Detection of shoreline changes using GIS and DSAS technique: Case of Kuchchaveli DS Division, the East coast of Sri Lanka

Vyddiyaratnam Pathmanandakumar[1]

Abstract

Coastal erosion is affecting a large number of coastal areas.The coastal zone consists of immense geological, geomorphological, and ecological interests. The shoreline change has its impact, but it is mostly invisible. There should be a long and continuous set of data to observe the effects of shoreline change. This study aims to detect and analyse the shoreline changes along the Kuchchaveli DS Division coast between 1991 and 2021 using geographic information systems (GIS) and Digital Shoreline Analysis System (DSAS). Landsat imageries were geometrically and radiometrically corrected for the quantitative coastline delineation analysis. DSAS was used as a reliable statistical approach for the rate of coastline change. The shoreline change rate was demarcated based on End Point Rate (EPR) and Linear Regression Rate of change (LRR). The findings of the study indicate remarkable shoreline changes (1.151m/yr withdrawal and -0.800 m/yr erosion) in some parts of the research area between 1991 and 2021. Even though a large part of the study area show accretion, eroding shorelines are observed in the cost of GN divisions: Thiriyai GN, Senthur GN, Jayanagar GN, Cassim Nagar GN, Kuchchaveli GN, Kumpurupiddi North GN, Velor GN, and Iqbalnagar GN. This research gives a synoptic outlook of the potential threat to the shoreline of the Kuchchaveli DS division, allowing for the adoption of appropriate measures to prioritise the management of the coast.

Keywords: Accretion, DSAS, Erosion, GIS, Shoreline change

Introduction

Coastal zones consist of essential ecosystem services and ecological productivity, which have traditionally been the source of wealth for many communities involved in the fishing and aquaculture industry. The beaches were great places for leisure and recreation. Since then, demand for coastal tourism has increased, leading to intense exploitation of the coast (Rodríguez et al., 2009). Detection of shoreline changes in time is essential for monitoring and managing coastal zones. Li et al. (2001) Defined a shoreline as the line of contact between land and a body of water (Aedla et al., 2015). Further, Genz et al. (2007) defined shoreline as the position of the land-water interface at one point in time (Hakkou et al., 2018). The area, such as Geographical exploration, coastal erosion monitoring, coastal resource management, seeks essential information about coastal line position, orientation, and geometric shapes (Liu & Jezek, 2004).

Coastal erosion affects more than 70% of the world's coastal regions. Shoreline change is considered one of the most dynamic processes in coastal areas, and observed changes indicate

[1] Attached to Department of Geography, Faculty of Arts & Culture, Eastern University, Sri Lanka. Email: pathmananthakumarv@esn.ac.lk

coastal erosion or accretion (Castelle et al., 2018). Both natural processes and anthropogenic activities induced shoreline change (Senevirathna et al., 2018). The most prominent natural contributors are winds and storms, near-shore currents, relative sea-level rise, and slope processes. 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).

Shoreline changes occur over a wide range of time scales, from geological to short-lived extreme events (Natesan et al., 2015). The shift in shoreline is mainly associated with waves, tides, winds, periodic storms, sea-level change, and the geomorphic processes of erosion and accretion and human activities (Salghuna & Bharathvaj, 2015). Shoreline also depicts the recent formations and destructions along the shore. Waves change the coastline morphology and form distinctive coastal landforms (Salghuna & Bharathvaj, 2015). Marfai et al. (2008) mention that mapping shoreline changes became important as input data for coastal hazard assessment (Kuleli et al., 2011). Shoreline changes have become one of the major environmental problems affecting the coastal zones worldwide in recent years. Indeed, nearly 80% of the world's coasts are eroding, with rates ranging from 1 cm/year to 10 m/year (Pilkey & Hume, 2001).

The spatial and temporal analysis of shoreline changes has been the subject of several studies worldwide (Abu Zed et al., 2018; Aedla et al., 2015; Alesheikh et al., 2007; Castelle et al., 2018; Ford, 2013; Gopikrishna & Deo, 2018; Guneroglu, 2015; Hakkou et al., 2018; Harley et al., 2019; Kaliraj et al., 2017; Kankara et al., 2015; Kermani et al., 2016; Klein & Lichter, 2006; Kuleli et al., 2011; Li & Damen, 2010; Liu & Jezek, 2004; Maiti & Bhattacharya, 2009; Misra & Balaji, 2015; Moussaid et al., 2015; Ozturk & Sesli, 2015; Pilkey & Hume, 2001; Ramírez-Cuesta et al., 2016; Rodríguez et al., 2009; Salghuna & Bharathvaj, 2015; Shetty et al., 2015; Toure et al., 2019). Coastal areas continually modify due to a wide variety of phenomena, such as sea level variation, storm surge, tidal inundations, tectonic and land subsidence, sediment budget change, and human activities that play fundamental roles in coastal erosion (Hakkou et al., 2018). Coastal erosion often influences hundreds of kilometres of shoreline and represents a severe socio-economic problem at both the local and regional levels.

Sri Lanka is a country with many 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 and substantial economic and social demands (Senevirathna et al., 2018). Since the 1980s, coastal erosion has been a primary 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 erosion rate 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 due to 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 threaten Trincomalee district's coastal areas (beaches) (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).

