# Coastline change detection adjacent to Salli GN Division in Trincomalee, Sri Lanka

**V. Pathmanandakumar**


## Abstract

*Monitoring shoreline is importantt for planning and development in the coastal region. This research aims to detect and analyze the rate of shoreline changes in the Salli Grama Niladhari (GN) division between 1991 and 2021. In this study, the shoreline change rate along the coastline was analyzed using multi-temporal Landsat imagery and the Digital Shoreline Analysis System (DSAS). The analysis revealed a significant rate of both accretion and erosion along the coast of the study area. Remotely acquired, multi-temporal Landsat images with 30 m resolution were collected at 10-year intervals from 1991 to 2021. To perform the quantitative analysis of shoreline delineation, geometric and radiometric corrections were applied to all Landsat images. Shorelines were then automatically extracted in ArcGIS 10.8 using the Tasseled Cap (Landsat toolbox), and the rate of shoreline change was analyzed using the Digital Shoreline Analysis System extension. End Point Rates and Linear Regression Rates were used to calculate the net rate of shoreline change over 30 years from 1991-2021. The rates of shoreline change and net movement along transects were determined. Two hundred twenty-one transects at 20m intervals were cast for the entire coast of the study area, the bulk of which revealed coastline erosion (78.6%). The analysis showed that some parts of the research area experience remarkable shoreline changes (averagely 0.237m/yr accretion and -0.676 m/yr erosion base on Linear Regression Rates and 0.28 m/yr accretion and -0.671 m/yr erosion based on End Point Rates) between 1991 and 2021. The combined effects of the different natural and human activities on the coast of the study area have caused this shoreline change. An "erosion" type coast can be seen in the study area and coastal protection is therefore considered important for this area as well.*


**Keywords**: Shoreline change, Landsat images, Shoreline extraction, DSAS, EPR & LRR

## Introduction

A shoreline is defined as the line of contact between land and a body of water (Dewi & Bijker, 2020; Kuleli et al., 2011; Moussaid et al., 2015; Yasir et al., 2021). The shoreline change has been the subject of several studies around the world (Abu Zed et al., 2018; Castelle et al., 2018; Hakkou et al., 2018; Harley et al., 2019; Ozturk & Sesli, 2015; Raj et al., 2019; Toure et al., 2019; Yasir et al., 2021). Despite covering less than 20% of the worldwide land surface, coastal regions are home to more than 45% of the world's population (Dewi & Bijker, 2020). Shoreline change has emerged as one of the biggest environmental challenges in recent years, with 20% of the world's coasts eroding at rates ranging from 1 cm/year to 10 m/year (Kermani et al., 2016).

Coastal areas are used for various purposes, including human settlement, agriculture, industry, fishing, transportation, and recreation, among others (Senevirathna et al., 2018). The majority of these activities threaten the coastal area through coastal erosion, flooding, sedimentation, and habitat and resource degradation (Dewi & Bijker, 2020). Coastal erosion is a natural process that continually reshapes shorelines through ocean currents, tidal movements, and wind and wave action (Airoldi et al., 2005). Coastal erosion affects more than 70% of the world's coastal regions, and shoreline change is considered one of the most dynamic processes in coastal areas (Kuleli et al., 2011). Both natural processes and anthropogenic activities induced shoreline change (Senevirathna et al., 2018). Winds and storms, near-shore currents, relative sea-level rise, and slope processes are the most prominent natural contributors. In contrast, human-induced factors of coastal erosion include coastal engineering, land reclamation, dam or reservoir construction, dredging, mining, and water extraction (Moussaid et al., 2015). These changes on the shoreline lead to erosion and accretion of coastal areas (Kermani et al., 2016; Natesan et al., 2015). Understanding past and current shorelines changes are necessary for managing the coastal area as it demands a detailed understanding of trends in shoreline change (Kermani et al., 2016; Ozturk & Sesli, 2015).

Sri Lanka is a country with a lot of world-historic monuments, and it is an island with a coastline that stretches for around 1600 kilometres (Senevirathna et al., 2018). The country's coastal landscape is particularly appealing, with a diverse range of natural resources and rich biodiversity. As a result, the land area of the coastal belt has significant environmental value as well as strong economic and social demands (Senevirathna et al., 2018). Since the 1980s, coastal erosion has been a major national concern in Sri Lanka (Kottawa-Arachchi & Wijeratne, 2017; Mehvar et al., 2019; Ratnayakage et al., 2020). In Sri Lanka, low-lying coastal areas with less than one meter elevation and extending up to 1-2 kilometres inland result in a high level of vulnerability to erosion (Dastgheib, Jongejan, Mehvar, et al., 2018; Dastgheib, Jongejan, Wickramanayake, et al., 2018; Mehvar et al., 2019). The negative impacts of the rate of erosion were offset by the continuous supply of sediment from rivers. However, erosion has recently become a serious threat due to a lack of sediment supply as a result of irregular sand mining procedures in major and minor river networks (Lin & Pussella, 2017). The coastal erosion is most noticeable on the east coast. These coastal hazards already pose a threat to the coastal areas (beaches) of Trincomalee district (Mehvar et al., 2019). However, the mechanism and causes of coastal erosion are not entirely understood and have not been thoroughly investigated. As a result, tensions between the government and fishing communities have grown (Ratnayakage et al., 2020).

Monitoring the spatiotemporal changes of the coast can help understand the spatial distribution of coastal erosion, predict trends, and promote coastal erosion research (Dewi & Bijker, 2020). Remote sensing data can provide valuable preliminary estimates of change and is a tool for researching and monitoring shoreline change. Furthermore, maps generated from satellite data have a high potential for projecting recent changes in shorelines (Kuleli et al., 2011). Many studies have used remotely sensed data to analyze shoreline change (Castelle et al., 2018; Ciritci & Türk, 2020; Dewi & Bijker, 2020; Hakkou et al., 2018; Marzouk et al., 2021; Raj et al., 2019; Yasir et al., 2021). End Point Rates (EPR) and Linear Regression Rates (LRR), which have been used in several studies to detect shoreline change, were utilized to determine the rate of shoreline change in this research (Kermani et al., 2016; Moussaid et al., 2015; Natesan et al., 2015). This research aims to detect and analyze the rate of shoreline changes in the Salli GN division between 1991 and

2021 utilizing Geographic Information Systems (GIS) and automatic computation (DSAS).

## Study Area

"Salli" GN Division is one of the well-known fishing villages in Trincomalee district, Sri Lanka, with a 4.3 km long coastline and a total area of 2.392 $Km^2$ and a population of 2167 (Divisional Secretariat - Trincomalee Town & Gravets, 2018). It is located in the eastern portion of Trincomalee District, approximately 15 kilometers east of Trincomalee town. The study area lies between Latitudes $8^0$ 37' 20" and $8^0$ 39' 20" N and Longitudes $81^0$ 13' 10" and $81^0$ 13' 40" E (Figure 1). The study area climate is characterized by a hot and humid tropical climate with an average annual rainfall of 1000-1500 mm and an irregular yearly distribution (Jayasingam, 2008). The mean annual temperature is 30°C, although typically this ranges from 25°C on cooler nights during the rainy seasons to 35.4°C during the rare day in the hot summer months (Jayasingam, 2008). It's warm and dry from March to September, and the coldest time of the year is December to January. Rainfalls are observed in two periods: from April to June (short rains) and November to January (long showers).

