Impacts of Kalu River Estuary Changes on Nearby Coastal Zones from 2017 to 2020: An Integrated Analysis using GIS and DSAS

SLJGEM
SRI LANKA JOURNAL OF GEOGRAPHY AND ENVIRONMENTAL MANAGEMENT
Volume I Issue I, July 2024 :1-84
ISSN: 2773 692X (Online)

Published by the Department of Geography and Environmental Management
Faculty of Social Sciences and Languages
Sabaragamuwa University of Sri Lanka
Website: https://www.sab.ac.lk/sljgem/

Piumi Fonseka and Ananda Y. Karunarathne*
Department of Geography, University of Colombo, P.O. Box 1490, Colombo 03, Sri Lanka.

Article Info

Received: 08 August 2023, Revised: 01 November 2023, Accepted: 03 November 2023.

How to Cite this Article:

Fonseka, Piumi and Karunarathne, Ananda Y. (2024). Impacts of Kalu River Estuary Changes on Nearby Coastal Zones from 2017 to 2020: An Integrated Analysis using GIS and DSAS, 1(1), 62-84.

ABSTRACT

Coastal environments are dynamic and sensitive systems subject to various natural and anthropogenic influences. This study investigates landform changes near the Kalu River estuary in Sri Lanka from 2017 to 2020, using Geographic Information System and Digital Shoreline Analysis System. Multiple shoreline change analysis methods, including Linear Regression Rate (LRR), Transect line, Shoreline Change Envelope (SCE), and Net Shoreline Movement (NSM), quantify erosion and accretion patterns have been utilized in the study. Zone 2 experienced significant erosion while accretion was observed in Zone 3(see, figure 10) and 717 Kalutara North. The interconnectedness of estuaries and coastal environments is highlighted, emphasizing the direct impact of estuarine changes on nearby beaches. The study underscores the importance of understanding estuarine dynamics in coastal management and planning. It sheds light on vulnerable areas and offers opportunities for coastal protection and sustainable development. The research contributes valuable insights into coastal system complexities, calling for comprehensive assessments to safeguard coastal communities and environments in the face of ongoing environmental changes. The integrated analysis provides a foundation for targeted strategies to mitigate erosion, enhance coastal resilience, and promote sustainable coastal disaster risk reduction (CDRR) practices in the study area. Ultimately, such comprehensive assessments are crucial for safeguarding the ecological integrity and socio-economic well-being of coastal communities and environments in the face of ongoing environmental changes.

Keywords: Kalido Beach; Kalu River Estuary; Coastal Erosion and accretion; GIS and DSAS; Coastal Disaster Management (CDM) and Coastal Disaster Risk Reduction (CDRR)

***Corresponding author:** E-mail address: ananda@geo.cmb.ac.lk

1. INTRODUCTION

The Earth's dynamic landscapes have been shaped for over millions of years through natural geological processes. However, the emergence of human civilizations has resulted in a new era where human activities significantly influence changes in landform. From the smallest hill to the grandest mountain range, human impacts have left an indelible mark on the planet's topography. Many research papers in the extant body of literature delve into the multifaceted ways in which human activities have altered landforms, exploring the consequences of such changes on the environment and the need for sustainable practices. One of the most profound human impacts on landforms is the rapid expansion of urban areas and land conversion for agriculture. As populations grow and cities sprawl, natural landscapes are modified to accommodate human settlements. Vast areas of forests, wetlands, and grasslands have been cleared, leading to soil erosion, habitat loss, and disruptions in ecological balance (Anon, 2002). Urbanization often involves filling wetlands, leveling hills, and draining marshes, leading to irreversible changes in the landscape and affecting natural drainage patterns (Karunarathne, 2021; Karunarathne and Lee, 2019; Karunarathne and Gress, 2022).

Mining activities for valuable minerals and resources have caused significant changes to landforms. Open-pit mining and strip-mining lead to massive excavations and removal of topsoil, altering the shape of mountains and valleys. These activities result in land subsidence, landslides, and increased sedimentation in rivers and streams. Moreover, the disposal of mine waste and tailings can lead to acid mine drainage, polluting water bodies and further impacting surrounding ecosystems. Deforestation, which is also one of cardinal issues, driven by logging, agriculture, and infrastructure development, has left an alarming scar on the earth's surface. Forests play a vital role in stabilizing slopes, maintaining water flow, and preserving biodiversity. Their destruction leads to increased soil erosion, reduced water infiltration, and heightened vulnerability to landslides and floods. The loss of vegetation also contributes to climate change by releasing stored carbon dioxide back into the atmosphere (Karunarathne, 2021). And also, in coastal regions, humans have undertaken extensive land reclamation projects for urban development and agriculture. This involves dredging and filling of coastal areas, which alters natural shorelines, wetlands, and estuaries. These modifications disrupt coastal ecosystems, reduce natural buffers against storms, and exacerbate coastal erosion and flooding risks. The construction of dams and river channelization projects is another significant human impact on landforms. While these structures provide benefits like hydroelectric power and irrigation, they also lead to downstream consequences. Dams trap sediments, leading to erosion downstream and reducing the fertility of farmland. River channelization alters natural water flow patterns, increasing the risk of floods and impacting aquatic habitats. Human-induced climate change has accelerated the retreat of glaciers and ice sheets in many regions. This phenomenon alters the landscape by exposing new land surfaces previously covered by ice. The melting of glaciers also contributes to rising sea levels, which further modifies coastal landforms and leads to the loss of low-lying areas (Karunarathne, 2022; Karunarathne and Lee, 2022; Karunarathne and Lee, 2020a; Karunarathne and Lee, 2020b). Tourism and recreational activities in ecologically sensitive areas can have detrimental impacts on landforms. Overcrowding and improper waste management can lead to soil erosion, degradation of fragile ecosystems, and disruption of wildlife habitats. Popular tourist destinations are often vulnerable to erosion, particularly when visitors deviate from designated paths and trample on delicate terrain (Karunarathne, 2021).

