlights the importance of integrating geospatial data for effective planning and decision-making [5, 35-36]. Jain and Roy (2023) studied the use of remote sensing for shoreline monitoring using multi-temporal satellite data. The study demonstrated how repeated observations from satellite imagery can be used to track the shoreline movement and identify long-term trends in erosion and accretion [6, 37-38]. Jensen explained the application of remote sensing techniques for detecting coastal changes. The study emphasized the importance of using multi-date satellite data for understanding shoreline dynamics

and highlighted the role of image processing techniques in improving feature extraction. The QGIS Geographic Information System (Open-Source Geospatial Foundation) provides an open-source platform for processing and analysing geospatial data. It offers various tools for raster and vector data processing, digitization, and spatial analysis. QGIS is widely used in shoreline studies due to its flexibility, accuracy, and cost-effectiveness [8, 39-40]. Lilles and Kiefer, in his work on digital image processing discussed techniques for analyzing satellite images and extracting meaningful information from multispectral data. His work is widely used as a reference for image processing in remote sensing applications, including shoreline analysis. It provided a comprehensive overview of remote sensing principles and applications. Their work explains how satellite imagery can be used for environmental monitoring, land use analysis, and coastal studies, making it highly relevant for shoreline analysis [9-10].

3. Site Area Analysis

The study area selected for this project is the coastal region of Machilipatnam, located in Krishna District, Andhra Pradesh, India, along the Bay of Bengal. Geographically, this region lies on the eastern coast of India and is characterized by a low-lying coastal plain with sandy beaches, tidal flats, and river mouths. The flat terrain and proximity to the sea make this area highly dynamic and sensitive to shoreline changes. The Machilipatnam coastline is influenced by various natural processes such as wave action, tidal variations, ocean currents and sediment transport. These processes continuously reshape the coastal boundary, resulting in changes in shoreline position over time. Sediment deposition and removal play a key role in determining whether the region experiences erosion (loss of land) or accretion (gain of land). Seasonal variations and monsoonal patterns further influence these coastal processes. In addition to natural factors, climatic conditions significantly impact the study area [41-42]. The region is frequently affected by cyclones, storm surges, and heavy rainfall, which can cause rapid shoreline changes and coastal flooding. Sea-level rise due to climate change also contributes to long-term shoreline instability, increasing the vulnerability of the coastal zone. Machilipatnam coast holds significant ecological, economic, and social importance. It supports diverse coastal ecosystems and provides livelihood opportunities through fishing, agriculture, and small-scale industries. The region also plays an important role in local trade and economic activities. However, the area is highly vulnerable to coastal hazards such as flooding, land loss, erosion, and environmental degradation. These challenges make it essential to monitor and analyse shoreline changes regularly. Understanding the behaviour of coastline helps in identifying vulnerable zones, planning coastal protection measures, and ensuring sustainable development. Therefore, the selection of Machilipatnam as the study area is highly suitable for shoreline analysis, as it provides an opportunity to study coastal dynamics using Remote Sensing and GIS techniques and to support effective coastal management strategies [43-44].

3.1 Selected Site Analysis

The selected site for this study is located along the eastern coastline of India, specifically in the Machilipatnam region of Krishna District, Andhra Pradesh. This area lies adjacent to the Bay of Bengal and forms part of the coastal plains of southeastern India. The site falls under a tropical climatic zone, characterized by high temperatures, humidity and seasonal variations influenced by the southwest and northeast monsoons. The region experiences significant rainfall during monsoon seasons, which affects sediment transport and coastal processes. The presence of nearby river systems and deltaic

formations contributes to sediment deposition along the coast, playing an important role in shaping and modifying the shoreline. These factors make the site highly dynamic, where continuous interactions between land and water result in noticeable changes in coastal features. The terrain of the study area is predominantly flat and low-lying, which increases its vulnerability to coastal hazards such as flooding, storm surges, and sea-level rise. Even small environmental changes can lead to significant shifts in shoreline position, making this site highly sensitive and suitable for detailed coastal analysis [45-46].



Fig.1. Landsat map of study area Machilipatnam seashore

In this study, the Landsat ETM+ satellite imagery was used to analyze the selected site over multiple years from 2018 to 2022. In Fig. 1 shown that the Lansat map of study area at Machilipatnam seashore. The availability of consistent, multi-temporal satellite data enables effective monitoring of shoreline changes. The use of GIS tools further enhances the accuracy of analysis, making this site ideal for studying coastal dynamics and understanding long-term shoreline variations.

3.2 Machilipatnam seashore

Machilipatnam seashore forms an important part of the eastern coastline of India, facing the Bay of Bengal. It is characterized by sandy beaches, flat coastal plains, and dynamic shoreline conditions, making it a significant region for coastal studies. The seashore is influenced by various natural processes such as wave action, tidal fluctuations, ocean currents, and sediment transport, which continuously modify the coastal boundary. The movement of sediments along the coast plays a crucial role in shaping the shoreline. Depending on the balance between sediment deposition and erosion, certain areas experience accretion (land gain) while others undergo erosion (land loss). These processes are influenced by seasonal variations, monsoon patterns, and coastal hydrodynamics, making the shoreline highly dynamic in nature. The Machilipatnam coast is also highly

vulnerable to natural hazards such as cyclones, storm surges, and coastal flooding, which are common in the Bay of Bengal region. These extreme events can cause rapid and significant changes in shoreline position within a short period. Over time, the cumulative effect of these processes leads to noticeable spatial and temporal variations in the coastline. In addition to natural factors, human activities such as coastal development and land use changes may also influence shoreline behavior. These factors can alter natural sediment flow and contribute to changes in coastal stability. In this research work, the Machilipatnam seashore was analyzed using Landsat ETM + satellite data and QGIS software. The shoreline was digitized, and spatial analysis was performed to measure the shoreline length and calculate land and water areas over multiple years (2018–2022). This analysis provides a better understanding of coastal dynamics and helps in identifying patterns of erosion and accretion. The study of Machilipatnam seashore is important for coastal zone management, environmental monitoring, and sustainable planning, as it provides valuable information for protecting coastal resources and minimizing risks associated with shoreline changes.

4. Methodology of study in Machilipatnam seashore areas

The methodology of this study involves the use of Remote Sensing and GIS techniques to analyze shoreline changes over a period from 2018 to 2022. Landsat ETM + satellite images were used as the primary data source. The images were processed using QGIS software to extract meaningful information about shoreline position, land area, and water area. In Fig.2 shown that the Methodology diagram of the various study areas. Initially, the satellite data was collected and pre-processed using band combination and colour composition techniques. The shoreline was identified based on visual interpretation and digitized as a line layer. Similarly, land and water areas were digitized as polygon layers. Further, GIS tools were used to calculate shoreline length and area measurements. Finally, spatial analysis was performed to understand multi-year changes and identify erosion and accretion patterns.