Understanding long-term shoreline changes is an essential step for managing the coastal area (Aiello et al., 2013; Ozturk & Sesli, 2015). Hence, authorities need to identify the status of the coastal erosion in the Trincomalee district. In addition, a limited number of studies on coastal erosion within the study area have been undertaken to date. Those studies mainly focus on the socio-economic and environmental impacts of coastal erosion. However, In the current study, the status of coastal erosion is integrated into the Geographical Information System (GIS) platform with the help of the Digital Shoreline Analysis System (DSAS) technique to identify the eroding and prograding coast within the study area. Identifying, monitoring, and conserving the coast is essential for informed coastal conservation and management. Thus, identifying shoreline change using an appropriate technical approach is necessary to address the coastal erosion in the district. GIS and Remote sensing-based approaches provide a better platform for collecting shoreline positional information, which enables estimating shoreline changes. Kuchchaveli Divisional Secretary (DS) division is one of the most vulnerable divisional secretariats in the Trincomalee district to coastal erosion. Also, most of the Grama Niladhari

(GN) divisions in this DS division are connected to the coast area, and the people who live in those GN divisions have been active in fishing for a long time. The fishing community in the Kuchchaveli DS division is facing a tremendous problem due to coastal erosion. It is critical to investigate the trend and pattern of coastal erosion in this research region. Therefore, this paper aims to detect and analyse the shoreline changes along the Kuchchaveli Divisional Secretary (DS) Division coast between 1991 and 2021 using GIS and DSAS techniques.

Study Area

Kuchchaveli DS division is located in the Trincomalee District in the East part of Sri Lanka. It lies between $8^0$30'0"- $8^0$56'0" N Latitude and $81^0$2'0"- $81^0$14'0" E Longitude and has an area of 438 km^2 with an approximately 45 km long coast (Department of Census & Statistics, 2013) (Figure 1). The Kuchchaveli DS division coastal area, comprising sandy beaches, bays, mangroves, and marine landscapes (Pathmanandakumar, 2019). The study area climate is characterised by an irregular sub-tropical humid with two seasons: a cold and rainy winter and a hot and dry summer. However, the proximity effect of the sea confers to this area a temperate climate. Indeed, the summer season ranging from April to October is characterised by relatively moderate temperatures 27.8^{0}C. The average annual rainfall is greater than 1631mm. The study area comprises some settlements. Generally, fishing on the shore, aquaculture by the near-shore area, and agricultural cultivation in the land are mainly adapted.

Kuchchaveli Divisional Secretary Division is the longest DS Division in Trincomalee District with approximately 48 km long coastline. It is situated in the Eastern coastal area. The total Geographical area of the Kuchchaveli Divisional Secretary Division is 504.23 Sq. Km (Divisional Secretariat - Kuchchaveli, 2021). There are 24 GN divisions under Kuchchaveli Divisional Secretary Division i.e Periyakulam, Iqbal Nagar, Veloor, Nilaveli, Gopalapuram, Vaalaiyootru, Irakakandy, Kumpurupity South, Kumpurupity North, Kumpurupity East, Iranaikeny, Veerancholai, Kuchchaveli, Casim Nagar, Jayanagar, Senthoor, Kattukulam, Kallampathai, Thiriyai, Pulmoddai - 01, Pulmoddai - 02, Pulmoddai - 03, Pulmoddai - 04, Thennamaravady (Divisional Secretariat - Kuchchaveli, 2021). 19 of the 24 GN divisions are connected with coastal areas, such as Periyakulam, Iqbal Nagar, Veloor, Nilaveli, Gopalapuram, Vaalaiyootru, Irakakandy, Kumpurupity East, Iranaikeny, Veerancholai, Kuchchaveli, Casim Nagar, Jayanagar, Senthoor, Thiriyai, Pulmoddai - 01, Pulmoddai - 02, Pulmoddai - 03, Pulmoddai - 04. The population of the Kuchchaveli Divisional Secretariat is

42,577 persons as per the latest figures released by Kuchchaveli Divisional Secretariat. The statistics show that males and females were 21,059 and 21,518, respectively (Divisional Secretariat - Kuchchaveli, 2021). As per the statistical report 2020 of the Kuchchaveli Divisional Secretariat, the population density of the Kuchchaveli Divisional Secretary Division is 84.43 persons per Sq. Km. Kuchchaveli Divisional Secretary Division has different occupational structure (Divisional Secretariat - Kuchchaveli, 2021). Due to a coastline of about 48 km, Divisional Secretary Division is one of the most important maritime Divisional Secretariat of the Trincomalee district. Fishing is considered the major occupation, and 3703 persons have been involved in fishing as a means of livelihood (Divisional Secretariat - Kuchchaveli, 2021). The fishing industry is mainly dependent upon marine resources.