Especially, the dynamic nature of a river mouth is a fascinating aspect of geomorphology, where a river meets a larger body of water, such as an ocean, sea, or lake. This juncture is a dynamic zone characterized by continuous changes in its shape, position, and sedimentary patterns. The river mouth is not a fixed point but rather a dynamic interface that responds to various natural processes and anthropogenic factors.

The present study delves into the key elements contributing to the dynamic nature of a river mouth, exploring the forces that shape it and its significance in the broader context of coastal environments. One of the primary factors influencing the dynamic nature of a river mouth is the balance between riverine sediment supply and the erosive power of the receiving water body. When a river enters the larger water body, it encounters different hydrodynamic conditions, such as tidal currents, wave action, and longshore currents. These forces can lead to the deposition or erosion of sediments, causing changes in the river mouth's size and shape over time (Karunarathne, 2021). Tidal dynamics play a crucial role in shaping the river mouth. In estuarine environments, where freshwater meets seawater, tidal movements create complex patterns of sediment deposition and erosion. During high tides, the seawater moves upstream, promoting sediment accumulation and forming sandbars or islands. Conversely, during low tides, the seawater retreats, leading to sediment erosion and the deepening of the river channel. The ebb and flow of tides, coupled with seasonal variations, contribute significantly to the dynamic nature of the river mouth. Wave action is another influential force in shaping the river mouth. Waves carry energy from the open ocean and can transport sediments along the coastline. When waves approach the river mouth, they can influence the movement and distribution of sediments, leading to changes in the river mouth's position and morphology. The wave energy can promote erosion or deposition of sediments, altering the coastline and contributing to the dynamic nature of the river mouth.

Human activities also play a cardinal role in shaping river mouths. Human interventions such as dredging, construction of dams, and channelization can significantly impact the sediment transport and deposition patterns in river mouths. Dredging, for instance, can lead to the removal of sediments from the river channel, affecting sediment supply downstream and altering the river mouth's dynamics. On the other hand, the construction of dams can trap sediments upstream, reducing sediment supply to the river mouth and influencing its geomorphology. The dynamic nature of river mouths has broader implications for coastal environments and ecosystems. River mouths are critical habitats for various species of plants and animals, including fish and migratory birds. The shifting sediment patterns can create new habitats or alter existing ones, influencing the distribution and abundance of wildlife. Moreover, the changing shape and position of the river mouth can impact coastal erosion and accretion rates, influencing the stability of nearby shorelines and coastal ecosystems.

Over the course of several years, the Kalu River estuary has experienced significant landform changes due to a variety of anthropogenic factors. Notably, in close proximity to the Kalu River mouth, a highly dynamic sand reef/sand dune has been identified. The dynamism of this area stems from the obstruction of the normal river flow caused by human activities, as authorities have continuously cut and reduced the sand reef. An illustrative example of this pertains to instances of mass flooding in areas such as Rathnapura, Millakanda, Kuruvita, Dodangoda, Madurawala, Bullathsihala, Palinda Nuwara, and lower valley regions encompassing both Rathnapura and Kalutara districts. During such flood events, the authorities have taken measures to cut approximately 200 meters from the 3.2-kilometer-long Sand Reef/Sand Dune in an attempt to mitigate the impact. These actions have had a notable impact on the dynamics and morphology of the Kalu River estuary over the years.

More importantly, based on daily observations spanning from 2019 to 2020, field observations in June 2020, and data collected from Google Earth Pro covering the period between 2004 and 2020, it has been established that the Kalu River estuary was initially located in the 730A Kalapuwa area. However, following the cutting of the sand reef, its position shifted to Kalutara South. Additionally, the sand reef, which extended from Kalido beach, was destroyed, subsequently giving rise to a new sand reef that formed from the railway station in Kalutara South. Moreover, in response to the destruction of Kalido beach, the government initiated a sand deposition project along Kalutara North Coast, but this endeavor faced challenges when the area experienced sea overflow on 7th April

2020. Notably, coastal erosion is a common occurrence during the southwest monsoon, while coastal sedimentation predominantly takes place during the northeast monsoon. Consequently, the long-term dynamics of the Kalu River estuary and sand reef have exhibited minimal changes. However, following the intervention of cutting the sand reef, short-term alterations to the estuary and sand reef were observed. This study primarily concentrates on assessing the impact of landform changes in the Kalu River estuary over a short-term period, emphasizing the effects resulting from the cutting of the sand reef. On this context, this study will bridge the gaps of the existing body of literature by seeking answers to the research questions of (i). Have there been any changes in Kalu River estuary landform in a short time period? (ii). Have there been erosion and sedimentation on the nearby beaches? (iii). What are the areas which have high erosion and high sedimentation?

More importantly, the clarity of the question suggests that the research seeks to investigate potential changes in the estuary's geographical features, sediment patterns, or overall morphology over a specific and limited period. It inquires whether erosion and sedimentation have occurred on the nearby beaches. This query aims to investigate the presence and extent of any coastal erosion or sediment deposition processes that may have impacted the beaches in the vicinity of the location under study. The results of such an investigation could provide valuable insights into the coastal dynamics and geomorphological changes in the area, contributing to a comprehensive understanding of the coastal environment's stability and resilience. All in all, the findings from this analysis can have significant implications for coastal management and conservation efforts. Areas with high erosion may require erosion control measures to protect valuable coastal assets and infrastructure, while areas with high sedimentation may need proper management to maintain balanced ecological conditions. Investigating the areas with both high erosion and high sedimentation will provide valuable information for coastal planners, policymakers, and researchers to implement effective strategies for sustainable coastal development and environmental preservation.