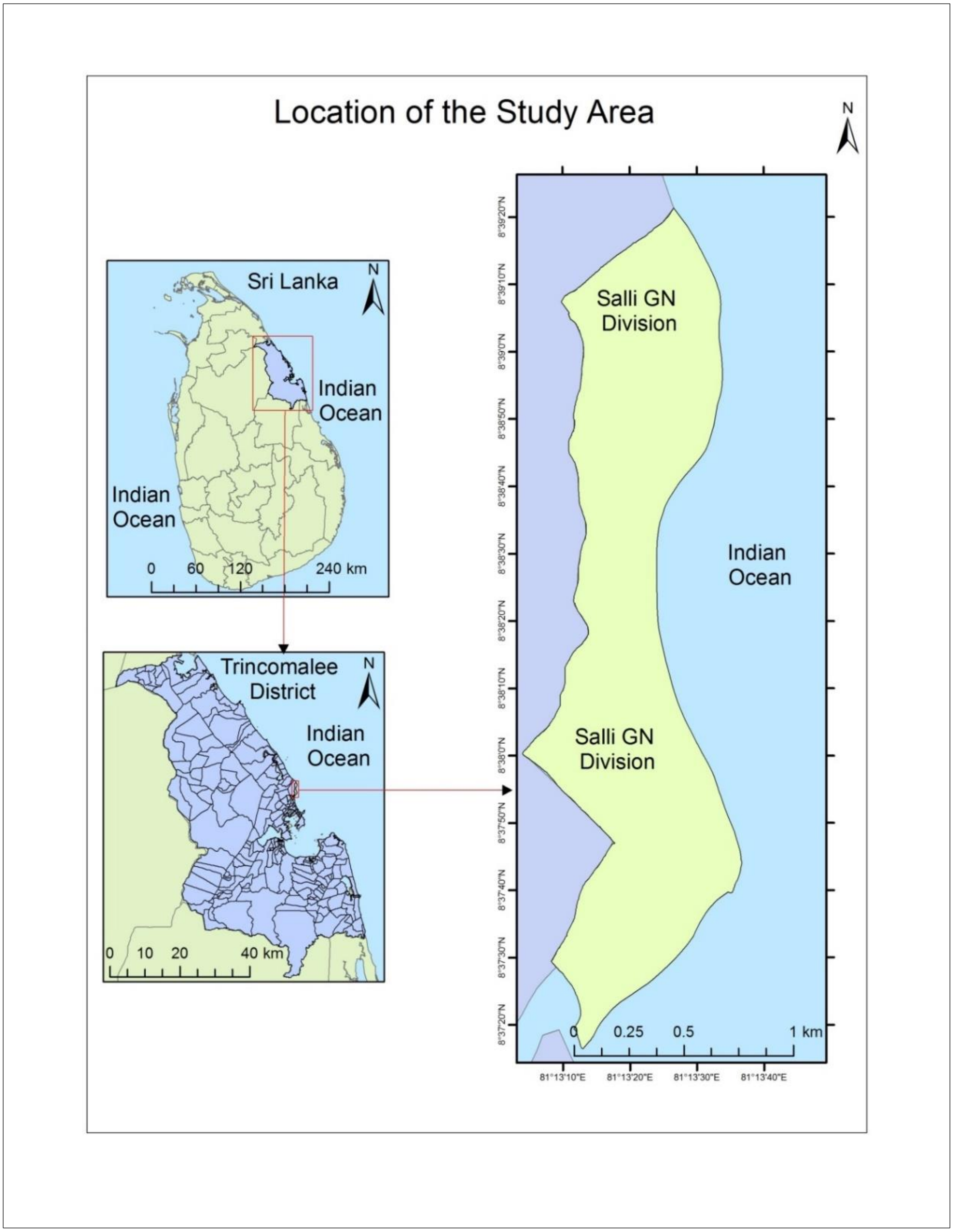


**Figure 1: Location of the Study Area**

# Materials and methods

The method used in this study to detect and analyze the shoreline changes comprise of three stages: 1) geometric and radiometric corrections of Landsat images, 2) Automatic extraction of shorelines, 3) Determination of the rate of shoreline change. Landsat multi-temporal satellite data (Landsat 5 Thematic Mapper -TM, Landsat 7 Enhanced Thematic Mapper Plus –ETM+, and Landsat-8 Operational Land Imager and Thermal Infrared Sensor -OLI-TIRS) with a spatial resolution of 30m are used in the research work to cover the study area in 1991, 2001 2011, and 2021. The images were collected from the Earth Explorer website (http://earthexplorer.usgs.gov) of the US Geological Survey (USGS), all of which were rectified and projected with a geographical error of 0.5 pixels using the Universal Transverse Mercator method in the World Reference System (WGS84) results (Table 1).

**Table 1: Specification of satellite images**

| Date Acquisition | Path/Raw | Satellite & Sensor | Spatial Resolution | Data Source |
|---|---|---|---|---|
| 1991-09-03 | 141/54 | Landsat 5-TM | 30m | USGS |
| 2001-06-09 | 141/54 | Landsat 7– ETM+ | 30m | USGS |
| 2011-06-03 | 141/54 | Landsat 5-TM | 30m | USGS |
| 2021-06-01 | 141/54 | Landsat -OLI_TIRS | 30m | USGS |

Various techniques for coastline extraction and change detection from satellite imagery have been developed. Some of the more typical change detection techniques are manual, image enhancement, comparison of two independent land cover classifications, density slice using single or multiple bands and multi-spectral classification (Supervised and Unsupervised: e.g. ISODATA, PCA, Tasseled Cap) (Kuleli et al., 2011). Automatic coastline extraction using "Tasseled Cap" is applied in accordance with the aim of the study (Figure 3).

After shorelines were extracted for four different years (1991, 2001, 2011, 2021), all the shorelines necessary for this study were in shapefile format. The shoreline positions were compiled in ArcGIS 10.8 with six attribute fields: Object ID, Shape (polyline), Shape Length, ID, Date (first survey year), and uncertainty values. The different shoreline features have been merged as a single feature on the attribute table, allowing multiple coastline files to be appended together into a single shapefile. These shorelines were used to create a geo-database analyzed with DSAS developed by United States Geological Survey. This extension was used to calculate the rate of shoreline movement and changes. DSAS technique is a widely accepted quantitative methodology in coastal morphology research (Guneroglu, 2015). It can also be integrated into the ArcGIS environment (Guneroglu, 2015). In our study, the DSAS was carried out in four steps: (1) shoreline preparation, (2) baseline creation, (3) transect generation, and (4) computation of rate of shoreline change. Transects were automatically created from the onshore baselines toward the coast. Shorelines changes rate along the coast of "Salli GN division" were calculated on 221 transects that were automatically created from the baselines toward the coast with DSAS, which were oriented perpendicular to the baseline located onshore at a 20 m spacing and 4.3 km length along the East Coast, Sri Lanka. Transects numbered 1 to 221, with transect 1 at the bottom and transect 221 at the top of the study area (Figure 2).