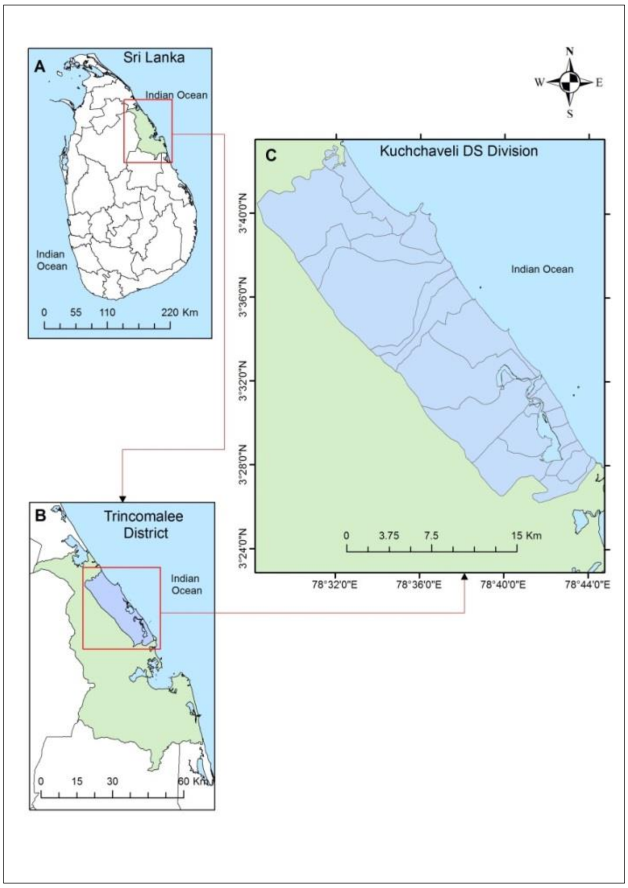

Figure 1: Location of the Study Area: (A) map of Sri Lanka, (B) Map of Trincomalee District (C)Tthe extend of Kuchchaveli DS division

Materials and Methodology

Landsat Multi-spectral Scanner (MSS), Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) data have been widely used in coastal research and environmental studies for many years (Kuleli et al., 2011). Multi-spectral features and easy availability make Landsat suitable for monitoring coastline change (Kuleli et al., 2011). In this study, TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus), and OLI (Operational Land Imager) datasets acquired for the period 1991-2021 were used as primary data sources to demarcate the shoreline changes along the Kuchchaveli DS division coast. The transformation of the coast in the study area was analysed for a period of 30 years (1991 to 2021), which is considered as medium-term analysis (Hegde & Akshaya, 2015). Satellite imageries from 1991-2021 were obtained from the Earth Explorer (USGS), and they are collected in multiple time periods (1991,2000,2010,2021) (Figure 4).

The data used for the study were selected based on the criteria of cloud cover less than 10%, the season in which the data was acquired. The datasets were obtained predominantly from June to October to acquire cloud-free images. Data has been processed in Arc GIS 10.4.1 software. All the image sets are projected in UTM projection with zone no 44N and WGS 1984 datum. In this study, shoreline changes in spatial and temporal aspects were analysed using integrated remote sensing, GIS, and DSAS technology (Figure 4). Further information about the specifications of satellite data used in the study is given in (
Table 1).

Table 1: Specifications of satellite data

Path/Raw	**Acq. date**	**Sensor**	**File Type**	**Resolution**	**Data Source**
141/54	1991-09-03	"TM"	"GEOTIFF"	30m	USGS
141/54	2000-07-17	"ETM"	"GEOTIFF"	30m	USGS
141/54	2010-06-03	"TM"	"GEOTIFF"	30m	USGS
141/54	2021-06-01	"OLI_TIRS"	"GEOTIFF"	30m	USGS

Various techniques have been developed for coastline extraction and change detection from satellite imagery, for instance, manual, write function memory insertion, image enhancement, multi-date data classification and comparison of two independent land cover classifications, density slice using single or multiple bands and multi-spectral classification (Kuleli et al., 2011).

Figure 2: Shoreline change of the coast of Kuchchaveli DS division (1991-2021)

The Landsat satellite images obtained were taken as an input for spectral pre-processing. Using the layer stacking method, the individual bands of the satellite data were converted into a False Colour Composite image. The geometric transformation was done using a first-order polynomial equation. The shorelines datasets from the multi-date satellite data from 1991 to 2021 were extracted using Arc GIS 10.4.1 software (Figure 4).

The determination of a shoreline position in satellite data is a very subjective one. In the past, researchers had used various proxies for shoreline positions such as high tide line, high water line (HWL), wet-dry line, vegetation line, dune line, toe, or berm of the beach, cliff base or top, mean high water (MHW) line. After considering all these factors, the high water line (HWL) mark (the effective shoreline is equivalent "wet/dry line" of the previous tide) is found most appropriate to monitor the changes (Ozturk & Sesli, 2015). High waterline boundary (HWL) was considered the shoreline proxy and demarcated using Arc GIS software. The shoreline positions were compiled in ArcGIS with five attribute fields: Object ID, shape (polyline), shape length, ID, date (original survey year), and uncertainty values. All different shoreline features were merged as a single feature on the attribute table, which enabled the multiple coastline files to be appended together into a single shapefile. DSAS version 5.0, an extension to ArcGIS developed by the USGS, was used to calculate the shoreline change rate (Figure 4).

The vector layers of shorelines were overlaid, and erosion/accretion rates were calculated at 50 m intervals along the Kuchchaveli DS division coast using the Digital Shoreline Analysis System (DSAS). Several statistical methods are used to calculate the shoreline change rates, with the most commonly used being End Point Rate (EPR) calculations or Linear Regression Rate (LRR) of change (Guneroglu, 2015; Kankara et al., 2015; Kermani et al., 2016; Kuleli et al., 2011; Moussaid et al., 2015; Nassar et al., 2018). EPR and LRR are the most commonly applied statistical technique for expressing shoreline movement and estimating rates of change (Guneroglu, 2015; Kankara et al., 2015; Kermani et al., 2016; Kuleli et al., 2011; Moussaid et al., 2015; Nassar et al., 2018). EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements. The following equation is used for EPR calculation.

$$\mathrm{EPR}\left(\frac{\mathrm{m}}{\mathrm{y}}\right) = \frac{\text{Distance (A} - \text{B)in meter}}{\text{Time between youngest and oldest shoreline}} \qquad (1)$$

In the present study, shoreline changes were estimated using EPR and LRR. The LRR can be determined by fitting a least-squares regression line to all shoreline