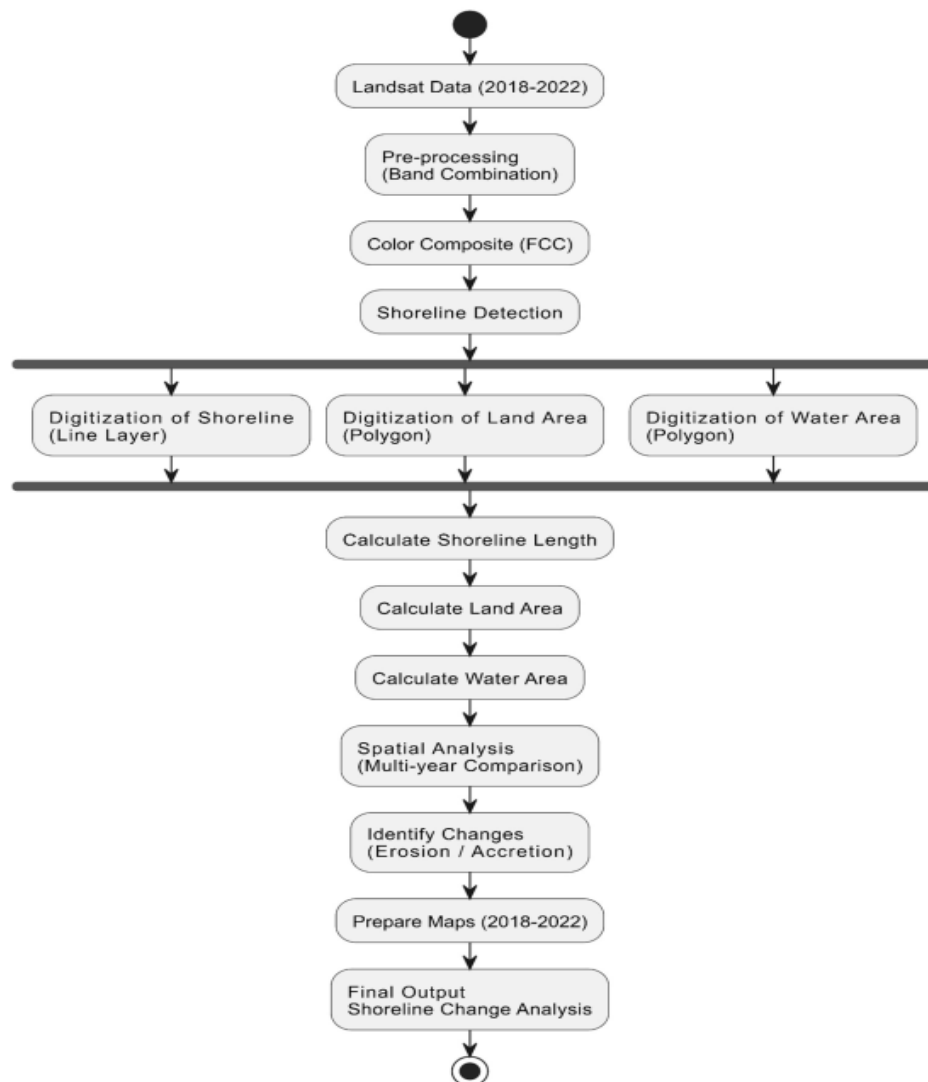


Fig.2. Methodology diagram of the various study areas

4.1 Description of methodology study areas in LANDSAT ETM+ DATA

Landsat ETM+ (Enhanced Thematic Mapper Plus) data is a widely used satellite imagery source for observing and analysing the Earth's surface. It provides multispectral images with a spatial resolution of 30 meters for multispectral bands, 15 meters for the panchromatic band, and 60 meters for the thermal band, making it suitable for regional-scale studies such as shoreline analysis.

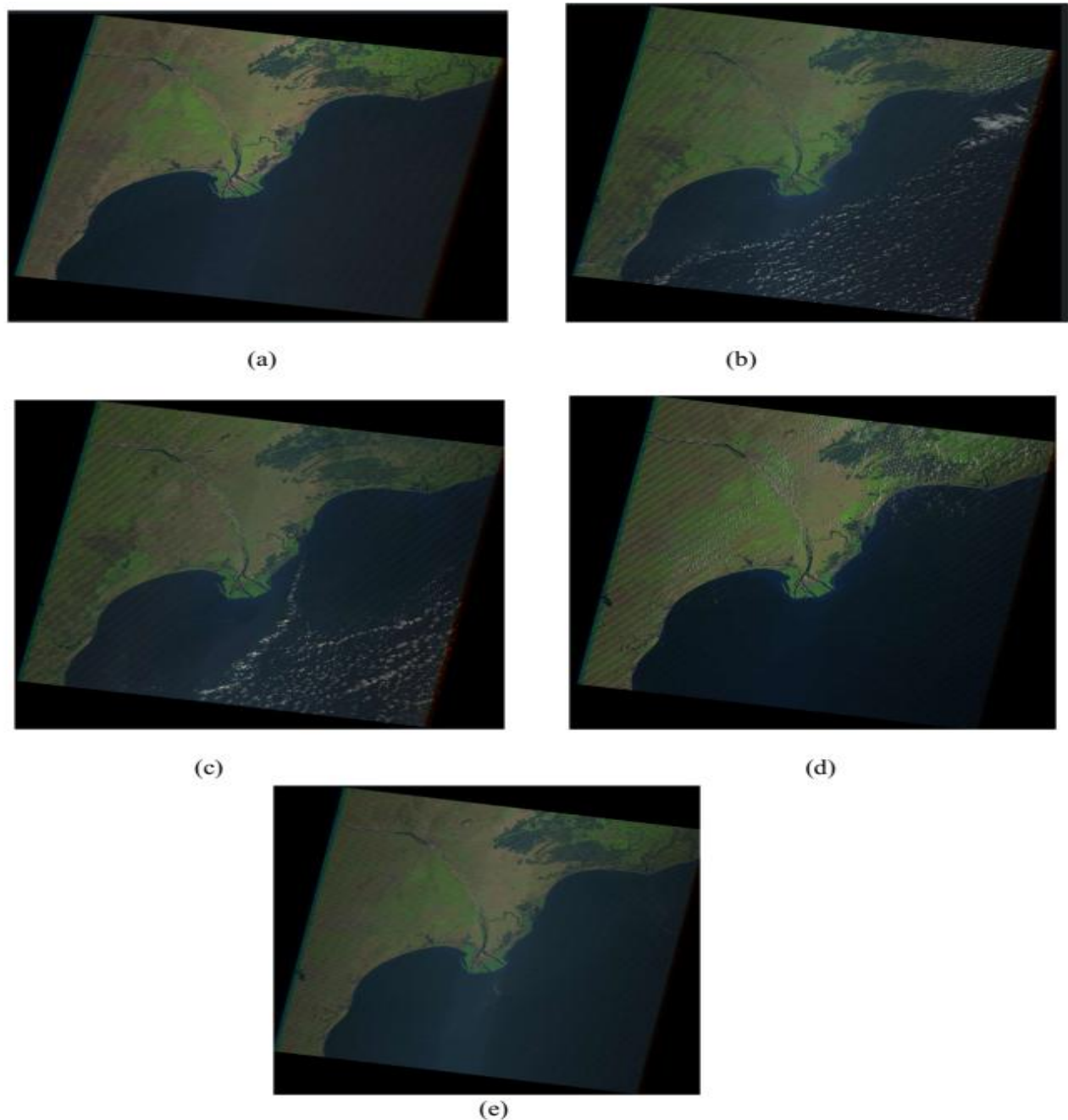


Fig.3. Land ETM 7 data images of Machilipatnam (a)study area of year 2018 (b)Study area of year 2019 (c) study area of year 2020 (d) study area of year 2021 (e) study area of year 2022

In this research work, Landsat ETM + satellite images for the years 2018 to 2022 were obtained from the United States Geological Survey (USGS), which provides free and reliable access to Earth observation data. The images consist of multiple spectral bands, including visible (blue, green, red), near-infrared (NIR) and shortwave infrared (SWIR) bands. These bands are useful for distinguishing different surface features such as land, water bodies, and vegetation. In Fig. 3 shown that the Land ETM 7 data images of Machilipatnam of study areas in year 2018-2022. The multispectral nature of Landsat data allows for effective identification of the land–water boundary, which is essential for shoreline detection. Water bodies typically absorb more energy and appear darker in satellite images, while the land and vegetation reflect more energy and appear brighter. This contrast makes

it easier to extract shoreline features using image processing techniques. Landsat ETM + data also provide consistent temporal coverage, enabling the analysis of shoreline changes over multiple years. Its wide spatial coverage, ease of availability, and reliability make it one of the most commonly used datasets in coastal studies, environmental monitoring and land use analysis. Thus, Landsat ETM + data play a crucial role in this project by providing the necessary information for accurate shoreline detection, digitization and analysis using GIS tools.

4.2 Pre-Processing

Pre-processing is a fundamental step in satellite image analysis, which involves preparing raw satellite data for further processing and interpretation. This step is essential to improve the quality, accuracy and usability of the images, ensuring reliable identification of features such as land and water. In this research work, the pre-processing was carried out using QGIS software. The Landsat ET + images were initially examined to ensure proper alignment, clarity, and consistency across different years. Any discrepancies in image quality or positioning were checked to maintain uniformity in analysis. Band combination techniques were applied to enhance image quality and improve the distinction between different surface features. A False Colour Composite (FCC) was generated by assigning appropriate spectral bands to the red, green, and blue (RGB) channels. In the FCC image, water bodies appear in darker tones due to low reflectance, while land and vegetation appear in brighter or greenish tones due to the higher reflectance. This contrast greatly facilitates the identification of shoreline boundaries. Pre-processing also helps in minimizing noise, correcting minor distortions, and enhancing overall visualization. These improvements are essential for accurate shoreline detection, digitization, and subsequent spatial analysis. Thus, pre-processing ensures that the satellite data is reliable and suitable for detailed shoreline analysis.

4.3 Layer-stack in Machilipatnam seashore areas

Layer stacking is the process of combining multiple raster bands of satellite imagery into a single composite image for analysis. In remote sensing, each spectral band captures different information about the Earth's surface, such as vegetation, water bodies, and soil characteristics. By stacking these bands together, a comprehensive dataset is created that enhances the interpretation of surface features. In this research work, Landsat ETM + raster bands were used to create a stacked image using QGIS software. The required spectral bands were selected and combined into a single composite raster layer. Since the analysis was carried out for multiple years (2018–2022), layer stacking was performed separately for each year's satellite image. The stacked image integrates spectral information from all selected bands, which improves the clarity and visibility of different features such as land, water and vegetation. This enhanced visualization makes it easier to distinguish the shoreline and supports accurate digitization. Additionally, layer stacking simplifies the data management by reducing multiple raster layers into a single dataset, making further processing steps such as colour composition, shoreline detection, and spatial analysis more efficient. Thus, the layer stacking is an important step in preparing satellite data, as it improves image interpretation and ensures accurate results in shoreline analysis.