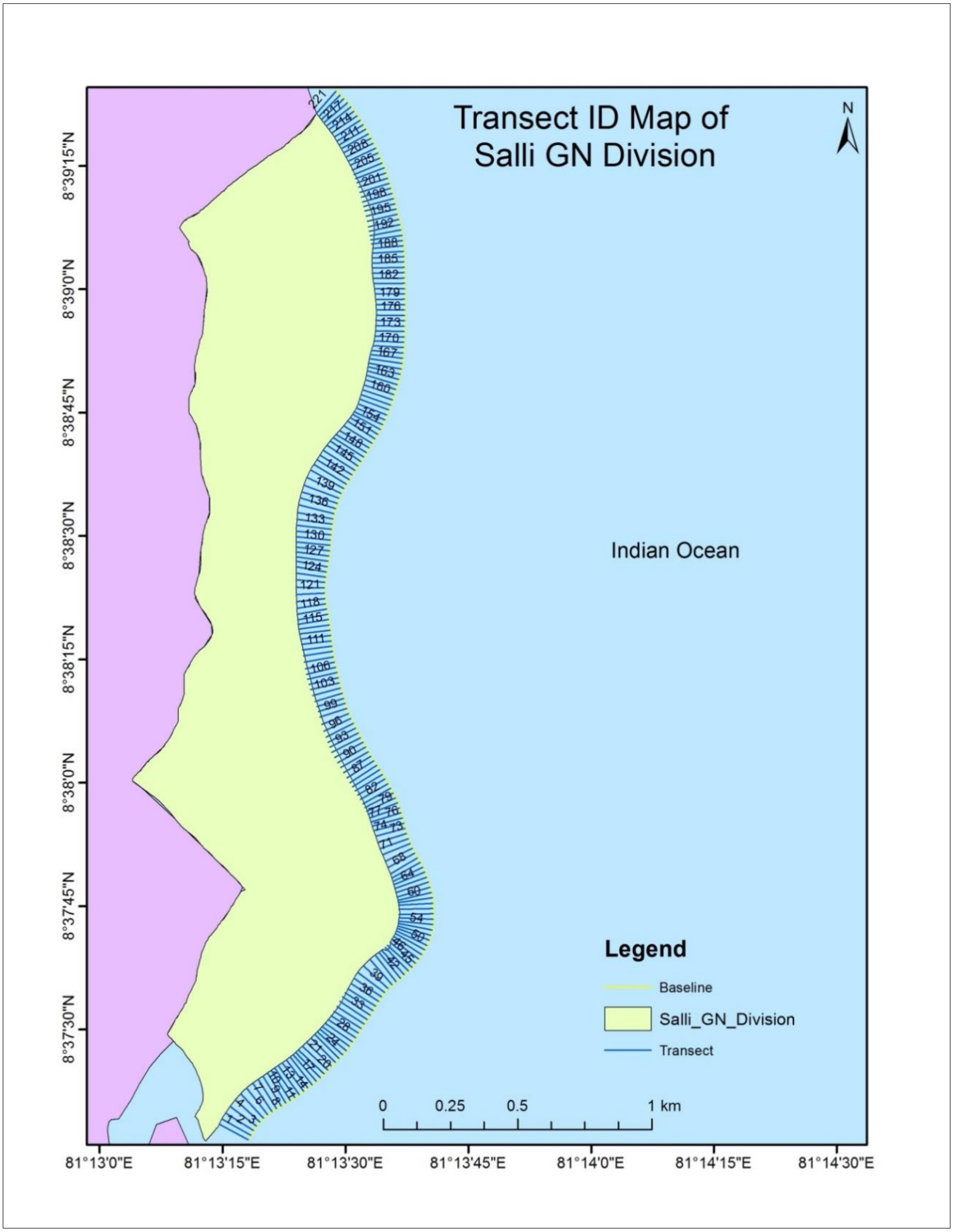


**Figure 2: Transect IDs Map of Salli GN Division**

Shoreline erosion/accretion rates can be calculated using various data analysis techniques (Guneroglu, 2015; Kankara et al., 2015; Kermani et al., 2016; Kuleli et al., 2011; Moussaid et al., 2015). In this study, shoreline changes are computed using two different statistical approaches, such as the End Point Rate (EPR) and Linear Regression Rate (LRR), which have been used by many scholars to investigate the rate of shoreline change (Guneroglu, 2015; Kankara et al., 2015; Kermani et al., 2016; Kuleli et al., 2011; Moussaid et al., 2015). The End Point Rate (EPR) is calculated by dividing the distance (in meters) separating two shorelines by the number of years between the dates of the two shorelines, which is suitable for short term changes analysis (Kankara et al., 2015). The LRR can be determined by fitting a least-squares regression line to all shoreline points for a particular transect obtained from the analysis, which is the most suitable way to calculate long-term shoreline changes. It is widely used by different coastal researchers (Guneroglu, 2015; Kankara et al., 2015; Kermani et al., 2016; Kuleli et al., 2011; Moussaid et al., 2015). The obtained erosion and accretion rates for the Salli GN division coast were divided into three categories based on Table 2 (Raj et al., 2019).

**Table 2: Shoreline Classification based on EPR and LRR**

| No | Rate of Shoreline Change (m/yr) | Shoreline Classification |
|---|---|---|
| 1 | >-2 | Very High Erosion |
| 2 | >-1 to <-2 | High Erosion |
| 3 | >-1 to<0 | Moderate Erosion |
| 4 | 0 | Stable |
| 5 | >0 to <1 | Moderate Accretion |
| 6 | >1 to <2 | High Accretion |
| 7 | >2 | Very High Accretion |

Source: (Raj et al., 2019)

Ground truthing is essential for any studies that rely heavily on remotely sensed data. It helps the researcher interact with the actual subject of study, enable the reader to make meaning from the data, and check for inaccuracies (Dube et al., 2020). During the ground-truthing process, the researchers walked along the shoreline, observing and photographing indications of coastal erosion and other preventative measures being implemented. The extracted coastline was validated by ground-truthing through field measurement. The kappa method was used to assess the accuracy of the extracted shoreline. The researcher picked 25 random points along the coastline and then compared them to the extracted shoreline of 2021 for validation (Figure 3).

A snowball sampling technique was used to interact with the local residences (Key informants). A total of 20 key informant interviews were conducted. Participation was through voluntary consent. It took 15 to 30 minutes for each interview. Notes were taken during the interviews. During the post the data collection process, interview data were transcribed and cleaned out, and thematic analysis was conducted following an iterative process as outlined by Jaspal (2020).