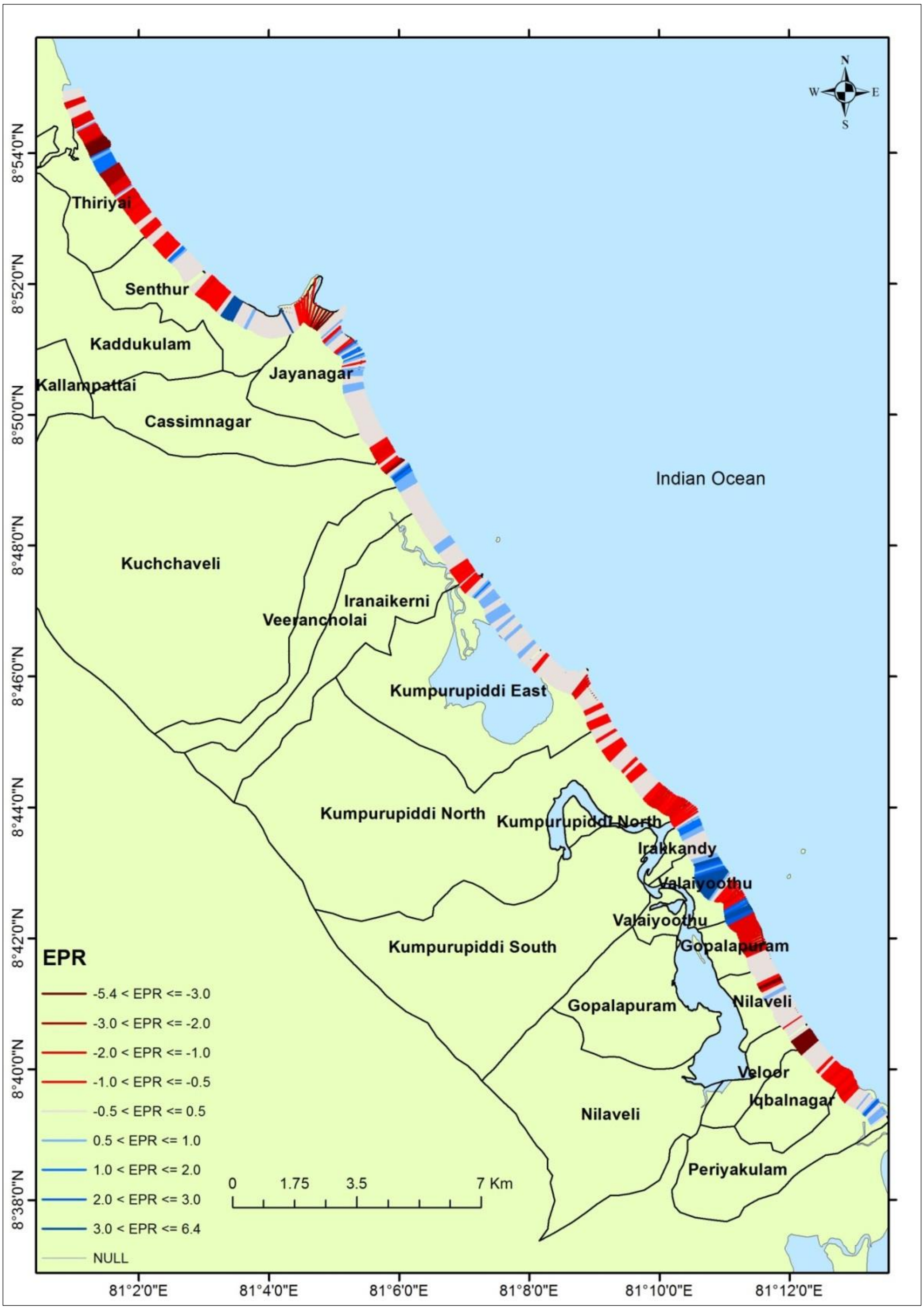

Figure 3:EPR Maps of the coast of Kuchchaveli DS Division

points for a particular transect obtained from the analysis (Kermani et al., 2016; Nassar et al., 2018). An on-shore baseline was created with a position of approximately 500m distance behind the shorelines to assess the shoreline trend. The erosion/accretion regimes were calculated for 50 m orthogonal transects along the coastline based on the baseline and shoreline. The beach widths (m) variation was calculated for each transect to obtain shoreline change rates (m/y). Positive LRR values represent shoreline movement towards the sea (i.e., the rate of accretion), and negative values indicate movement towards the land (i.e., the rate of erosion) (Nassar et al., 2018). Transect shoreline intersections along this baseline are then used to calculate the rate of change statistics. Finally, the obtained erosion and accretion rates for the Kuchchaveli DS division coast were divided into seven categories (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 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.

A snowball sampling technique was adopted to communicate with the local residents (Key informants). Fifteen key informant interviews were done in all. Consent was obtained voluntarily. Each interview lasted between 15 and 20 minutes. Throughout the interviews, notes were taken. Following the data gathering process, interview data were transcribed and cleaned, and thematic analysis was undertaken systematically according to Jaspal (2020).