2. STUDY AREA

The study area (see, Figure 1) encompasses the Kalu River estuary, the sand reef, and the nearby beaches, extending up to 2 kilometers north and south of the estuary. It is situated in the Kalutara district on the southwest coast of Sri Lanka. The targeted study area includes five village service domains, namely 717 Kalutara North, 725 Kalutara South, 725A Kalutara South, 730 Wettumakada, and 730A Kalapuwa. The absolute location of this area, according to Google Earth Pro, falls within north latitudes 6°33'27''-6°36'6'' and east longitude 79°56'46''-79°58'13''. The study area is bounded by the Colombo district to the north, Ratnapura district to the east, Galle district to the south, and the Indian Ocean to the west.

The study area experiences distinct precipitation patterns throughout the year. From May to September, southwest monsoons bring rains to the region, while convection rain occurs from March to April. The annual rainfall in this area ranges between 2500 to 3500mm, with an average of 2700mm per year. The temperature in the study area typically ranges from 25 to 27.5 degrees Celsius. In this region, the Kalu River estuary and its surroundings are subject to dynamic environmental conditions shaped by the interplay of monsoonal rains, river flow, tidal dynamics, and wave action from the nearby ocean. The estuarine ecosystem is of paramount significance, supporting diverse flora and fauna, and providing critical habitats for various species. However, the delicate balance of the ecosystem can be influenced by natural processes and human interventions, necessitating a comprehensive understanding of the area's climate, hydrology, and geomorphology.

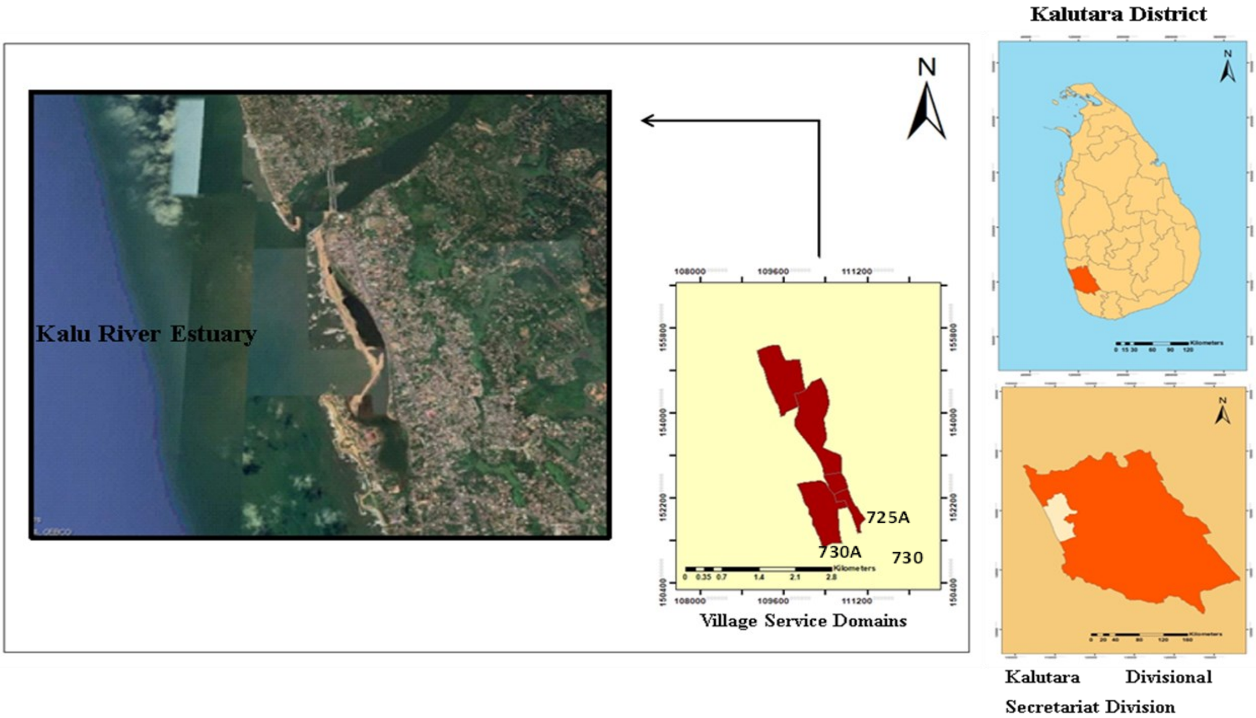


Figure 1: Absolute and relative location of the study area
Source: Compiled by the authors, 2021

The provided information lays the foundation for studying the complex dynamics of the Kalu River estuary and its coastal environment. It sets the stage for exploring the impact of erosion, sedimentation, and landform changes within this critical study area. Understanding these environmental factors is vital for formulating effective management strategies, sustainable development practices, and conservation efforts to preserve the ecological integrity of this vital coastal ecosystem in the Kalutara district of Sri Lanka.

3. MATERIALS AND METHODOLOGY

The study utilized a combination of empirical/field observations and secondary data to fulfill all the data requirements of the research. This comprehensive approach allowed for a thorough examination of the subject matter. The methodological framework was primarily divided into two distinct parts, each aligned with the specific objectives of the study. By employing a multi-faceted approach, the research was able to gather valuable insights from on-the-ground observations as well as existing data sources, ensuring a well-rounded and robust analysis. The empirical/field observations involved direct data collection from the study area, enabling researchers to obtain firsthand information and real-time data related to the phenomena under investigation. This on-site data collection approach allowed for the validation of existing data and provided a deeper understanding of the complex dynamics at play in the field.