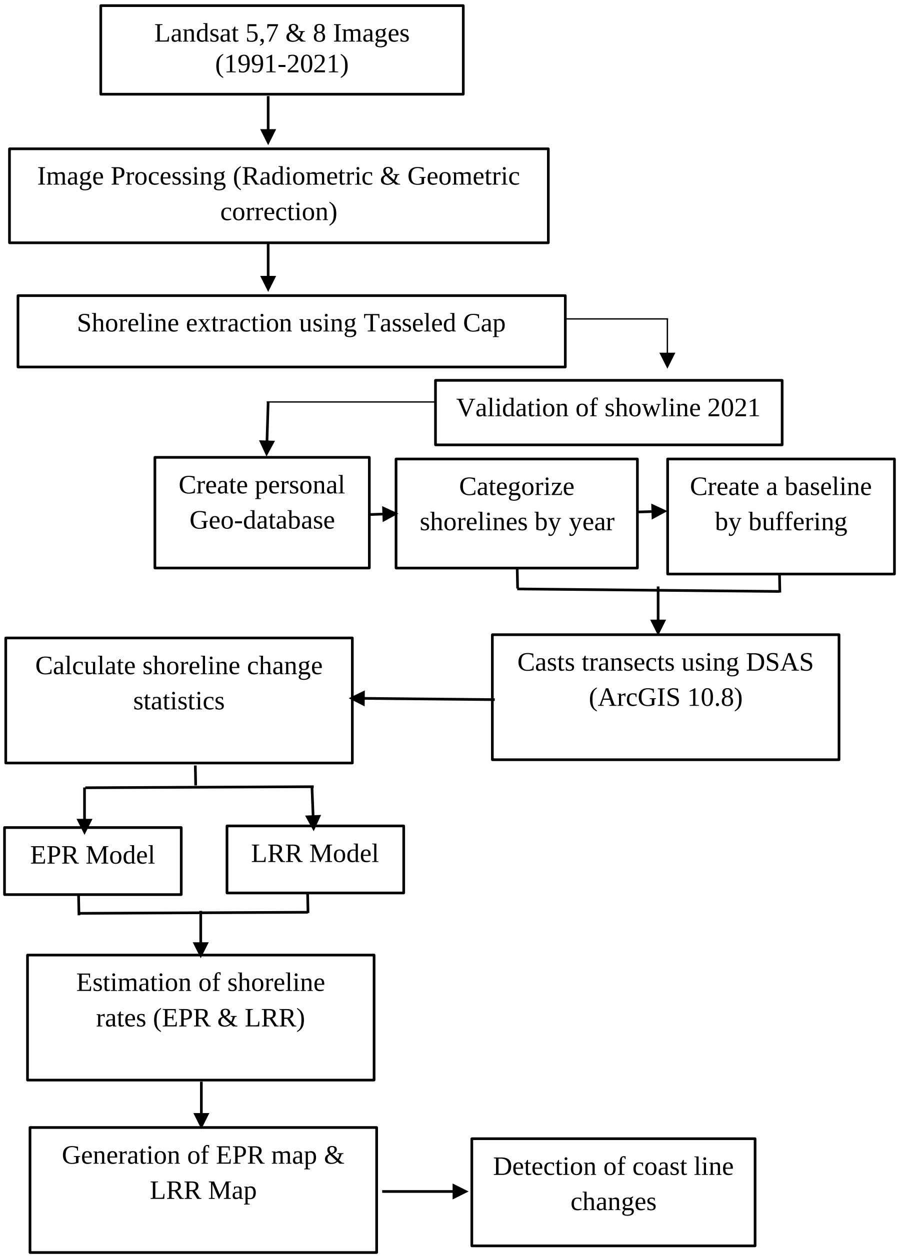


**Figure 3: The methodology flowchart**

## Results and discussion

The shorelines are changing at a faster rate. The shoreline position reveals the movement of the coastline and provides data on coastal erosion and accretion.

Changes in the coast's shoreline may indicate natural or human-caused influences. As a result, accurate detection of shoreline changes is important for understanding the trends of shoreline change. Whether erosion or accretion, Shoreline changes can be expensive since they directly impact coastal infrastructure, communities, and ecosystems.

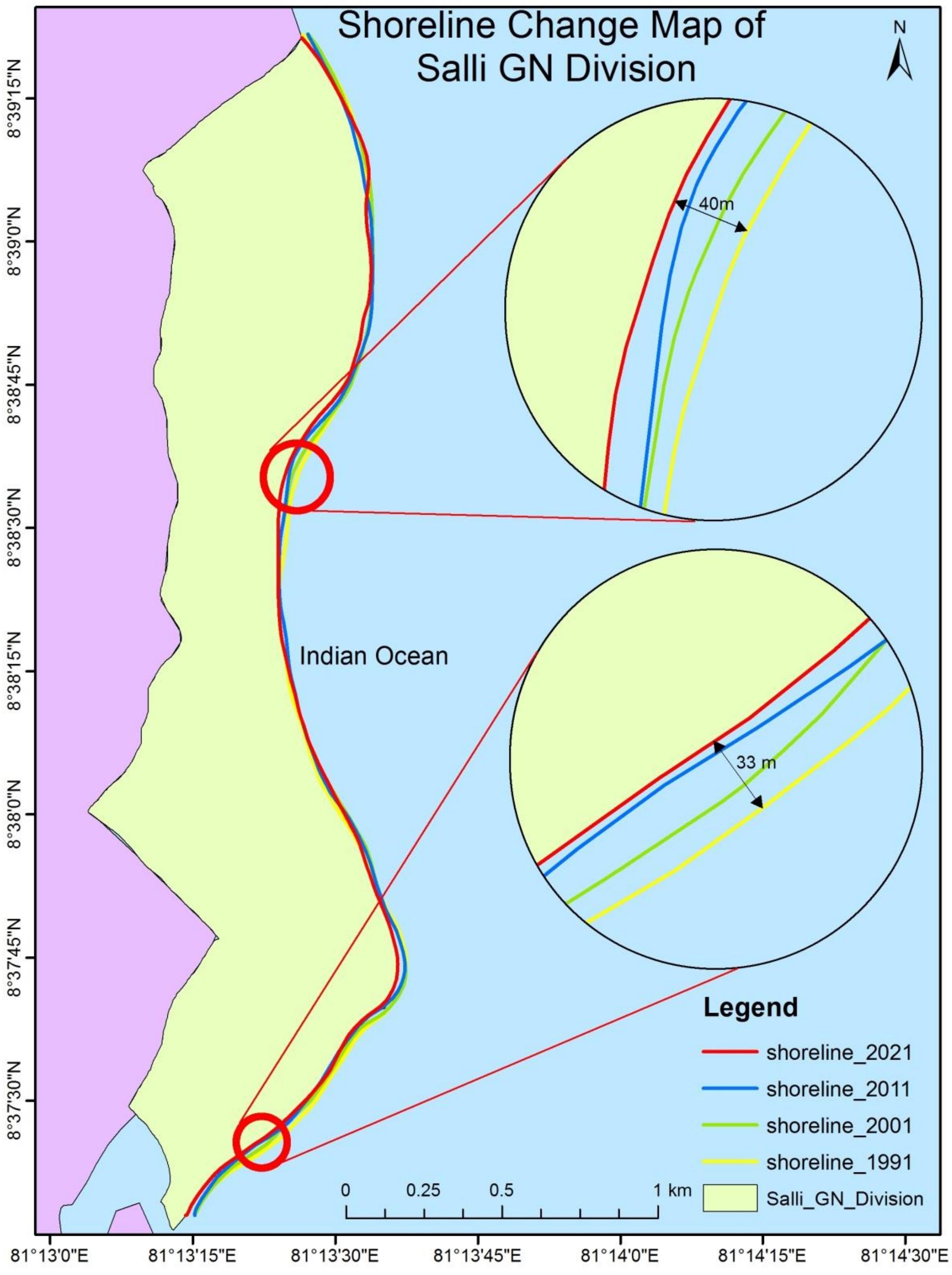
Shoreline Change Map of
Salli GN Division
N
40m
33 m
Indian Ocean
Legend
shoreline_2021
shoreline_2011
shoreline_2001
shoreline_1991
Salli_GN_Division
0
0.25
0.5
1 km
8°39'15"N
8°39'0"N
8°38'45"N
8°38'30"N
8°38'15"N
8°38'0"N
8°37'45"N
8°37'30"N
81°13'0"E
81°13'15"E
81°13'30"E
81°13'45"E
81°14'0"E
81°14'15"E
81°14'30"E