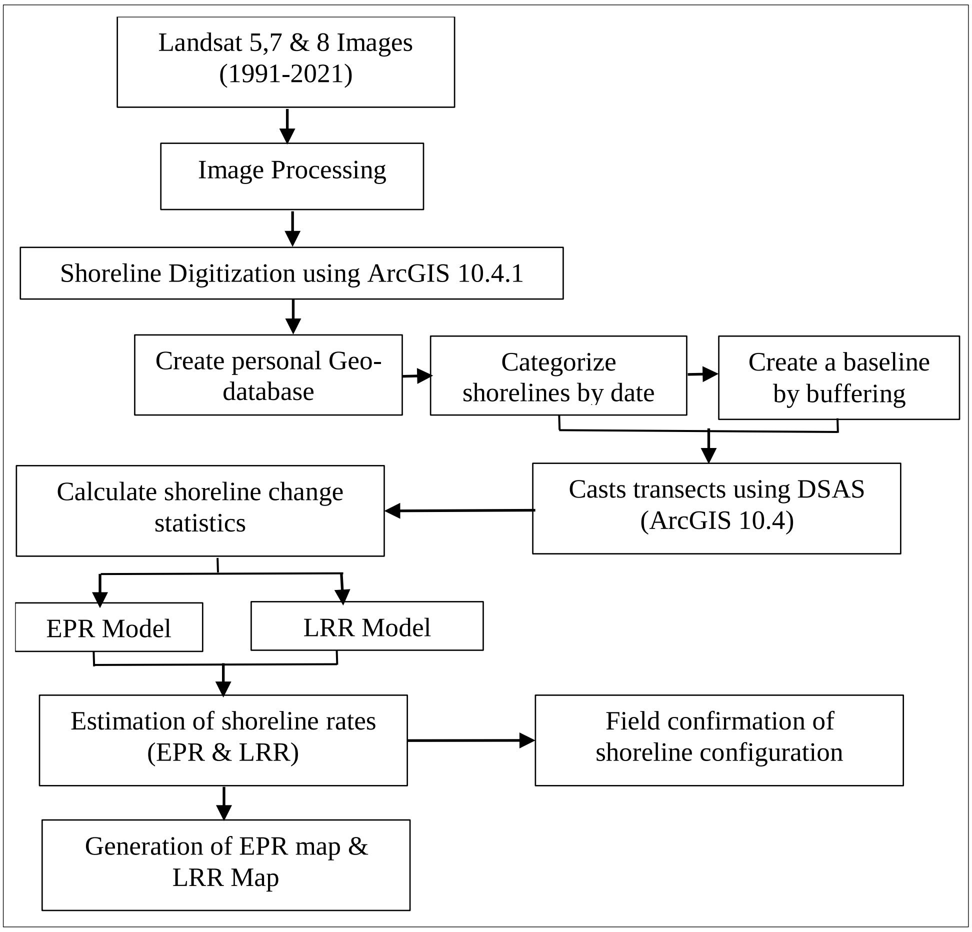

Figure 4: The flowchart of the methodology used for the detection of shoreline change

Result and Discussion

The study of the shoreline change of the Kuchchaveli DS division coast has been delineated from Landsat (30 m resolution) imageries of different years 1991,2000,2010, and 2021 (Figure 2). The coastal erosion and accretion were found on the coast of the Kuchchaveli DS division (Figure 3, Figure 5). The direction of shoreline change was quantified from erosion and accretion of the study area for 30 years from 1991 to 2021 using Remote Sensing and GIS.

DSAS generated 799 transects for the coast of the Kuchchaveli DS division. These transects oriented perpendiculars to the baseline at 50 m spacing along 44.11 km length of Thiriyai GN division coast to Periyakulam GN division coast. The legends in the map are classified according to the range of LRR and EPR of erosion and accretion value, as shown in Figure 3 and Figure 5.