In parallel, the study relied on secondary data from various reputable sources to supplement and complement the empirical findings. Secondary data encompassed a wide range of previously recorded information, including historical records, statistical data, scholarly publications, and official reports. This approach enriched the dataset of the study and facilitated comparisons with existing knowledge in the field, contributing to the overall depth and credibility of the research. Furthermore, the methodological division into two distinct parts catered to the specific research questions. Each approach was tailored to address different aspects of the study, enabling the researchers to holistically explore the research questions and draw comprehensive conclusions. The rigorous combination of empirical/field observations and secondary data utilization underscored the study's commitment to accuracy and reliability. By employing multiple methods, the research minimized potential biases and enhanced the overall validity of the findings. This approach also provided valuable triangulation opportunities, wherein the consistency of results from both approaches lent further credibility to the study's outcomes. All in all, the study employed a well-structured and comprehensive methodology, integrating both empirical/field observations and secondary data. The distinct divisions of the approach were tailored to meet the specific research objectives, enabling a holistic exploration of the subject matter. The systematic integration of various data sources contributed to the study's robustness, reaffirming the rigor of the research and the credibility of its findings.

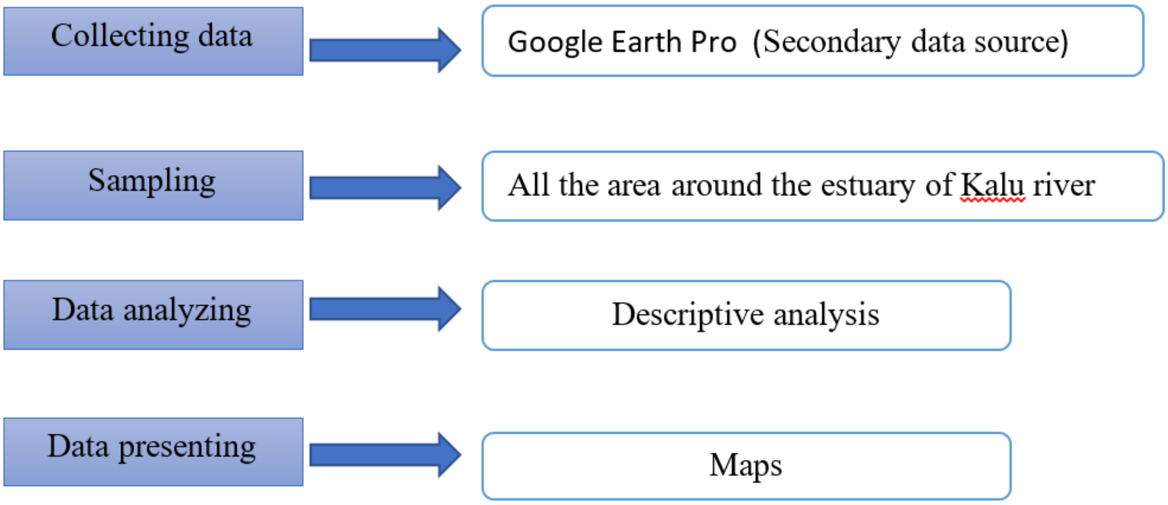


Figure 2: Flow chart exemplifying the Study of the Kalu River estuary changes in a short-term period.

In this study, six Landsat satellite images were employed to discern and analyze changes in the river estuary and sand reef. The key event under investigation was the cutting of the estuary, which occurred on 27th May 2017. To compare the estuary's condition before and after this critical event, the researchers utilized the satellite image captured on 8th January 2017 to represent the pre-cutting state. Subsequently, six additional satellite images were employed to observe and evaluate the estuary's post-cutting condition.

By employing Landsat satellite imagery, the research team gained access to valuable visual data spanning a considerable time frame. This enabled them to observe and record the changes in the river estuary and sand reef over an extended period. The choice of Landsat satellite images facilitated a detailed analysis of the estuary's dynamics, allowing for a robust understanding of the impacts resulting from the cutting event. Moreover, by utilizing multiple satellite images after the estuary cutting, the researchers could monitor the evolving nature of the river estuary and sand reef over time (Al-Zubieri et al., 2020; Bheeroo et al., 2016). This provided essential insights into the short-term and potentially longer-term consequences of the cutting, shedding light on the subsequent changes to the estuarine ecosystem and surrounding coastal environment.

The integration of Landsat satellite imagery into the study methodology exemplified the research team's commitment to employing cutting-edge technology to address their scientific objectives. Satellite imagery serves as a powerful tool in monitoring and assessing changes in Earth's landscapes, making it invaluable for studies centered around coastal environments, river systems, and natural phenomena.