**Figure 4: Coast line change of Salli GN Division**

Automatic coastline extraction using "Tasseled Cap" is used in this study to extract the shoreline from satellite images for 1991, 2001, 2011, and 2021. The rate of shoreline change was calculated using DSAS, an ArcGIS plugin. The rates of shoreline erosion/accretion were computed using two different statistical approaches: End Point Rate (EPR) for short-term changes and Linear Regression Rate (LRR) for long-term changes. An onshore baseline parallel to the extracted shoreline was built. DSAS generated 221 transects at 20 m spacing along the coast of the Salli GN division (Figure 4). At each transect, the rate of shoreline change was calculated. The LRR and EPR maps of the Salli GN division coast are shown in Figure 5 and Figure 7. These maps depict the pattern of erosion and accretion. The shorelines were categorized according to the value range of LRR and EPR, as shown in Table 2. Shoreline 2021 obtained an overall shoreline extraction accuracy of 88.12 % and a Kappa coefficient (overall kappa statistics) of 0.8477.

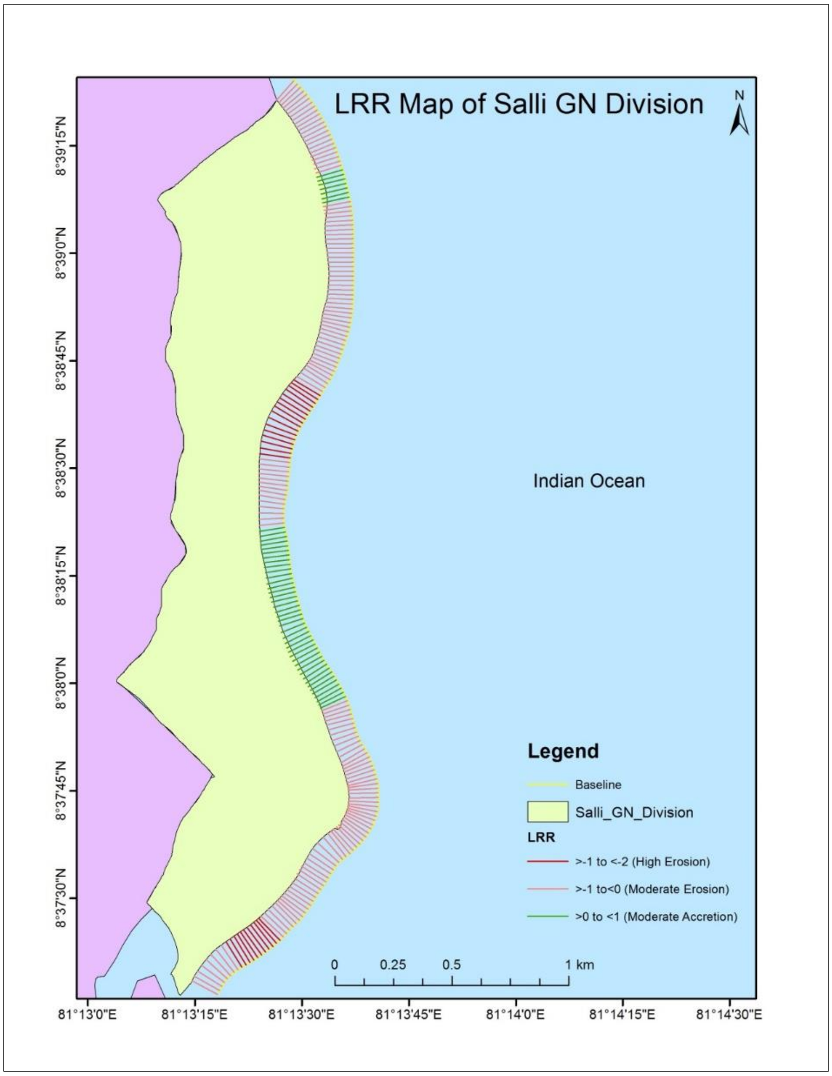


**Figure 5: LRR Map of Salli GN Division**

The trend of accretion and erosion was calculated over 221 transects along the coast of the study area (Figure 2, Figure 5 and Figure 7). Despite the fact that the findings of this study revealed both erosion and accretion, most parts of the coast of the study area experience erosion (Figure 5and Figure 7). An overall average of 0.237m/yr (LRR) accretion and -0.676 m/yr (LRR) erosion was noticed along the coast of Salli GN division. Maximum accretion/erosion rates of 0.28 m/yr and -0.671 m/yr are observed along the coat of the Salli GN division based on EPR. High eroding shorelines are observed at transect from 9-19 and 134-149, whereas moderate prograding shorelines are observed at transect form 80-119, and 193-199 (Figure 2, Figure 5 and Figure 7). Transect from 20 to 68 predominantly falls under the moderate erosion category. (Figure 2, Figure 5 and Figure 7) High erosion rate is noticed at transects 143 at the rate of -1.470 m/yr (LRR) and -1.410 m/yr (EPR), whereas very high accretion rate is observed at transect 93 at the rate of 0.50 m/yr (LRR) and 0.64 m/yr (EPR) (Figure 2, Figure 5 and Figure 7). Table 3: Shoreline change trend summarizes the rate of shoreline change, where the positive rate of shoreline change represents accretion and the negative rate of shoreline change represents erosion.