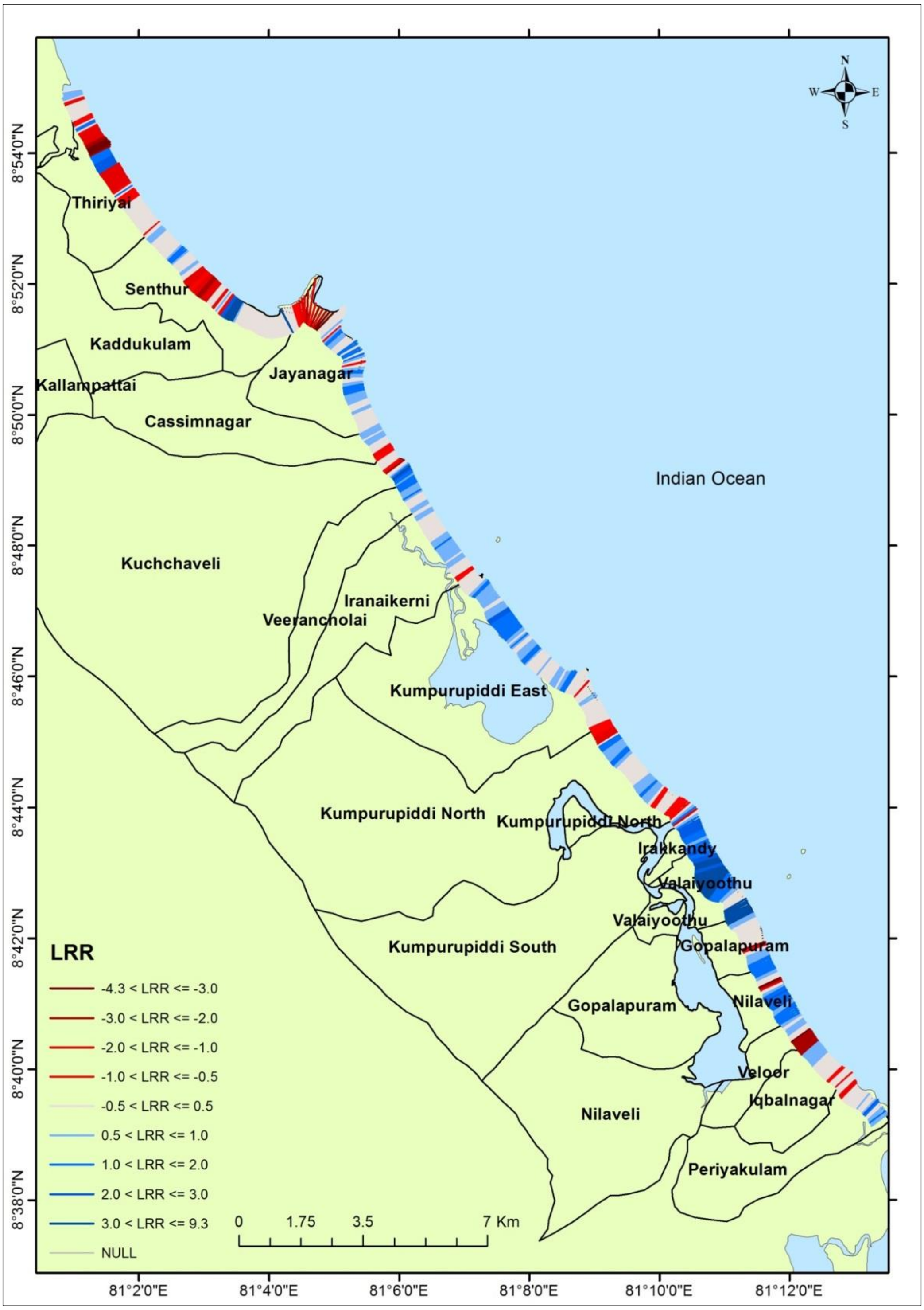

Figure 5: LRR Maps of the coast of Kuchchaveli DS Division

This range classification was carried out in the ArcGIS tool. The process of movements of sediments drives the significant shoreline change in different parts of the coastal area due to the action of physical parameters. The coast has been affected by sea waves, winds, sea currents, tidal activities, etc. Results of Landsat satellite data analysis and DSAS are discussed in detail as follows.

An overall average of 1.151m/yr (LRR) accretion and -0.800 m/yr (LRR) erosion was noticed along the Kuchchaveli DS division coast. Maximum accretion/erosion rates of 6.350 and -5.360 m/yr are observed along the Kuchchaveli DS division coast based on EPR (Figure 6). LRR shows 9.27 and -4.21 m/yr accretion and erosion rates on both locations (Figure 6). Figure 3 and Figure 5 depict the rate of shoreline changes based on EPR and LRR. Eroding shorelines are observed at the following coast of GN division such as Thiriyai GN, Senthur GN, Jayanagar GN, Cassim Nagar GN, Kuchchaveli GN, Kumpurupiddi North GN, Velor GN, and Iqbalnagar GN. In contrast, prograding shorelines are observed at the following coast of GN division: Veerancholai GN, Iranaikerni GN, Kumpurupiddi East GN, Irakkanday GN, Valaiyoothu GN, Kopalapuram GN, Nilaveli GN, Periyakulam GN.

A very high erosion rate is noticed in the cost of Thiriyai GN at the rate of -4.15 (LRR) and -5.19 (EPR) m/yr. In contrast, a very high accretion rate is observed in the coast of Valaiyoothu GN at the rate of 9.27 (LRR) and 4.63 (EPR) m/yr The area of accretion is dominant than the rate of erosion. The negative value in the table indicates erosion, whereas the positive value represents accretion. The table shows the details of EPR and LRR with an uncertainty of (+/-) 4.4m, a default setting of DSAS.

Table 3: Details of EPR and LRR

	EPR(m/yr)	LRR(m/yr)
Mean rate	-0.142	0.492
Standard Deviation	1.316	1.642
Highest accretion	6.350	9.270
Highest erosion	-5.360	-4.210

Accretions have been found on the coast of the study area, which was caused by both natural and human causes. According to key informant interviews, primary drivers of coastal erosion in the study area include high wave action and fishing. Coastline erosion in the study area has accelerated during the decades that it has been used as a landing spot for fishermen. Parking fishing boats and generating boat wakes are only a few activities that contribute to and exacerbate coastal erosion in the study area. Additionally, they stated that the intensity of the waves varies periodically and that erosion is most severe during the rainy season (November to January). It is recommended that revetments built with rocks can be applied along the coast where erosion are high as they have been successfully implemented at sites with a wide range of mean annual erosion rates (0.3–2.4 m/year) and episodic erosion (6.0–22.9 m) due to the low costs and easy construction, inspection, and decommissioning (Liew et al., 2020).