4.4 Geo-Referencing

Geo-referencing is the process of assigning real-world geographic coordinates to satellite images so that they accurately align with the Earth's surface. It ensures that spatial data is correctly positioned and can be integrated and analysed with other geographic datasets within a GIS environment. In this research work, Landsat ETM+ images were used, which are generally pre-geo-referenced and provided with standard coordinate systems. However, it is essential to verify that all images are properly aligned and referenced to the same Coordinate Reference System (CRS) before performing any analysis. This step ensures consistency across multi-temporal datasets used for different years (2018–2022). Proper geo-referencing allows accurate overlay of raster and vector layers in QGIS, which is crucial for identifying shoreline positions and comparing changes over time. It also ensures that measurements such as shoreline length, land area, and water area are calculated accurately in the real-world units. Any misalignment or inconsistency in geo-referencing can lead to errors in spatial analysis and incorrect interpretation of results. Therefore, the careful verification of projection systems and alignment of datasets is necessary to maintain the reliability and precision of the study. Thus, geo-referencing plays a vital role in ensuring the accuracy, consistency, and reliability of shoreline change analysis using GIS techniques.

4.5 Colour Composition

Colour composition is the process of assigning different spectral bands of satellite imagery to the red, green and blue (RGB) channels to create a visually interpretable image. This technique enhances the differentiation of surface features such as land, water, and vegetation by utilizing their unique spectral reflectance properties. In Fig. 4 show that colour compositions of the Machilipatnam locations.

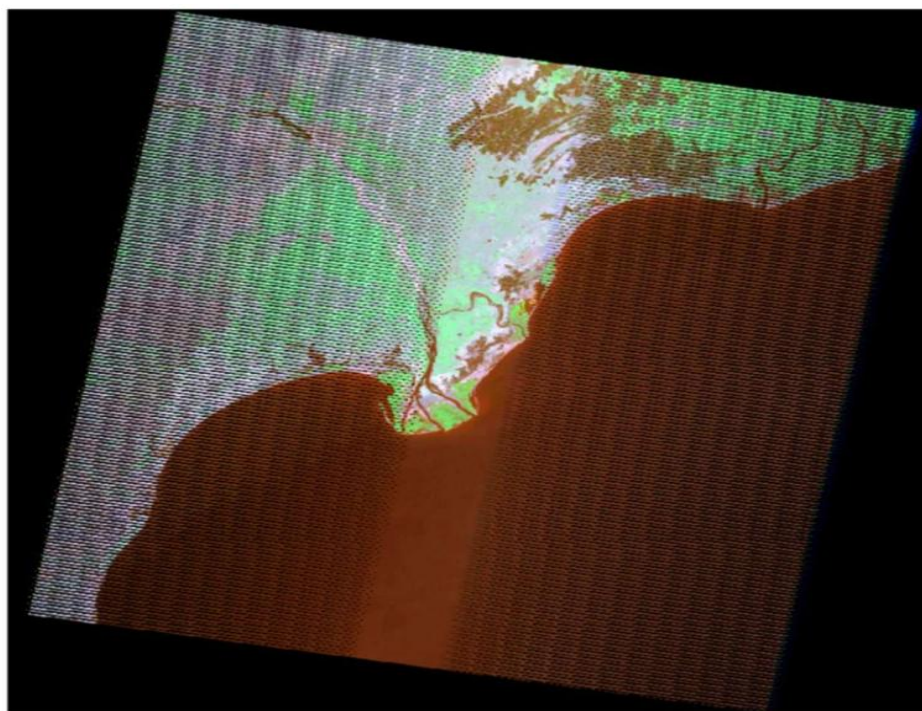


Fig.4. Colour compositions of Machilipatnam locations

In this research work, the colour composition was performed using Landsat ETM+ data in QGIS software. Suitable band combinations were selected to generate a False Colour Composite (FCC) image, which improves the visual distinction between various features. Typically, the near-infrared (NIR) and visible bands are combined to highlight vegetation and water bodies effectively. In the FCC image, water bodies appear in darker tones due to low reflectance, while land and vegetation appear in brighter or greenish tones because of higher reflectance. This clear contrast between the land and water makes it easier to accurately identify the shoreline boundary. Colour composition significantly improves image interpretation by enhancing feature visibility and reducing ambiguity during analysis. It plays a crucial role in supporting the accurate shoreline detection and precise digitization of land and water areas. Thus, the colour composition is an important step in the methodology, as it ensures better visualization and contributes to reliable shoreline analysis using remote sensing and GIS techniques.

5. Machilipatnam Shoreline Detection

Shoreline detection is the process of identifying the boundary between land and water using satellite imagery. It is a critical step in coastal analysis, as it defines the exact position of the coastline, which is essential for further spatial analysis and change detection. In this project, shoreline detection was performed using the False Colour Composite (FCC) images generated from Landsat ETM + data in QGIS software. The distinction between land and water was made based on their spectral and visual characteristics. Water bodies generally appear in darker tones due to low reflectance, whereas land and vegetation appear in brighter or greenish tones due to higher reflectance.

The shoreline was identified through visual interpretation, carefully tracing the boundary where the tonal variation between land and water is most distinct. This approach is effective when high-quality satellite imagery is available and provides reliable results for regional-scale analysis. In Fig. 5 shown that the shoreline detection data images of Machilipatnam Study area of year 2018 to 2022. Special attention was given to ensure accuracy during shoreline identification, as any error in this step can affect subsequent processes such as digitization and measurement. The detected shoreline serves as the base for creating vector layers and performing further analysis. Accurate shoreline detection is essential for calculating shoreline length, estimating land and water areas, and analysing coastal changes such as erosion and accretion over time. Therefore, this step plays a vital role in ensuring the reliability and precision of the overall shoreline analysis.

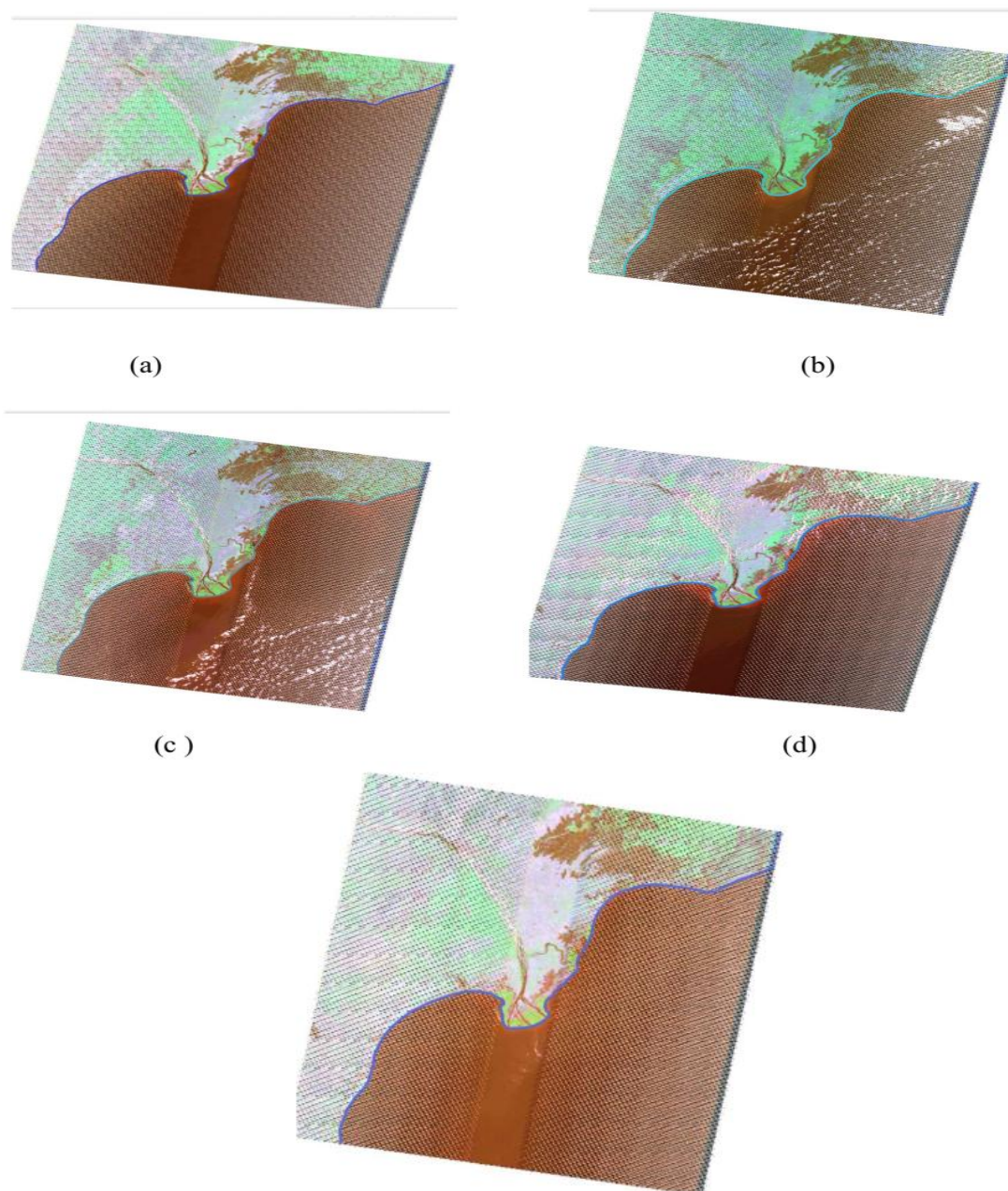


Fig.5. Shoreline detection data images of Machilipatnam (a) Study area of year 2018 (b) Study area of year 2019 (c) study area of year 2020 (d) study area of year 2021 (e) study area of year 2022