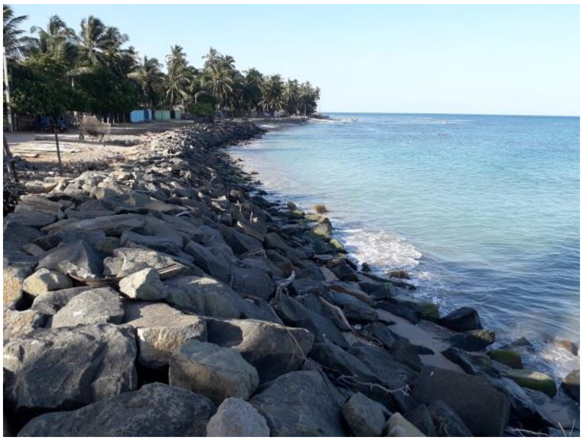

**Figure 6: Coastal erosion in Salli GN division (Source: Google Earth & Field Study, 2021)**

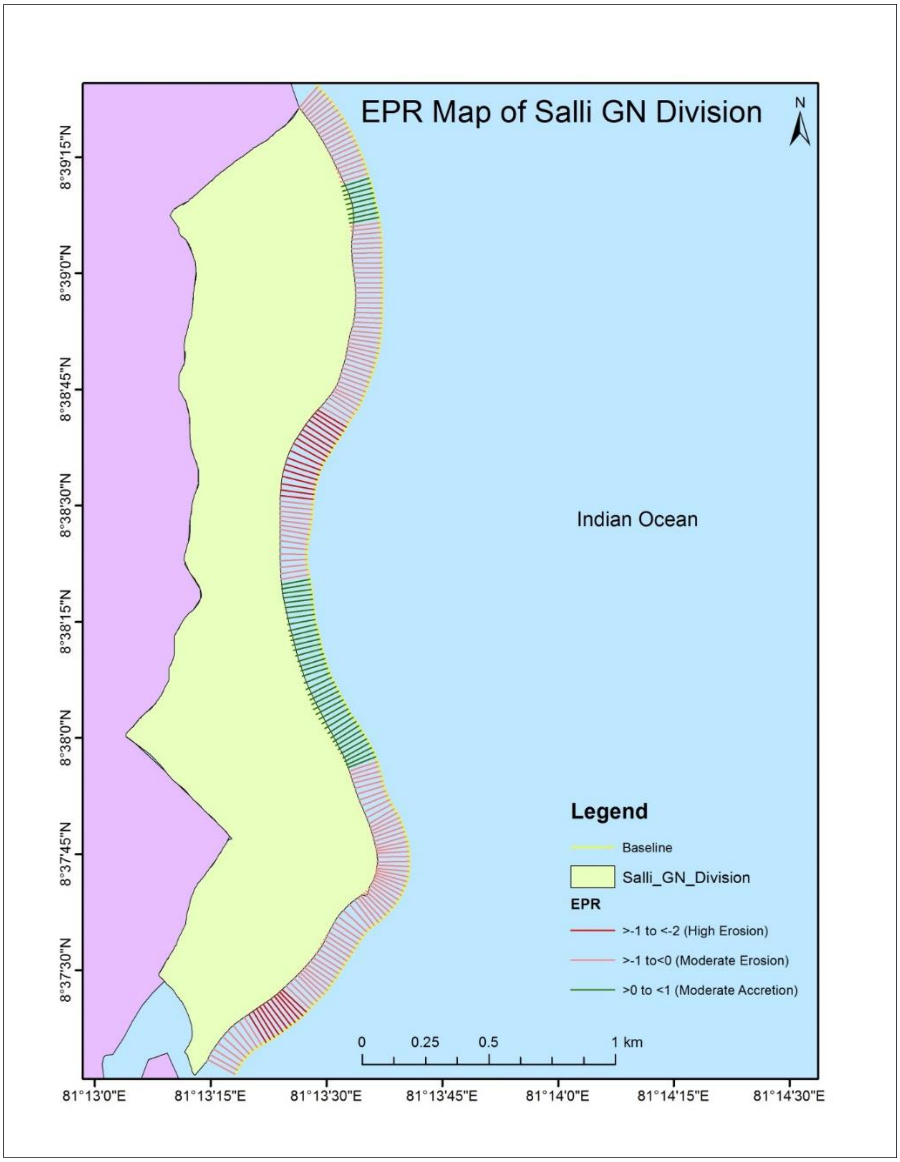


**Figure 7: EPR Map of Salli GN Division**

The rate of shoreline change obtained by EPR and LRR was compared with EPR vs LRR (Figure 8). Figure 8 showed a good correlation between EPR vs LRR for the period of 30 years from 1991 to 2020. The rate of shoreline change obtained by EPR, LRR statistical approach is very close in the study area (Figure 9).

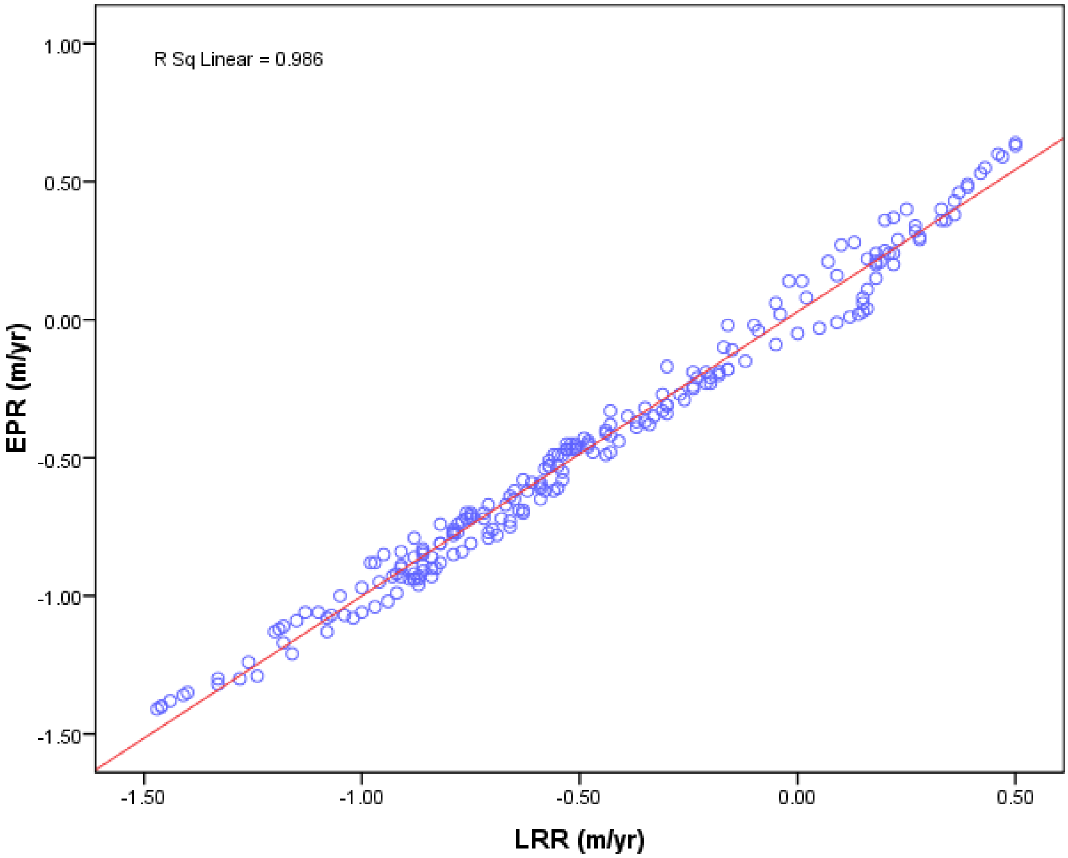


**Figure 8: Comparison of shoreline rates obtained by EPR, LRR.**

The EPR, and LRR values (m/year) were calculated along all transects (1618) of the study area during the period (1991 to 2021).