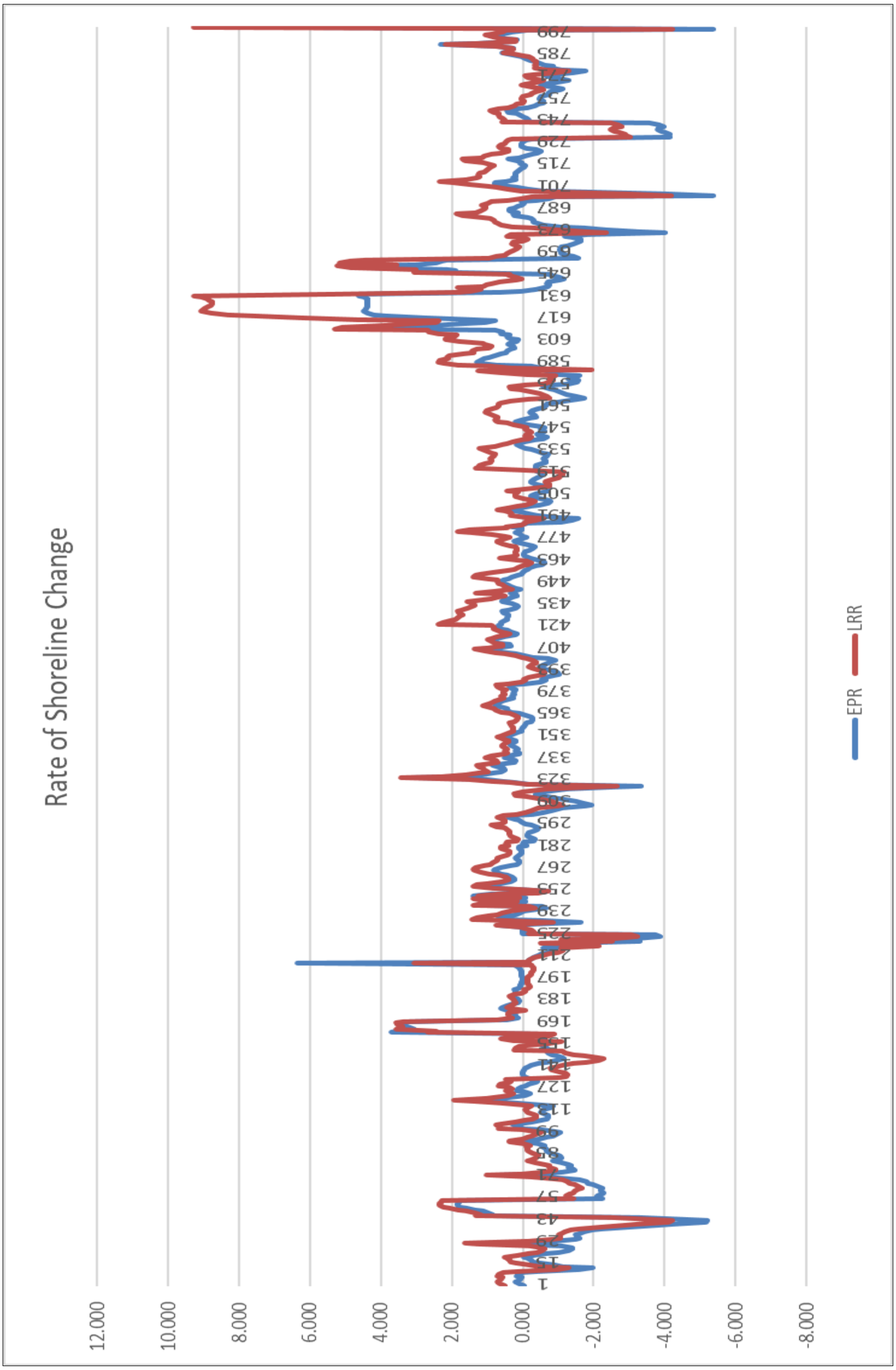

Figure 6: Rate of Shoreline Changes of the coast of Kuchchaveli DS division (1991-2021)

Conclusion

Remote sensing and geospatial techniques, together with DSAS, will be helpful for shoreline change monitoring and provide a comprehensive view of erosion and accretion patterns of the coastal areas. This study focuses on shoreline change detection analysis from 1991 to 2021 using Landsat-satellite imageries, and the results are encouraging. Maximum accretion/erosion rates of 6.350, -5.360 m/yr and 9.270, -4.210 m/yr are observed along the Kuchchaveli DS division coast based on EPR and LRR, respectively. Even though a large part of the study area show accretion, eroding shorelines are observed in Thiriyai GN, Senthur GN, Jayanagar GN, Cassim Nagar GN, Kuchchaveli GN, Kumpurupiddi North GN, Velor GN, and Iqbalnagar GN divisions. A receding shoreline was found along the study area, driven by natural processes and human activities. Based on the observation, the study area's leading causes of coastal erosion are intense wave action and fishing. However, the erosion and creation process vary based on the season. Continuous monitoring of the shoreline is essential for the coastal areas to observe the changes in the future. The results of this study can be useful for the stakeholders, policymakers, coastal managers, scientists, and coastal livelihoods to sustainably manage the Kuchchaveli DS division coast to protect its natural integrity and coastal resources. Coastal erosion has significant socio-economic and environmental impacts. Therefore, a detailed examination of coastal erosion for each GN decision is recommended for future studies to empirically demonstrate the status of coastal erosion of each GN division. The methodology, techniques, and results of the present study may be helpful to assess the coastal erosion in similar coasts in Sri Lanka and the coast of the semi-arid regions around the world. This research will help policymakers better manage the coast and coastal resources and give scope for further research into the impacts of coastal erosion in the area.

Reference

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

Aedla, R., Dwarakish, G. S., & Reddy, D. V. (2015). Automatic Shoreline Detection and Change Detection Analysis of Netravati-GurpurRivermouth Using Histogram Equalization and Adaptive Thresholding Techniques. *Aquatic Procedia*, *4*(Icwrcoe), 563–570. https://doi.org/10.1016/j.aqpro.2015.02.073

Aiello, A., Canora, F., Pasquariello, G., & Spilotro, G. (2013). Estuarine , Coastal and Shelf Science Shoreline variations and coastal dynamics : A space e time data analysis of the Jonian littoral , Italy. *Estuarine, Coastal and Shelf Science*, *129*, 124–135. https://doi.org/10.1016/j.ecss.2013.06.012

Alesheikh, A. A., Ghorbanali, A., & Nouri, N. (2007). Coastline change detection using remote sensing. *International Journal of Environmental Science and Technology*, *4*(1), 61–66. https://doi.org/10.1007/BF03325962