5.1 Digitization of Machilipatnam regional areas

Digitization is the process of converting features from satellite images (raster data) into vector data for spatial analysis. It involves manually tracing geographic features such as boundaries, lines, and regions using GIS tools, enabling accurate representation and measurement of spatial features. In this project, digitization was carried out using QGIS software. The detected shoreline was digitized as a line layer, representing the boundary between land and water. In addition, the land area and water area were digitized as polygon layers, which were later used for calculating area measurements. The digitization process was performed carefully by following the shoreline boundary using the enhanced False Color Composite (FCC) images. Visual interpretation of tonal differences

between land and water helped in accurately tracing the shoreline. Tools such as snapping, vertex editing and layer editing options were used to improve precision and maintain continuity of features, avoiding gaps or overlaps. Special attention was given to ensure accuracy during digitization, as errors in this step can directly affect the calculation of shoreline length and area measurements. Proper digitization ensures that the extracted features closely represent real-world conditions.

In Fig 6 shown that the Digitization converts shoreline, land, and water features into vectors study area of year 2018 to 2022. Digitization plays a crucial role in transforming raster data into vector format, which allows for precise calculation of shoreline length, land area, and water area. It is an essential step for further spatial analysis, comparison across multiple years and interpretation of shoreline changes.

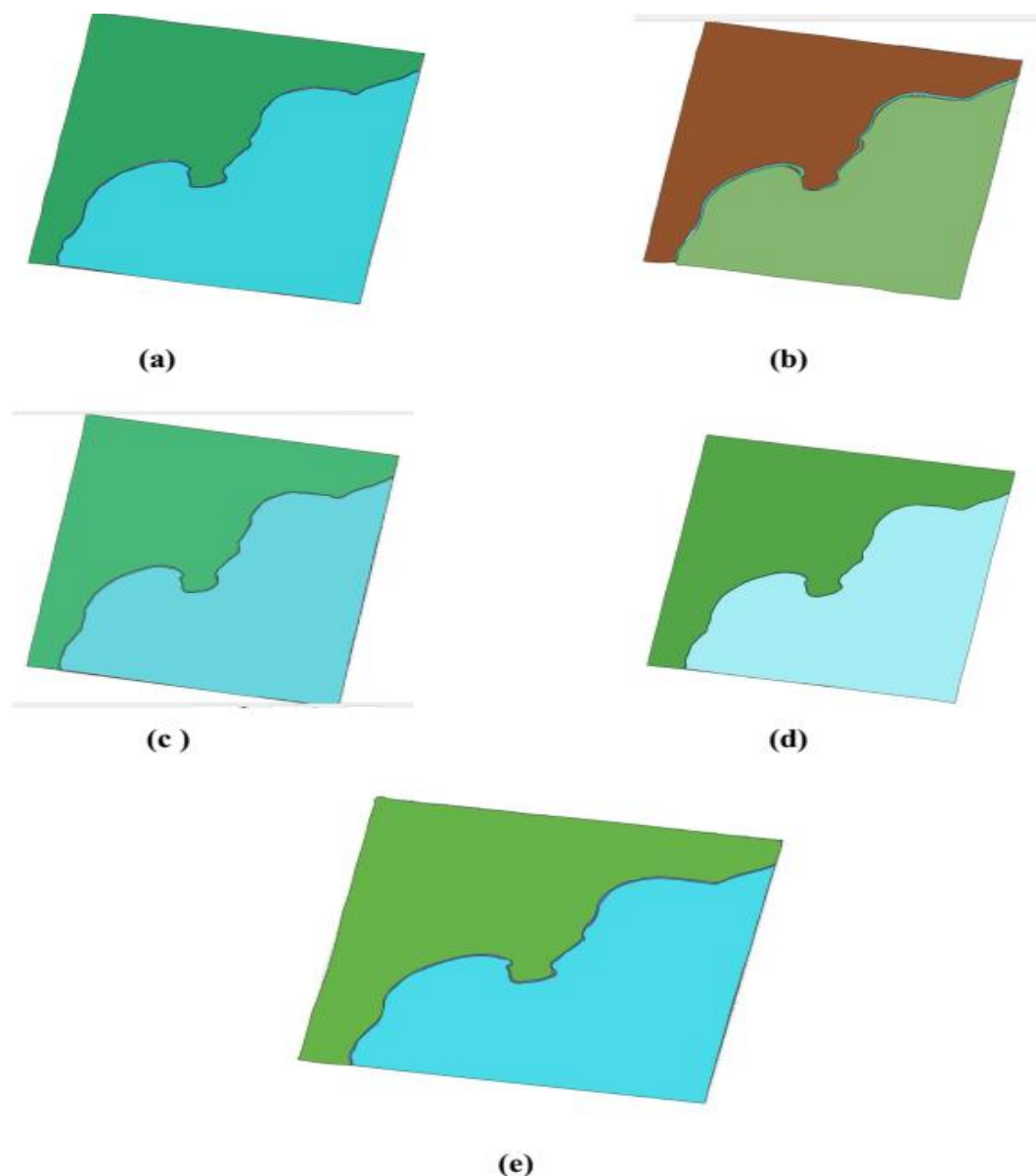


Fig.6: Digitization converts shoreline, land, and water features into vectors (a)study area of year 2018 (b) Study area of year 2019 (c) study area of year 2020 (d) study area of year 2021 (e) study area of year 2022

5.2 Calculations and analysis of Machilipatnam regional areas

After digitization, spatial calculations and analysis were carried out using QGIS tools to quantify shoreline characteristics. In this study, the shoreline was represented as a line layer, while land and water regions were represented as polygon layers. The calculations were performed using the Attribute Table and Field Calculator in QGIS. For the shoreline layer, the total length was calculated using the length function, which computes the length of the digitized line feature in map units (converted to kilometres where required). Similarly, for land and water polygons, the area was calculated using the area function, which provides accurate measurements of the spatial extent of each polygon.

The calculated values were stored as new fields in the attribute table, allowing easy comparison and analysis. In Fig. 7 represents that the calculations were carried out for each year from 2018 to 2022, ensuring consistency in projection and coordinate reference system (CRS) for accurate results. The results were then compared to analyse variations in shoreline length, land area, and water area over time. This comparison helped in identifying patterns of coastal change, including erosion (loss of land) and accretion (gain of land). Thus, the use of attribute table and field calculator enables precise computation of spatial parameters and plays a crucial role in interpreting shoreline dynamics and understanding the overall behaviour of the coastline.