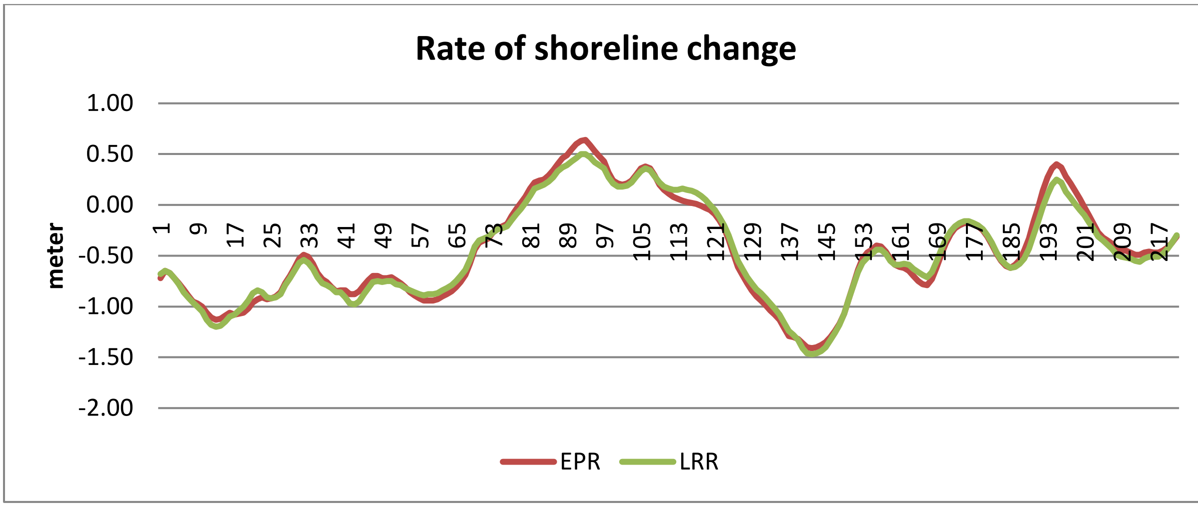


**Figure 9: EPR and LRR values (m/yr) calculated along all transects (221) of the study area during the period (1991-2021)**

**Table 3: Shoreline change trend**

| **Descriptive** | | **EPR** | **LRR** |
|---|---|---|---|
| No of Transects | 221 | | |
| Transect length (m) | 150 | | |
| Baseline length (m) | 4.3km | | |
| Baseline distance (m) | 100m | | |
| Max. accretion rate (m/yr) | | 0.64 | 0.50 |
| Max. erosion rate (m/yr) | | -1.41 | -1.47 |
| Erosion trend (m/yr) | | -0.67 | -0.676 |
| Accretion trend (m/yr) | | 0.28 | 0.237 |

The coastal erosion was the most significant at the Salli GN division's coast, with a maximum shoreline movement of 40 m towards the land. According to the findings, a receding shoreline was found along the study area, which was driven by natural processes as well as human activities. According to the key informant interviews, the main causes of coastal erosion of the study area are intense wave action and fishing. The coastal erosion in the study area has increased since it has been used by fishermen as a landing site for many decades. Parking fishing boats and boat wakes are some of the activities that harm coastal erosion and exacerbate it in the study area. Also, They mentioned that the intensity of the waves varies seasonally and during the rainy season the erosion is particularly high (November to January). The construction of a seawall along the coast is most remarkable, showing the intensity of the erosion along the coast (Figure 6). However, the key informant pointed out the construction of the seawall did not support to prevention of the coastal erosion of this area. Furthermore, it was seen that a segment of the seawall, which was built by the Department of Coast Conservation, Sri Lanka, was demolished by heavy wave action (Figure 06).

## Conclusion

The coast line change analysis was conducted along the Salli GN division's coast for a period of 30 years, from 1991 to 2021. The study area's coast line change was readily and quickly determined using Arc GIS and the DSAS extension. The changes were measured for the following years: 1991, 2001, 2011, and 2021. According to the study, the spatial and temporal scale of shoreline modification differs significantly.

According to the findings, out of the 4.3 km shoreline, approximately 3.38 km of coastline experiences erosion, and 0.92 km is under accretions. The entire coast of the study was classified into three categories, including high erosion, moderate erosion, and modrate accretion. According to the long-term analysis (LLR), 78.60% of the coast is subjected to erosion, while 21.4% of the shoreline subjected to accretion. A shoreline change in the study area is caused by natural processes as well as a human activity. However, it should be noted that natural processes and human activities must be studied separately. Despite the fact that artificial structures (seawalls) are constructed for protection, a regular monitoring process is required to analyze their impacts. LRR is a better technique for understanding shoreline changes since it analyzes the uncertainties/errors associated with each coastline position in relation to the data quality. According to the findings of this study, the

Department of Coast Conservation should consider the future of the coast under consideration by adopting management strategies to defend against erosion. Therefore, the current study suggests that suitable coastal nourishment projects should be implemented in the study area in order to preserve the coast from disaster.

## References

Abu Zed, A. A., Soliman, M. R., & Yassin, A. A. (2018). Evaluation of using satellite image in detecting long term shoreline change along El-Arish coastal zone, Egypt. *Alexandria Engineering Journal*, *57*(4), 2687–2702. https://doi.org/10.1016/j.aej.2017.10.005

Airoldi, L., Abbiati, M., Beck, M. W., Hawkins, S. J., Jonsson, P. R., Martin, D., Moschella, P. S., Sundelöf, A., Thompson, R. C., & Åberg, P. (2005). An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. *Coastal Engineering*, *52*(10–11), 1073–1087. https://doi.org/10.1016/j.coastaleng.2005.09.007

Castelle, B., Guillot, B., Marieu, V., Chaumillon, E., Hanquiez, V., Bujan, S., & Poppeschi, C. (2018). Spatial and temporal patterns of shoreline change of a 280-km high-energy disrupted sandy coast from 1950 to 2014: SW France. *Estuarine, Coastal and Shelf Science*, *200*, 212–223. https://doi.org/10.1016/j.ecss.2017.11.005

Ciritci, D., & Türk, T. (2020). Correction to: Automatic Detection of Shoreline Change by Geographical Information System (GIS) and Remote Sensing in the Seyhan Delta, Turkey (Journal of the Indian Society of Remote Sensing, (2019), 47, 2, (233-243), 10.1007/s12524-019-00947-1). *Journal of the Indian Society of Remote Sensing*, *48*(6), 959–962. https://doi.org/10.1007/s12524-020-01116-5

Dastgheib, A., Jongejan, R., Mehvar, A., & Ranasinghe, R. (2018). *Coastal Risk Assessment along the East Coast of Sri Lanka* (Issue January).