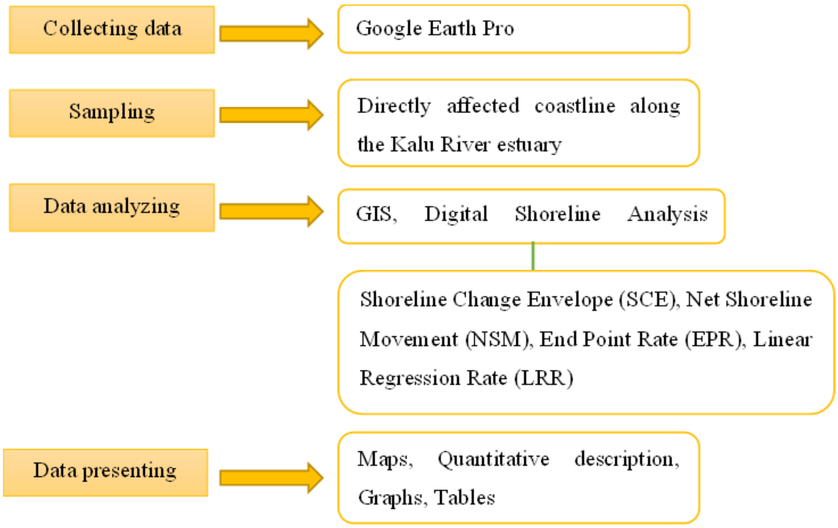


Figure 3: Mechanism of studying the impact of short-term changes in the Kalu River estuary on the surrounding coastline.

In this study, six shorelines were utilized to analyze and track changes in the shoreline position, with a resolution of 1154*632. These shorelines were strategically distributed at locations situated 2 kilometers north and south of the estuary. To delineate the extent of the study area, the northern shoreline's endpoint was identified at north latitude 6°36'18.96'' and east longitude 79°56'56.21'', while the southern shoreline's endpoint was located at north latitude 6°33'28.47'' and east longitude 79°57'49.54''. The segment of shoreline between these two endpoints was meticulously digitized using the polyline tool in Google Earth Pro. The utilization of six shorelines served as a representative dataset to capture and assess the dynamic changes in the shoreline over time. The strategic placement of these shorelines allowed researchers to observe variations in shoreline position both to the north and south of the estuary, contributing to a comprehensive understanding of the estuarine system's behavior.

To facilitate the analysis, the digitized shorelines were converted into a KML (Keyhole Markup Language) file format, which enabled seamless integration into geographic information systems (GIS) and geospatial software. This conversion process enhanced the ease of data manipulation and facilitated the extraction of valuable insights from the digitized shorelines. By employing Google Earth Pro and KML files, the study harnessed advanced geospatial tools, which are well-suited for investigating changes in coastal environments. The combination of high-resolution imagery and precise digitization techniques allowed for accurate delineation of shoreline positions, ensuring data accuracy and reliability (see, Himmelstoss, 2009).

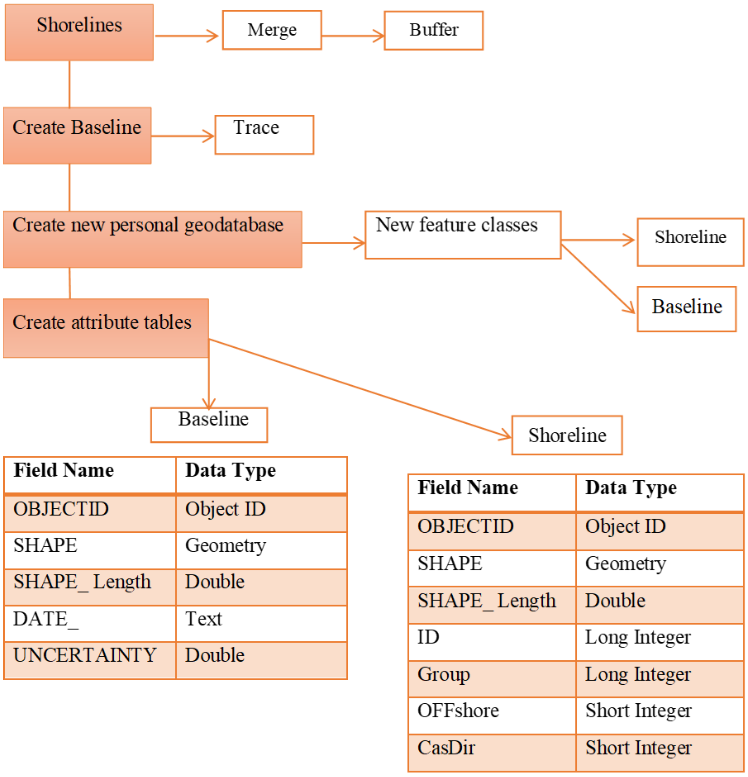
Table 1: Shoreline numbers and respective taken dates of RS images.

Shoreline No:	**Date**
1	2017.01.08
2	2017.12.17
3	2018.03.11
4	2018.11.19
5	2019.04.10
6	2020.05.10

Source: Prepared by surveyors, 2021

Especially, the KML files containing digitized shorelines were transferred to a Geographic Information System (GIS) platform for further analysis and processing. The shoreline data captured on 8th January 2017 was designated as the baseline for the study, serving as a reference point representing the shoreline condition before the estuary cutting event. All subsequent shoreline changes were analyzed and compared to this baseline, allowing researchers to assess the alterations that occurred after the estuary cutting. To integrate the shorelines into the GIS, a merging process was employed, effectively combining the individual shoreline datasets into a unified representation. This merged output was then buffered at a distance of 150 meters, creating a buffer zone around the shorelines. The buffer zone helps capture and visualize potential changes and variations in shoreline positions within a specific proximity to the estuary.

Subsequently, the outline of the buffered shorelines was traced to generate a finalized representation of the shoreline changes over time. This traced outline served as an essential component in the creation of the baseline, enabling a more precise and detailed analysis of the observed variations from the original condition.