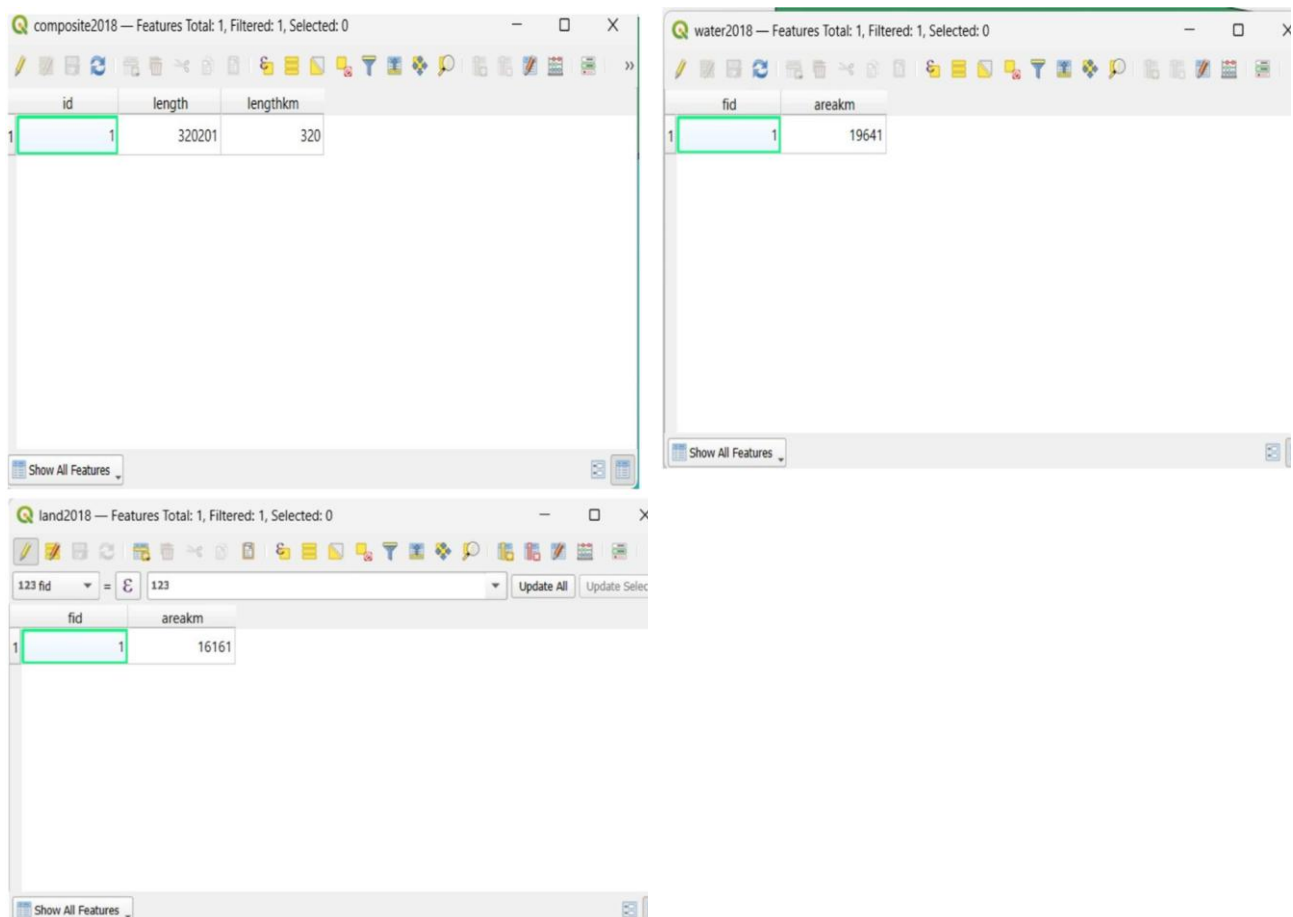


Fig.7. Shoreline length calculation using attribute table and Water area calculation using attribute table and Land area calculation using attribute table

6. Results and Analysis

The shoreline analysis for the Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2018 to 2022. The shoreline was digitized, and shoreline length along with land and water areas were calculated for each year.

6.1 In Year 2018

The methodology employed Normalized Difference Water Index (NDWI) models to distinguish land-water boundaries in the year 2018, mapping both erosion and accretion trends along the shoreline. Used multi-temporal Landsat imagery and QGIS for image stacking and False Colour Composite (FCC) generation to enhance land-water contrast. In Fig. 8 show the Machilipatnam coastal zone exhibits high dynamic fluctuation. While some areas experience pronounced erosion and retreat, other sections indicate significant growth in mangrove cover, protecting the region against tropical storms. Subsequent analysis involved digitization of shoreline features and classification of land and water areas within the QGIS environment.

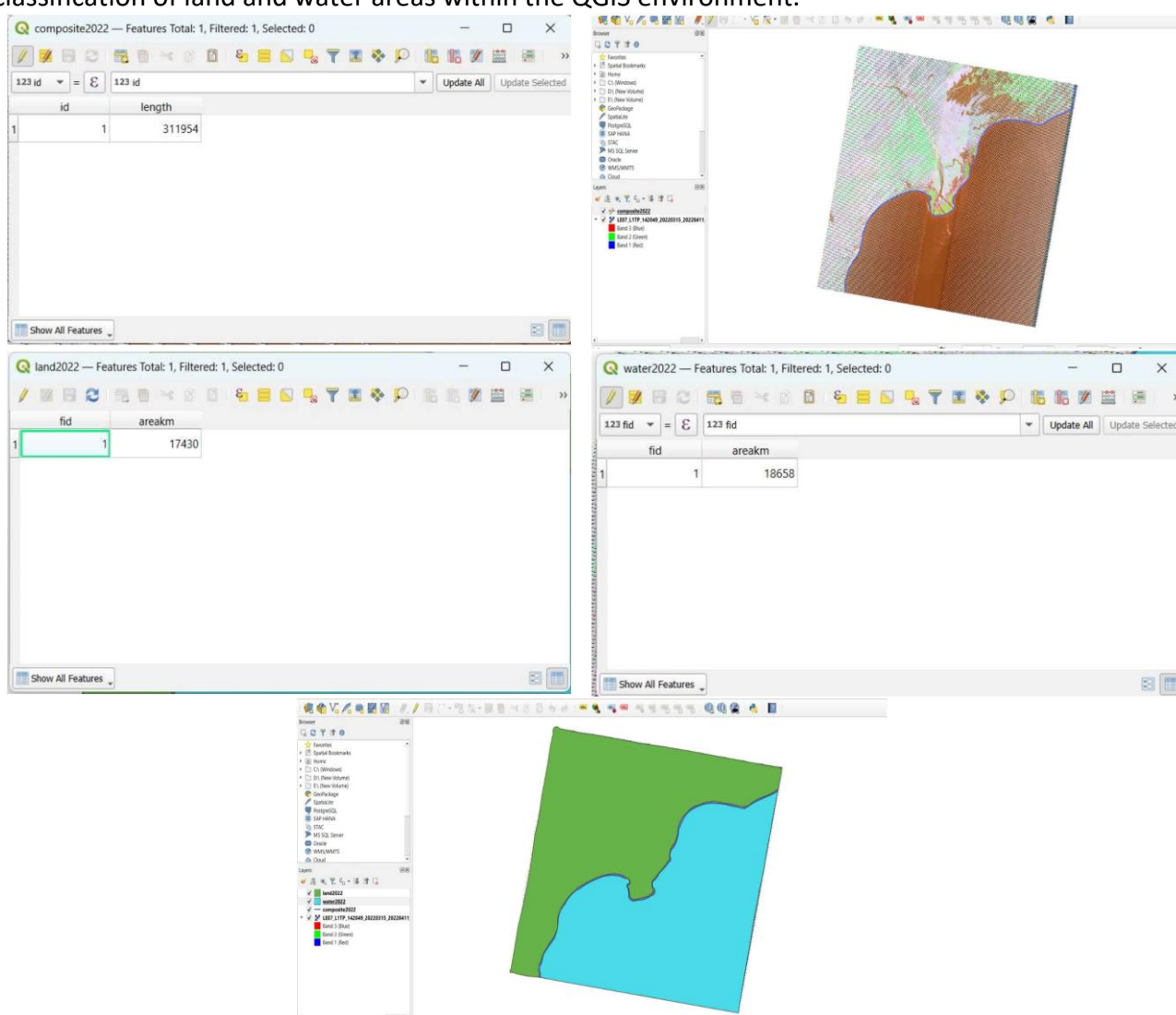


Fig. 8. Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2018

6.2 In 2019

Historical long-term studies (1990–2020) for this specific Krishna District coastline note maximum accretion rates of approximately 18.71 m/year in the Machilipatnam Mandal, alongside high erosion rates in adjacent areas like Nagayalanka Mandal. The observed shoreline dynamics are primarily influenced by wave action, sediment transport, tidal variations and potential sea-level rise. The integration of remote sensing and GIS techniques demonstrated in this study provides a reliable, cost-effective and scalable approach for the long-term coastal monitoring. The findings contribute valuable insights for coastal planners and policymakers in identifying the vulnerable zones and implementing appropriate mitigation strategies for sustainable coastal management.