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

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

Department of Census & Statistics, S. L. (2013). *Land area by province , district and divisional secretariat division: Statistical abstract 2011*. https://web.archive.org/web/20131215050207/http://www.statistics.gov.lk/Abstract2011/CHAP1/AB1-2-A.pdf

Divisional Secretariat - Kuchchaveli. (2021). *Statistical Handbook 2020*. Divisional Secretariat - Kuchchaveli. http://kuchchaveli.ds.gov.lk/index.php/en/statistical-information.html#statistical-hand-book-2020

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

Ford, M. (2013). Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. *Remote Sensing of Environment*, *135*, 130–140. https://doi.org/10.1016/j.rse.2013.03.027

Gopikrishna, B., & Deo, M. C. (2018). Changes in the shoreline at Paradip Port, India in response to climate change. *Geomorphology*, *303*, 243–255. https://doi.org/10.1016/j.geomorph.2017.12.012

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

Hegde, A. V., & Akshaya, B. J. (2015). Shoreline Transformation Study of Karnataka Coast : Geospatial Approach. *Aquatic Procedia*, *4*(Icwrcoe), 151–156. https://doi.org/10.1016/j.aqpro.2015.02.021

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.

Kaliraj, S., Chandrasekar, N., & Ramachandran, K. K. (2017). Mapping of coastal landforms and volumetric change analysis in the south west coast of Kanyakumari, South India using remote sensing and GIS techniques. *Egyptian Journal of Remote Sensing and Space Science*, *20*(2), 265–282. https://doi.org/10.1016/j.ejrs.2016.12.006

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

Klein, M., & Lichter, M. (2006). Monitoring changes in shoreline position adjacent to the Hadera power station, Israel. *Applied Geography*, *26*(3–4), 210–226. https://doi.org/10.1016/j.apgeog.2006.01.001

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

Li, X., & Damen, M. C. J. (2010). Coastline change detection with satellite remote sensing for environmental management of the Pearl River Estuary, China. *Journal of Marine Systems*, *82*(SUPPL.), S54–S61. https://doi.org/10.1016/j.jmarsys.2010.02.005

Liew, M., Xiao, M., Jones, B. M., Farquharson, L. M., & Romanovsky, V. E. (2020). Prevention and control measures for coastal erosion in northern high-latitude communities: A systematic review based on Alaskan case studies. *Environmental Research Letters*, *15*(9). https://doi.org/10.1088/1748-9326/ab9387

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

Liu, H., & Jezek, K. C. (2004). Automated extraction of coastline from satellite imagery by integrating Canny edge detection and locally adaptive thresholding methods. *International Journal of Remote Sensing*, *25*(5), 937–958. https://doi.org/10.1080/0143116031000139890

Maiti, S., & Bhattacharya, A. K. (2009). Shoreline change analysis and its application to prediction: A remote sensing and statistics based approach. *Marine Geology*, *257*(1–4), 11–23. https://doi.org/10.1016/j.margeo.2008.10.006

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

Misra, A., & Balaji, R. (2015). A study on the shoreline changes and Land-use/land-cover along the south Gujarat coastline. *Procedia Engineering*, *116*(1), 381–389. https://doi.org/10.1016/j.proeng.2015.08.311

Moussaid, J., Fora, A. A., Zourarah, B., Maanan, M., & Maanan, M. (2015). Using automatic computation to analyse 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

Nassar, K., Mahmod, W. E., Fath, H., Masria, A., Nadaoka, K., & Negm, A. (2018). Shoreline change detection using DSAS technique : Case of North Sinai coast , Shoreline change detection using DSAS technique : Case of North Sinai coast , Egypt. *Marine Georesources & Geotechnology*, *0*(0), 1–15. https://doi.org/10.1080/1064119X.2018.1448912

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

Pathmanandakumar, V. (2019). Mangrove Forest Cover Change Detection Along the Coastline of Trincomalee District, Sri Lanka Using GIS and Remote Sensing Techniques. *Journal of Marine Science Research and Oceanography*, *2*(1). https://doi.org/10.33140/jmsro.02.01.04

Pilkey, O. H., & Hume, T. (2001). The shoreline erosion problem: lessons from the past. *Water and Atmosphere*, *9*(2), 22–23.

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

Ramírez-Cuesta, J. M., Rodríguez-Santalla, I., Gracia, F. J., Sánchez-García, M. J., & Barrio-Parra, F. (2016). Application of change detection techniques in geomorphological evolution of coastal areas. Example: Mouth of the River Ebro (period 1957–2013). *Applied Geography*, *75*, 12–27. https://doi.org/10.1016/j.apgeog.2016.07.015

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

Rodríguez, I., Montoya, I., Sánchez, M. J., & Carreño, F. (2009). Geographic Information Systems applied to Integrated Coastal Zone Management. *Geomorphology*, *107*(1–2), 100–105. https://doi.org/10.1016/j.geomorph.2007.05.023

Salghuna, N. N., & Bharathvaj, S. A. (2015). Shoreline Change Analysis for Northern Part of the Coromandel Coast. *Aquatic Procedia*, *4*(Icwrcoe), 317–324. https://doi.org/10.1016/j.aqpro.2015.02.043

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

Shetty, A., Jayappa, K. S., & Mitra, D. (2015). Shoreline Change Analysis of Mangalore Coast and Morphometric Analysis of Netravathi-Gurupur and Mulky-pavanje Spits. *Aquatic Procedia*, *4*(Icwrcoe), 182–189. https://doi.org/10.1016/j.aqpro.2015.02.025

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