Field Name	Data Type
OBJECTID	Object ID
SHAPE	Geometry
SHAPE_ Length	Double
DATE_	Text
UNCERTAINTY	Double

Field Name	Data Type
OBJECTID	Object ID
SHAPE	Geometry
SHAPE_ Length	Double
ID	Long Integer
Group	Long Integer
OFFshore	Short Integer
CasDir	Short Integer

Figure 4: Data processing mechanism in GIS

For data processing and mapping purposes, the study utilized the WGS 1984 UTM zone 44 N projection. This specific projection system ensures accurate and consistent spatial measurements, allowing for precise data analysis and geospatial representation of the shoreline changes. By employing GIS and carefully applying data processing techniques, the study optimized its ability to analyze and visualize the shoreline changes in relation to the baseline. The utilization of a standardized projection system further enhanced the accuracy and reliability of the research outcomes. After data processing, DSAS was used to analyze the data (see, Figure 5).

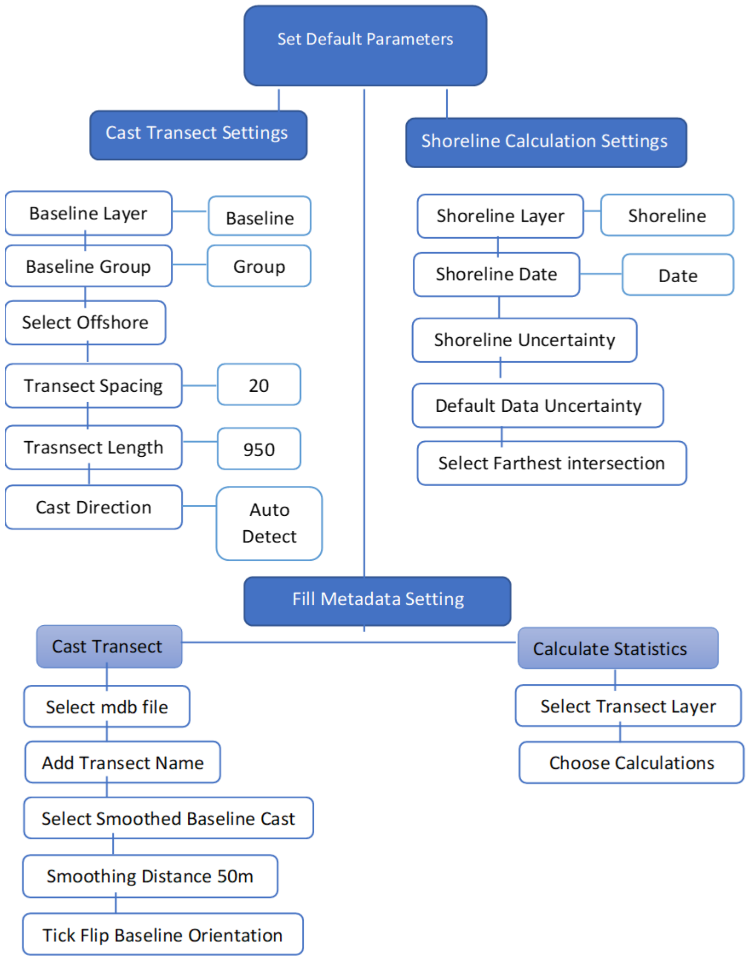


Figure 5: Analyzing framework of data in DSAS

Shoreline changes were calculated using LRR, EPR, SCE, and NSM. LRR and EPR were used to identify erosion and accretion that were classified as very high to low levels.

Table 2: Shoreline classification based upon EPR and LRR rates

Shoreline No:	**Shoreline classification**	**EPR and LRR rate of shoreline change (m/yr)**
1	Very high accretion	>2
2	high accretion	1-2
3	moderate accretion	0-1
4	stable	0
5	moderate erosion	-1-0
6	high erosion	-2-(-1)
7	very high erosion	<-2

Source: Raj *et al.*, 2021

Finally, two key methods, Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM) (figure 3) were employed to identify erosion and accretion patterns along the study area's shoreline. While SCE is not a rate but a distance measurement, it serves as a valuable indicator of the extent of shoreline variability over a specific time-period (Abou Samra, and Ali, 2020). SCE is calculated by determining the distance between the longest and nearest shorelines within the study area. This measurement provides insights into the maximum shoreline change that occurred during the analyzed time frame. On the other hand, NSM is a method based on shoreline dates, enabling the determination of the distance between the oldest and newest shorelines within the study area. NSM is designed to assess the net change in the shoreline position over time, indicating the cumulative erosion or accretion that has occurred since the earliest recorded shoreline to the most recent. By employing both SCE and NSM methods, the study was able to effectively capture different aspects of shoreline change dynamics. While SCE helps identify the maximum shoreline variability, NSM provides a comprehensive understanding of the net change over the entire time period. Together, these methods offer a comprehensive picture of the erosion and accretion patterns within the study area, aiding in the assessment of the estuarine system's geomorphological dynamics.

The integration of SCE and NSM into the study's methodology underscores the researchers' commitment to employing robust and established techniques in shoreline change analysis. These methods have been widely used in coastal studies and have proven to be valuable tools in understanding the impacts of various natural and anthropogenic factors on shoreline evolution.

4. RESULTS AND DISCUSSION

According to the revealed results (see, Figure 6 below), the image taken on January 18, 2017, captures the pre-cutting condition of the Kalu River estuary, which was present in the 730 Kalapuwa area. This estuary's existence wasn't limited to that specific date, as Landsat images spanning from 2004 to 2017 also confirm its presence. Fast forward to February 17, 2017, the subsequent image depicts the aftermath of the estuary's cutting, indicating significant erosion of the sand reef. The destructive impact becomes even more evident in the image from March 11, 2018, as it showcases the devastation of Kalido Beach and further destruction of the sand reef. The source of the sand deposition in this area can be traced back to the railway station at Kalutara South. Interestingly, the estuary persists in the Kalutara South area, as illustrated in the image dated November 19, 201. The visuals from April 10, 2019, highlight the deposition of sand both to the North and South of the estuary.