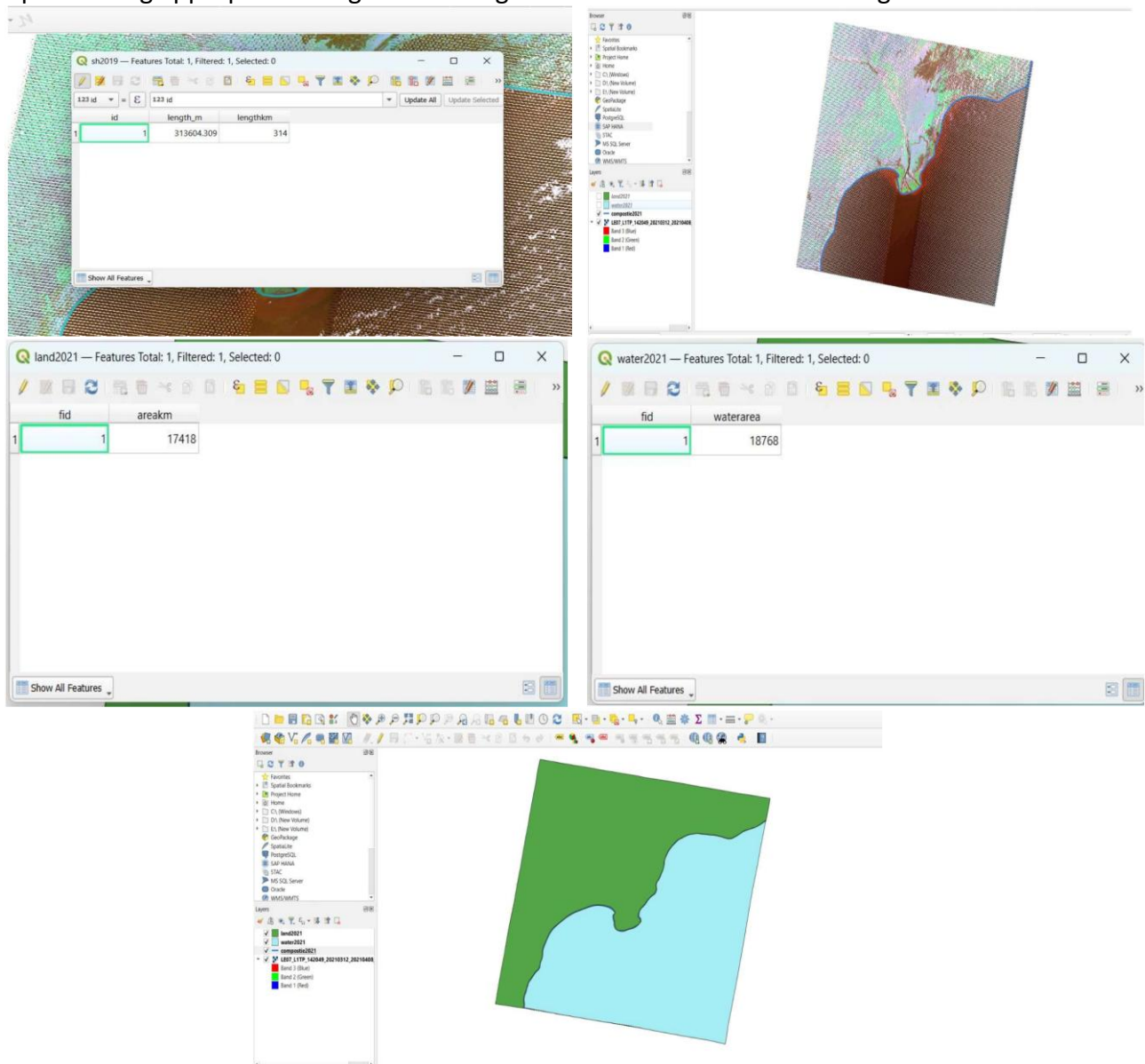


Fig.9. Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2019

In recent decades, increasing concerns over climate change, sea-level rise, and extreme weather events have intensified the need for systematic monitoring of shoreline dynamics. In Fig. 9 show the

Machilipatnam coast in Krishna District, Andhra Pradesh, represents one such vulnerable region characterized by low-lying terrain, deltaic formations, and active sediment transport processes.

6.3 In 2020

Understanding the nature and extent of shoreline changes in this region is essential for effective coastal zone management, disaster mitigation, and sustainable development planning. The advent of remote sensing and Geographic Information System (GIS) technologies has significantly improved the ability to monitor and analyse shoreline changes over large areas with higher efficiency and accuracy. In the year 2020 the Satellite data, particularly from Landsat missions, provide multi-temporal and multispectral information that enables effective discrimination between land and water features and supports long-term environmental monitoring. In Fig. 10 show that the Shoreline length calculation using attribute Machilipatnam coastal areas.

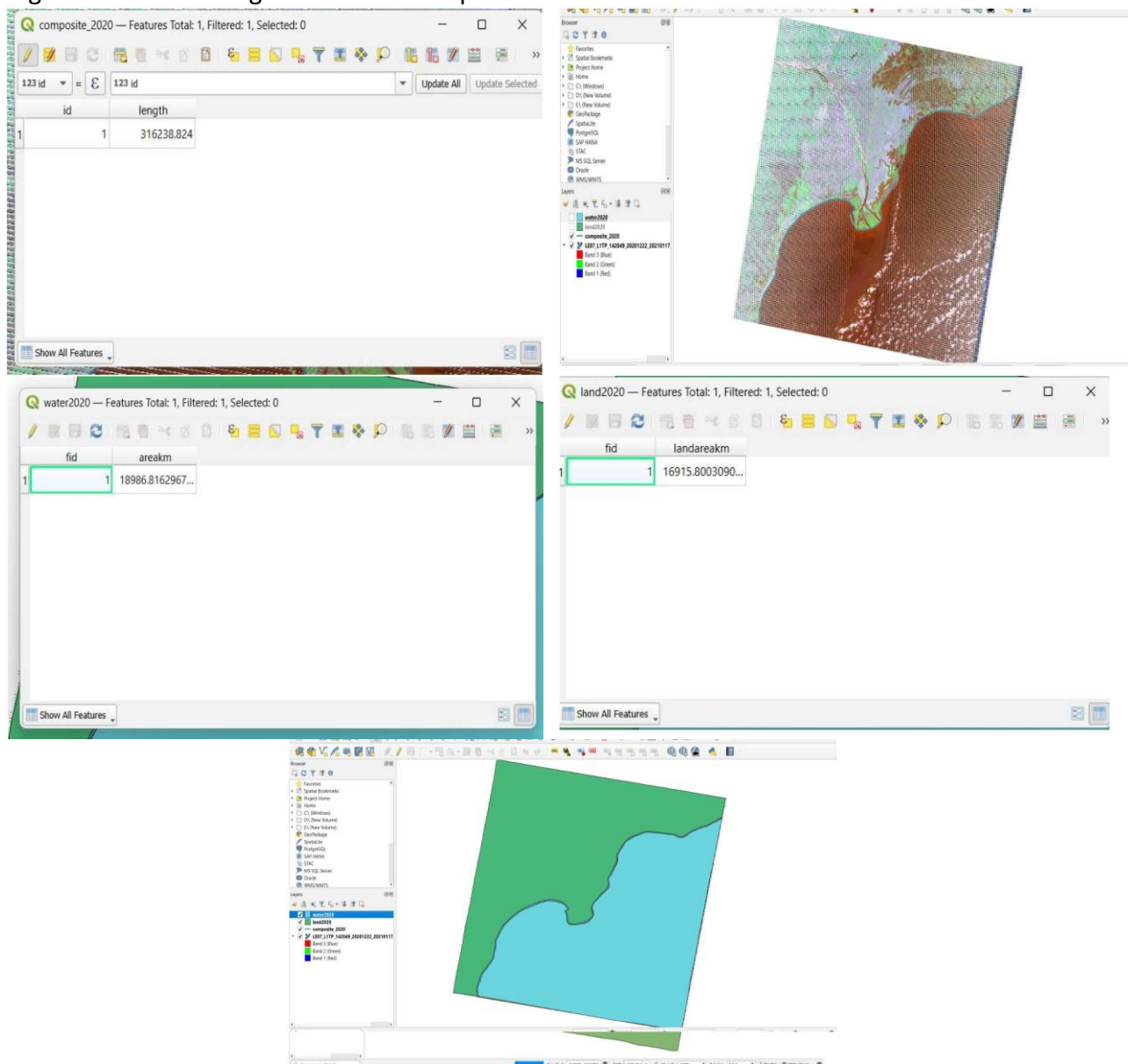


Fig.10. Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2020

6.4 In Year 2021

In this context, the present study aims to analyse shoreline changes along the Machilipatnam coast using multi-temporal Landsat 7 ETM + satellite imagery and QGIS. The study integrates image processing techniques, including band combination and the (NDWI), with spatial analysis methods to accurately extract shoreline positions and quantify changes over time. The specific objectives of this study are to detect and delineate shoreline positions for the period 2021, estimate changes in shoreline length, land area, and water area, and identify dominant coastal processes such as erosion and accretion.

In Fig. 11 shown that the Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2021 year. The outcomes of this research provide valuable insights into coastal dynamics and contribute to informed decision-making for coastal management and environmental sustainability. Over the past few decades, the various researchers have investigated the coastal dynamics to understand patterns of erosion and accretion and to support effective coastal zone management.