Dastgheib, A., Jongejan, R., Wickramanayake, M., & Ranasinghe, R. (2018). Regional scale risk-informed land-use planning using Probabilistic Coastline Recession modelling and economical optimisation: East Coast of Sri Lanka. *Journal of Marine Science and Engineering*, *6*(4), 1–32. https://doi.org/10.3390/jmse6040120

Dewi, R. S., & Bijker, W. (2020). Dynamics of shoreline changes in the coastal region of Sayung, Indonesia. *Egyptian Journal of Remote Sensing and Space Science*, *23*(2), 181–193. https://doi.org/10.1016/j.ejrs.2019.09.001

Divisional Secretariat - Trincomalee Town & Gravets. (2018). Statistical Details 2018-population. In *Divisional Secretariat - Trincomalee Town & Gravets*. http://www.trincomalee.ds.gov.lk/images/PDF/Statistical_Information_2018/Population_Details/Ethnic-Wise-Population---2018.pdf

Dube, K., Nhamo, G., & Chikodzi, D. (2020). Rising sea level and its implications on coastal tourism development in Cape Town, South Africa. *Journal of Outdoor Recreation and Tourism*, *33*(2021), 100346. https://doi.org/10.1016/j.jort.2020.100346

Guneroglu, A. (2015). Coastal changes and land use alteration on Northeastern part of Turkey. *Ocean and Coastal Management*, *118*, 225–233. https://doi.org/10.1016/j.ocecoaman.2015.06.019

Hakkou, M., Maanan, M., Belrhaba, T., El khalidi, K., El Ouai, D., & Benmohammadi, A. (2018).

Multi-decadal assessment of shoreline changes using geospatial tools and automatic computation in Kenitra coast, Morocco. *Ocean and Coastal Management*, *163*(January), 232–239. https://doi.org/10.1016/j.ocecoaman.2018.07.003

Harley, M. D., Kinsela, M. A., Sánchez-García, E., & Vos, K. (2019). Shoreline change mapping using crowd-sourced smartphone images. *Coastal Engineering*, *150*, 175–189. https://doi.org/10.1016/j.coastaleng.2019.04.003

Jaspal, R. (2020). Content Analysis Thematic Analysis and Discourse Analysis. In G. M. Breakwell, D. B. Wright, & J. Barnett (Eds.), *Research Methods in Psychology* (5th ed., pp. 285–312). Sage Publications Ltd.

Jayasingam, T. (2008). Eastern Province Biodiversity Profile and Conservation Action Plan. *Biodiversity Secretariat, Ministry of Environment and Natural Resources*, 1–44.

Kankara, R. S., Selvan, S. C., Markose, V. J., Rajan, B., & Arockiaraj, S. (2015). Estimation of long and short term shoreline changes along Andhra Pradesh coast using remote sensing and GIS techniques. *Procedia Engineering*, *116*(1), 855–862. https://doi.org/10.1016/j.proeng.2015.08.374

Kermani, S., Boutiba, M., Guendouz, M., Guettouche, M. S., & Khelfani, D. (2016). Detection and analysis of shoreline changes using geospatial tools and automatic computation: Case of jijelian sandy coast (East Algeria). *Ocean and Coastal Management*, *132*, 46–58. https://doi.org/10.1016/j.ocecoaman.2016.08.010

Kottawa-Arachchi, J. D., & Wijeratne, M. A. (2017). Climate change impacts on biodiversity and ecosystems in sri lanka: A review. *Nature Conservation Research*, *2*(3), 2–22. https://doi.org/10.24189/ncr.2017.042

Kuleli, T., Guneroglu, A., Karsli, F., & Dihkan, M. (2011). Automatic detection of shoreline change on coastal Ramsar wetlands of Turkey. *Ocean Engineering*, *38*(10), 1141–1149. https://doi.org/10.1016/j.oceaneng.2011.05.006

Lin, L., & Pussella, P. (2017). Assessment of vulnerability for coastal erosion with GIS and AHP techniques case study: Southern coastline of Sri Lanka. *Natural Resource Modeling*, *30*(4), 1–12. https://doi.org/10.1111/nrm.12146

Marzouk, M., Attia, K., & Azab, S. (2021). Assessment of Coastal Vulnerability to Climate Change Impacts using GIS and Remote Sensing: A Case Study of Al-Alamein New City. *Journal of Cleaner Production*, *290*, 125723. https://doi.org/10.1016/j.jclepro.2020.125723

Mehvar, S., Dastgheib, A., Bamunawala, J., Wickramanayake, M., & Ranasinghe, R. (2019). Quantitative assessment of the environmental risk due to climate change-driven coastline recession: A case study in Trincomalee coastal area, Sri Lanka. *Climate Risk Management*, *25*(November 2018), 100192. https://doi.org/10.1016/j.crm.2019.100192

Moussaid, J., Fora, A. A., Zourarah, B., Maanan, M., & Maanan, M. (2015). Using automatic computation to analyze the rate of shoreline change on the Kenitra coast, Morocco. *Ocean Engineering*, *102*, 71–77. https://doi.org/10.1016/j.oceaneng.2015.04.044

Natesan, U., Parthasarathy, A., Vishnunath, R., Kumar, G. E. J., & Ferrer, A. (2015). Monitoring longterm shoreline changes along Tamil Nadu , India using geospatial techniques. *Aquatic Procedia*, *4*, 325–332. https://doi.org/10.1016/j.aqpro.2015.02.044

Ozturk, D., & Sesli, F. A. (2015). Shoreline change analysis of the Kizilirmak Lagoon Series. *Ocean and Coastal Management*, *118*, 290–308. https://doi.org/10.1016/j.ocecoaman.2015.03.009

Raj, N., Gurugnanam, B., Sudhakar, V., & Francis, P. G. (2019). Estuarine shoreline change analysis along The Ennore river mouth , south east coast of India , using digital shoreline analysis system. *Geodesy and Geodynamics*, *April*, 1–8. https://doi.org/10.1016/j.geog.2019.04.002

Ratnayakage, S. M. S., Sasaki, J., Suzuki, T., Jayaratne, R., Ranawaka, R. A. S., & Pathmasiri, S. D. (2020). On the status and mechanisms of coastal erosion in Marawila Beach, Sri Lanka. *Natural Hazards*, *103*(1), 1261–1289. https://doi.org/10.1007/s11069-020-04034-4

Senevirathna, E. M. T. K., Edirisooriya, K. V.D., Uluwaduge, S. P., & Wijerathna, K. B. C. A. (2018). Analysis of Causes and Effects of Coastal Erosion and Environmental Degradation in Southern Coastal Belt of Sri Lanka Special Reference to Unawatuna Coastal Area. *Procedia Engineering*, *212*, 1010–1017. https://doi.org/10.1016/j.proeng.2018.01.130

Toure, S., Diop, O., Kpalma, K., & Maiga, A. S. (2019). Shoreline detection using optical remote sensing: A review. *ISPRS International Journal of Geo-Information*, *8*(2). https://doi.org/10.3390/ijgi8020075

Yasir, M., Hui, S., Hongxia, Z., Hossain, M. S., Fan, H., Zhang, L., & Jixiang, Z. (2021). A Spatiotemporal change detection analysis of coastline data in Qingdao, East China. *Scientific Programming*, *2021*. https://doi.org/10.1155/2021/6632450