By May 10, 2020, a stable estuary has developed in Kalutara South, indicating some signs of recovery. The sand reef has been gradually developing, and interestingly, sand deposition seems to originate from the former Kalido beach. These series of images (see, figure 6), provide valuable insights into the dynamic changes occurring in the Kalutara area, showcasing the impacts of estuary cutting, erosion of sand reefs, beach destruction, and subsequent recovery and expansion of the estuary. The continuous monitoring of these changes through satellite imagery plays a crucial

Figure 6: Shoreline Changes over years (from 2017 to 2020)
Source: Google Earth Pro,2021

role in understanding and managing the delicate coastal environments and their vulnerabilities. This monitoring process is instrumental in both understanding and effectively managing the vulnerabilities associated with delicate coastal ecosystems.

Satellite imagery offers a bird's-eye view of the coastal regions, enabling scientists, researchers, and environmentalists to observe and analyze changes over time. By regularly capturing and analyzing these images, they can track various environmental parameters such as shoreline changes, estuary dynamics, erosion patterns, sediment deposition, and habitat alterations. Understanding these changes is crucial because coastal environments are dynamic and highly sensitive to natural and human-induced factors.

Factors like sea-level rise, storm surges, coastal development, and pollution can have profound effects on coastal ecosystems. They can lead to coastal erosion, loss of natural habitats, and the disruption of ecosystems, impacting both marine and terrestrial species.

By continuously monitoring these changes, researchers can identify trends and patterns, assess the effectiveness of conservation and management efforts, and develop strategies to mitigate the negative impacts on coastal environments. It also aids in early detection of potential threats, allowing for timely intervention and adaptation measures to protect the delicate balance of coastal ecosystems.

More importantly, Figures 7 and 8 serve as illustrative examples of the shoreline conditions on January 8, 2017, with the purpose of identifying the state of the area before the estuary was cut. These figures are used as reference baselines to track and analyze changes in the shoreline after the estuary cutting occurred. Figure 7 provides a visual representation of the shoreline on January 8, 2017, showcasing the initial condition of the area before any alterations were made to the estuary. This baseline shoreline becomes a critical reference point for comparison with subsequent figures and datasets.

On the other hand, Figure 8 depicts the arrangement of the baseline and other shorelines in relation to the digital analysis process using the DSAS (Digital Shoreline Analysis System). The DSAS is a tool that helps analyze and measure shoreline changes over time by comparing multiple sets of shoreline data.

The DSAS allows us to quantify changes in shoreline positions and assess erosion or accretion trends. By arranging the baseline and other shoreline data within the DSAS, scientists can systematically study and interpret the alterations that occurred in the area after the estuary was cut. This analysis aids in understanding the impacts of human activities or natural processes on the coastal environment (Foti et al., 2019; Mujabar and Chandrasekar, 2013).

Moreover, Figure 9 presents the transects of the shorelines, which are lines or profiles drawn perpendicular to the coastline at specific intervals. These transects are based on the reference baseline (Figure 7) and extend to the more recent shorelines. They provide a detailed view of the changes that have taken place along the coast after the estuary cutting. Transects allow for precise measurements of shoreline movement and offer valuable insights into the extent and direction of erosion or accretion (Tanaka, 2006).

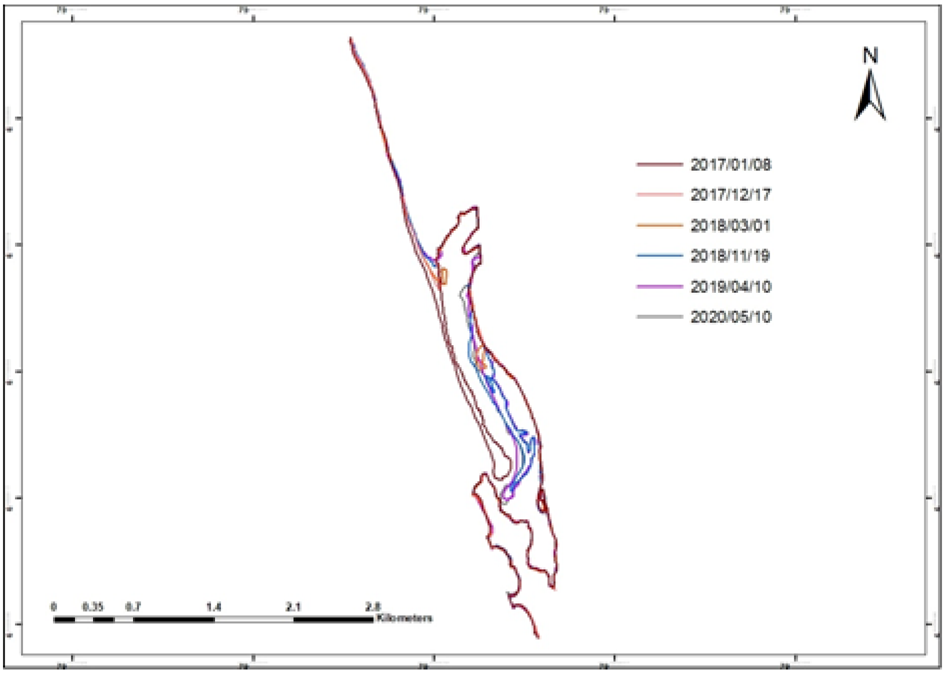


Figure 7: Deviated Shorelines over years.
Source: Prepared by authors based on Google Earth Pro data, 2021