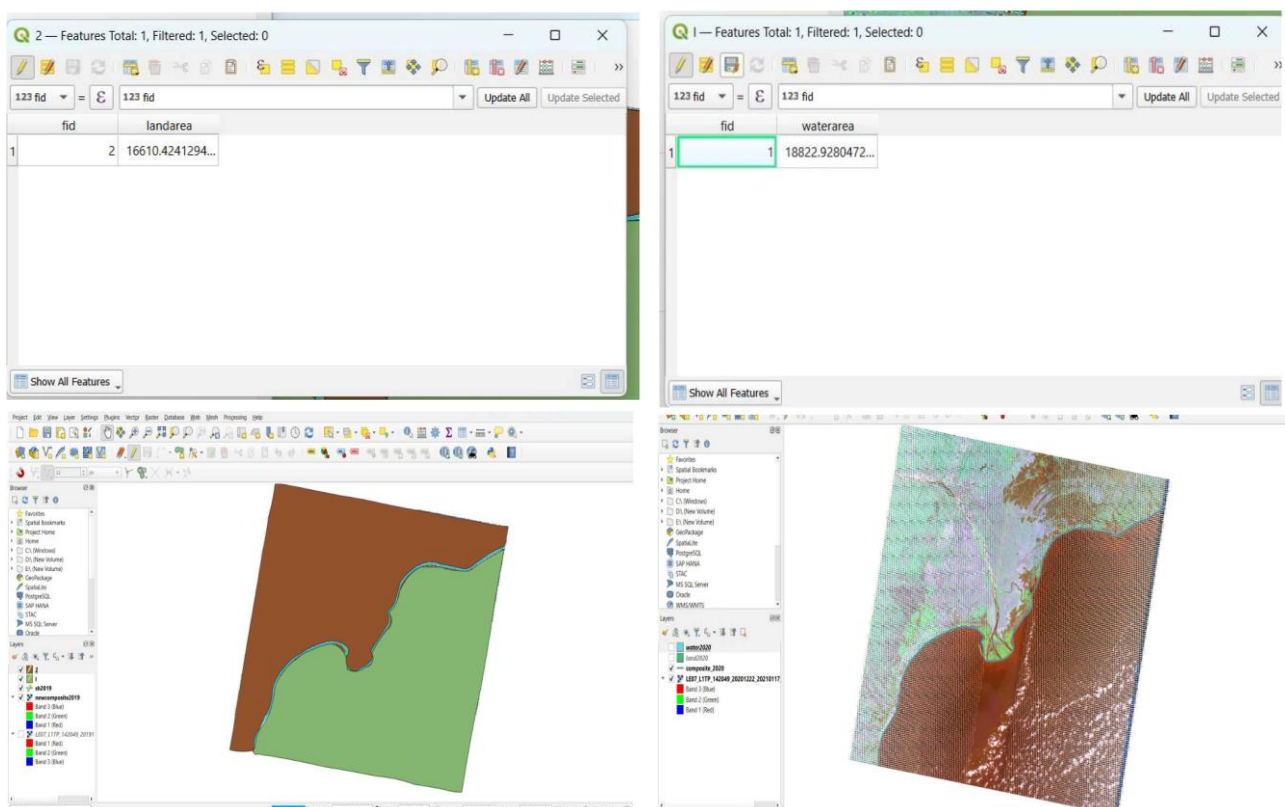


Fig.11. Shoreline length calculation using attribute Machilipatnam coast was carried out using the Landsat ETM+ data and QGIS software for the period from 2021

6.5 In Year 2022

This study employed statistical techniques to predict the future shoreline positions and highlighted the importance of long-term monitoring for understanding coastal evolution. Their findings emphasized that shoreline changes are highly influenced by both natural processes and human interventions, necessitating continuous observation. By applying parameters such as End Point Rate (EPR) and Linear Regression Rate (LRR), the study provided a quantitative assessment of shoreline movement. The use of DSAS demonstrated improved accuracy in measuring shoreline change rates and enabled the identification of erosion-prone and accretion-dominated zones.

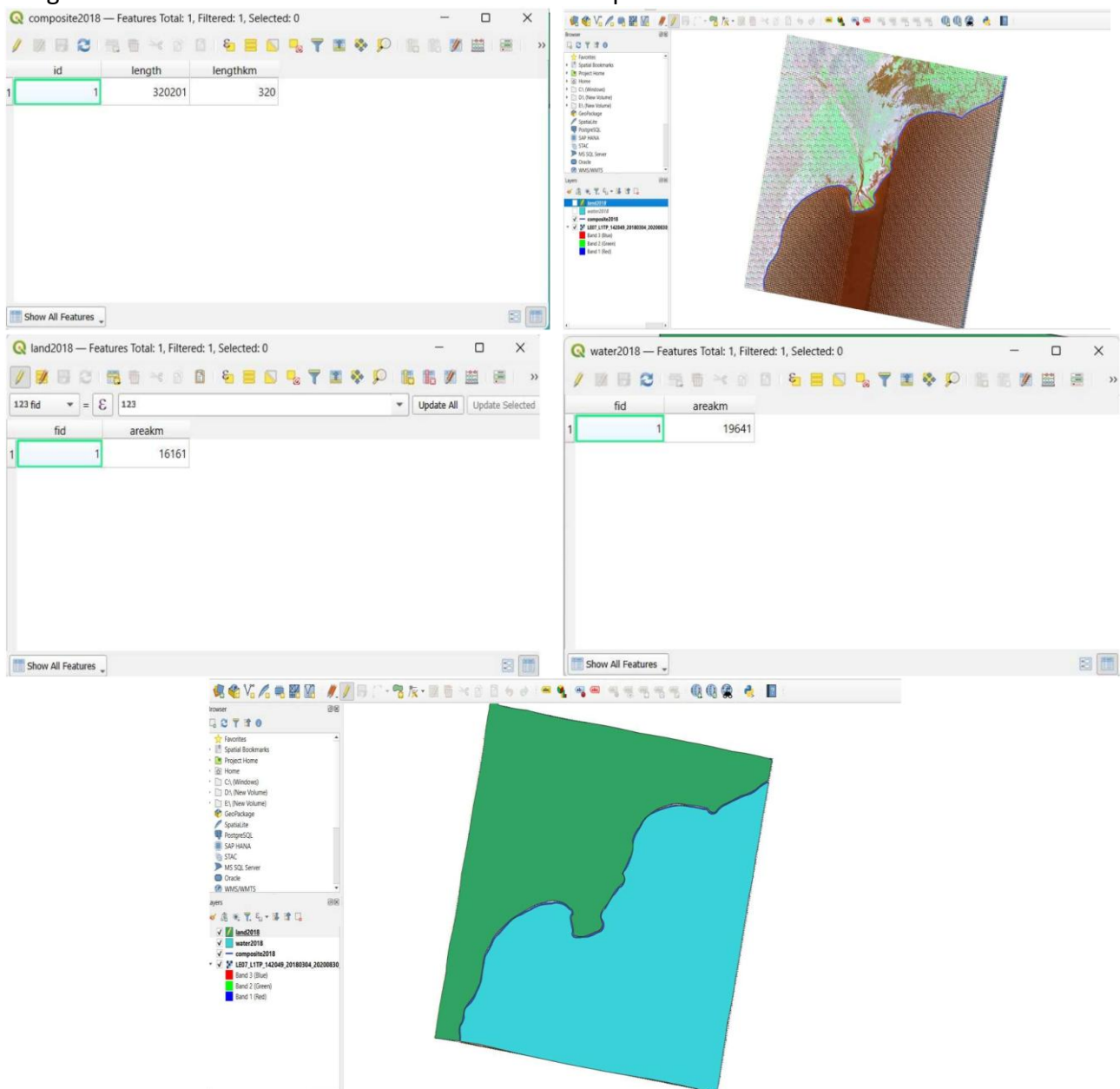


Fig.12. Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2022

Overall, this study demonstrates the effectiveness of remote sensing and GIS as powerful tools for monitoring coastal dynamics and provides valuable insights for the sustainable management of vulnerable coastal regions. The analysis of NSR, EPR and LPR rates, thus, reveals a pronounced shoreline retreat in the Machilipatnam coastal zone during the study period. In Figure 12 shown that the Shoreline length calculation using attribute Machilipatnam coast was carried out using Landsat ETM + data and QGIS software for the period from 2022. Beta forecasting was carried out to create Shoreline change envelope (SCE), and prediction maps of shoreline were produced for the next 10 and 20 years. The study has, thus, helped us manifest into a quantification of the trends and changes in the shoreline geometry and is a good precursor to efficient coastal classification and management. The RF classification helped in the auto-extraction of shorelines, while the image segmentation provided accurate shorelines and reduced the digitization errors, with a validation accuracy exceeding 95%. This highlights the significance of GIS and remote sensing integration in shoreline change detection and monitoring. The results observations:

1. Shoreline Length Variation

- Increased overall from 311 km (2018) to 320 km (2022)
- Slight fluctuation in 2021 (315 km), but general increasing trend
- Indicates coastal accretion (land gaining)

2. Land Area Trend

- Continuously decreased from 17430 km² (2018) to 16161 km² (2022)
- Suggests erosion or submergence of land

3. Water Area Trend

- Increased from 18658 km² (2018) to 19641 km² (2022)
- Shows expansion of water body

4. Overall Coastal Behaviour

- **Mixed pattern:**
 - o Shoreline length increasing → Accretion
 - o Land decreasing & water increasing → Erosion/Submergence
- Indicates dynamic and unstable coastal conditions

The results obtained from the analysis are summarized in the table 1:

Table 1

Shoreline Length, Land Area, and Water Area (2018–2022)

S.N.	Year	Shoreline Length (km)	Land Area (km ²)	Water Area (km ²)
1	2018	311	17430	18658
2	2019	314	17418	18768
3	2020	316	16915	18986
4	2021	315	16610	18822
5	2022	320	16161	19641

7. Result analysis of Machilipatnam Regional Areas

The results obtained from the shoreline analysis were examined to understand the spatial and temporal variations in shoreline length, land area, and water area along the Machilipatnam Coast during the period from 2018 to 2022. The analysis reflects the dynamic behaviour of the coastline influenced by natural coastal processes.

7.1 Shoreline Length

The shoreline length shows minor fluctuations during the study period. It was 311 km in 2018, increased to 314 km in 2019, slightly increased to 316 km in 2020, then marginally decreased to 315 km in 2021, and finally increased to 320 km in 2022. This variation indicates that the coastline is continuously adjusting due to wave action, tidal effects and sediment movement. The overall trend shows a slight increase in shoreline length, suggesting minor irregularities or extension of coastal features. However, since the changes are small, the coastline can be considered relatively stable.

7.2 Land Area

The land area shows a consistent decreasing trend from 17430 km² in 2018 to 16161 km² in 2022. This continuous reduction indicates the dominance of coastal erosion, where land is gradually being worn away by waves, currents and other marine forces. The decrease may also be influenced by factors such as reduced sediment deposition and possible sea-level rise.

7.3 Water Area

The water area exhibits a steady increasing trend from 18658 km² in 2018 to 19641 km² in 2022. This increase in water area corresponds directly with the decrease in land area, indicating that land is being converted into water-covered regions. This supports the conclusion that erosion is the dominant process along the coastline.

7.4 Relationship Between Land and Water Changes

There is a clear inverse relationship between land area and water area throughout the study period. As land area decreases, water area increases correspondingly. This relationship confirms that coastal erosion is actively reshaping the coastline, leading to the loss of land and expansion of water bodies.

7.5 Overall Coastal Behavior

The overall analysis indicates that the Machilipatnam coastline is undergoing gradual erosion. While the shoreline length shows only slight fluctuations, the significant decrease in land area and increase in water area clearly highlight the dominance of erosion processes. Despite these changes, the coastline does not show abrupt or extreme variations, suggesting that it is dynamic but moderately stable.

7.6 Future Scope of Machilipatnam Regional areas

7.6.1 Study Area Context

The present study was carried out along the Machilipatnam coast in Krishna District, which forms part of the eastern coastline of India along the Bay of Bengal. This region is highly dynamic due to the interaction of fluvial, marine, and atmospheric processes. The shoreline changes were analysed using multi-temporal satellite imagery obtained through Remote Sensing and processed using QGIS for the period from 2018 to 2022. The analysis revealed a dominant accretion trend, characterized by a

gradual increase in land area and a corresponding decrease in water spread. This indicates that the depositional processes are more active than erosional forces in the study region during the selected time frame.

7.6.2 Causes of Shoreline Changes

The shoreline dynamics observed in the study area are governed by a combination of natural coastal processes and anthropogenic interventions.

7.7 Natural Causes

7.7.1 Sediment Transport and Deposition:

The Krishna River plays a significant role in transporting large volumes of sediments from inland regions toward the coast. When the velocity of river flow decreases near the river mouth, sediments settle and accumulate, leading to gradual land formation. This process is the primary cause of accretion observed in the study area.

7.7.2 Wave Dynamics and Longshore Currents:

Wave action and longshore drift continuously move sediments parallel to the coastline. These currents redistribute deposited materials, contributing to shoreline advancement in certain areas while maintaining equilibrium in others.

7.7.3 Tidal Action

The cyclical rise and fall of tides influence sediment movement and deposition patterns. High tides carry sediments inland, while low tides expose newly formed land aiding in gradual the coastal expansion.

7.8 Climatic and Seasonal Variations:

Monsoon seasons significantly increase river discharge and sediment load, enhancing deposition rates. Conversely, the dry seasons show relatively stable shoreline conditions.

7.8.1 Cyclones and Extreme Events

The Bay of Bengal is prone to cyclones, which can temporarily alter shoreline configurations through storm surges and wave action. However, in the long term, the study area shows recovery and continued accretion.

7.9 Human-Induced Causes

7.9.1 River Regulation Structures

Construction of dams and barrages upstream alters sediment flow. Although such structures may reduce sediment supply in some regions, localized deposition still occurs near the coast.

7.9.2 Coastal Infrastructure Development:

Harbors, ports, groynes, and seawalls interfere with natural sediment transport, leading to localized accretion or erosion patterns.

7.9.3 Land Reclamation Activities:

Human interventions such as filling low-lying coastal areas for development contribute to an increase in land area.

7.9.4 Agricultural Expansion:

Conversion of coastal wetlands into agricultural land also modifies shoreline characteristics.

7.9.5 Impacts of Shoreline Changes

The shoreline changes observed in the Machilipatnam region have significant environmental, economic, and social implications.

7.9.6 Positive Impacts

- **Increase in Land Availability:** Newly formed land can be utilized for agriculture, aquaculture, and infrastructure development.
- **Natural Coastal Protection:** Wider coastal zones reduce the direct impact of waves and storm surges on inland areas.
- **Habitat Formation:** Accretion supports the growth of vegetation such as mangroves, which enhance biodiversity.
- **Economic Opportunities:** Expansion of land supports fisheries, salt production, and tourism-related activities.

7.9.7 Negative Impacts

- **Ecological Imbalance:** Rapid land formation can disturb existing marine and coastal ecosystems.
- **Alteration of Drainage Patterns:** Changes in shoreline position may affect natural water flow and lead to waterlogging.
- **Navigation Issues:** Sediment deposition near coastal areas may hinder navigation and port activities.
- **Future Instability Risks:** If sediment supply decreases or wave energy increases, the area may shift from accretion to erosion.

8. Solutions and Coastal Management Strategies

To ensure sustainable utilization and protection of coastal resources, the following measures are recommended:

8.1 Structural Measures

- Construction of Groynes and Breakwaters: These structures help control sediment movement and stabilize the shoreline.
- Seawalls and Revetments: Used to protect coastal infrastructure from wave attack.

8.2 Non-Structural Measures

- Integrated Coastal Zone Management (ICZM): A comprehensive approach that balances environmental conservation with economic development.
- Mangrove Afforestation: Planting mangroves enhances sediment trapping and protects against erosion and cyclones.
- Regulation of Coastal Development: Limiting unplanned construction activities along the coast.
- Sediment Budget Management: Ensuring natural sediment flow is not excessively disrupted.

8.3 Technological Measures

- Continuous Monitoring: Use of satellite imagery and GIS tools for periodic shoreline mapping.
- Early Warning Systems: For cyclones and storm surges to minimize damage.
- Use of High-Resolution Data: Incorporating advanced remote sensing techniques for accurate analysis

8.4 Applications / Uses of the Study

The outcomes of this study are highly useful in multiple domains:

- Coastal Zone Planning: Helps identify stable and suitable zones for development.
- Disaster Risk Reduction: Supports flood and cyclone hazard assessment.
- Environmental Conservation: Assists in protecting sensitive coastal ecosystems.
- Engineering Design: Provides essential data for designing coastal structures.
- Policy Formulation: Aids government agencies in decision-making and sustainable planning.
- Academic and Research Purposes: Serves as a reference for future shoreline studies

9. Conclusions

9.1 Analysis of Shoreline Changes

The study on shoreline changes along the Machilipatnam coast in Krishna District indicates a dominant accretion trend during 2018–2022.

The analysis shows a consistent increase in land area and a decrease in water area, indicating shoreline advancement.

The shoreline length shows only minor variations, suggesting relative stability of the coastline.

The rate of change is gradual and uniform, without abrupt fluctuations.

9.2 Coastal Processes and Influencing Factors

The study area is dominated by a depositional environment where sediment accumulation exceeds erosion. Sediment supply from river discharge, along with wave action and tidal forces, plays a key role in shaping the shoreline. Seasonal variations, especially monsoon periods, enhance sediment transport and deposition

9.3 Methodology and Tools

The use of Remote Sensing enabled accurate extraction of shoreline positions.

The application of QGIS facilitated efficient spatial analysis and calculation of shoreline parameters. The adopted methodology is accurate, reliable, and cost-effective.

9.4 Relevance to Global Warming

The study is important in the context of global warming, which leads to sea-level rise and coastal changes. The present accretion trend may provide temporary protection, but future climate changes may cause instability or erosion.

9.5 Practical Implications

The findings are useful for coastal zone management, environmental protection, and disaster risk assessment. The study helps in planning sustainable and climate-resilient coastal development

9.6 Final Inference

The Machilipatnam coastline is relatively stable with a positive sediment balance. With proper planning, regulation, and continuous monitoring, the accretion trend can be effectively utilized for sustainable development

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Data Availability Statement

The statements in the paper are properly cited in the manuscript and no additional data is available

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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