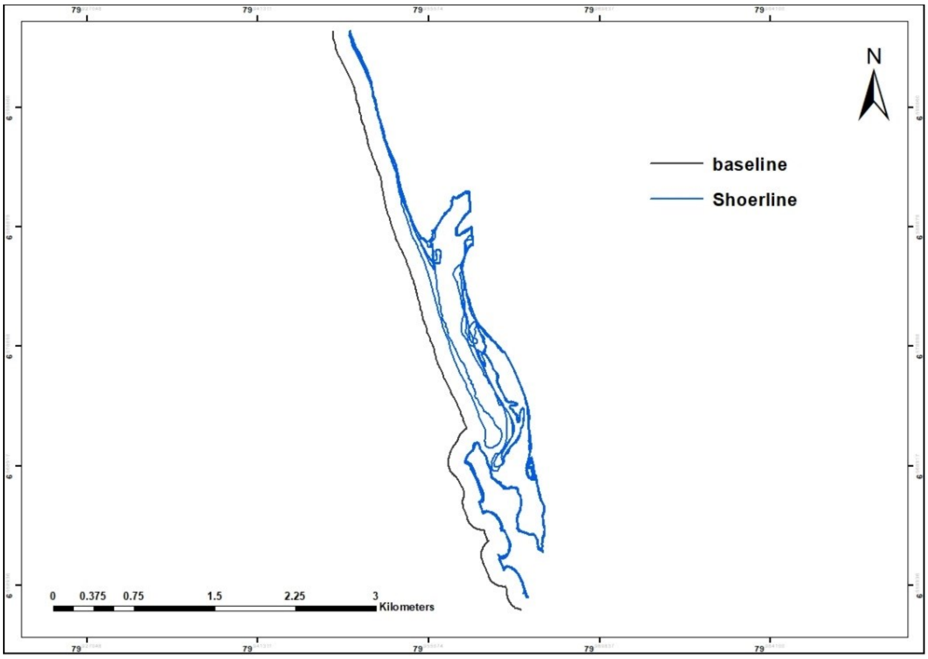


Figure 8: Different shorelines and Baseline/coastline
Source: Prepared by surveyors based on Google Earth Pro data, 2021

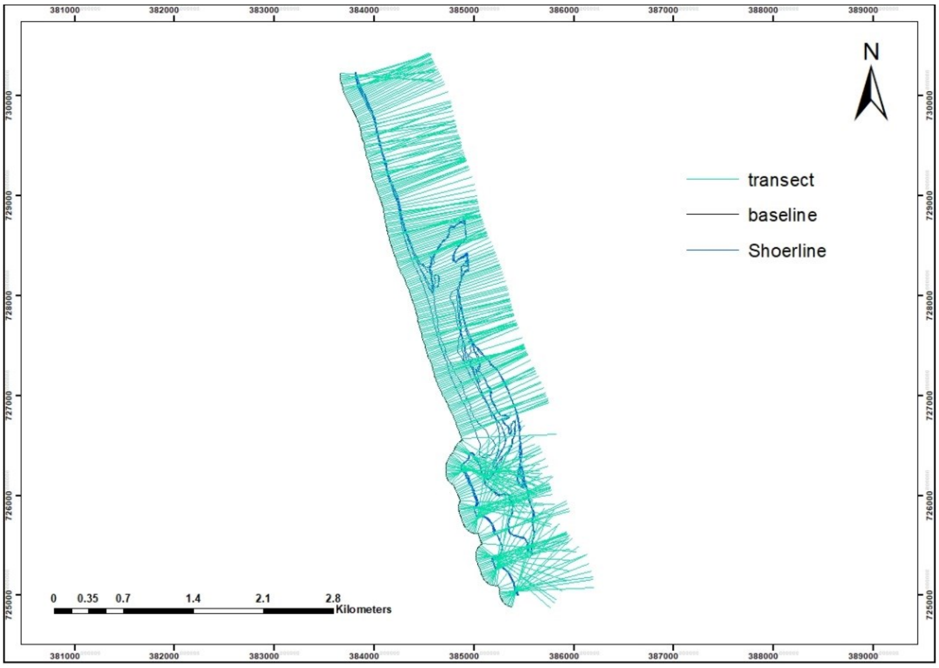


Figure 9: Transects of the shorelines based on the Baseline.
Source: Prepared by surveyors based on Google Earth Pro data, 2021

In Figure 10, the different rates of erosion and accretion along the coastal belt are depicted using the Linear Regression Rate (LRR) mechanism. The LRR mechanism is a method used to analyze and quantify the changes in shoreline positions over time. Zone 1 (Figure 10) illustrates a region characterized by high erosional patterns and moderate accretion natures. This demonstrates that, the shoreline has been experiencing significant erosion in this specific area, resulting in the retreat of the coastline over time. However, there are also some instances of accretion, where sediment accumulates and leads to the extension of the shoreline.

In Zone 2 of Figure 10, different erosional patterns are shown, primarily ranging from moderate to high erosion, and in some cases, reaching very high erosional patterns. This indicates that this particular section of the coastal belt is experiencing more severe erosion, leading to a considerable loss of land and shoreline retreat. The varying rates of erosion suggest that certain parts of this section are more vulnerable to erosion than others.

On the other hand, Zone 3 in Figure 10 exemplifies moderate, high, and very high accretion, with some moderate erosional patterns appearing as well. This section experiences substantial sediment deposition, leading to the growth and advancement of the shoreline. However, amid the accretion processes, there are still some areas where erosion occurs to a moderate extent.

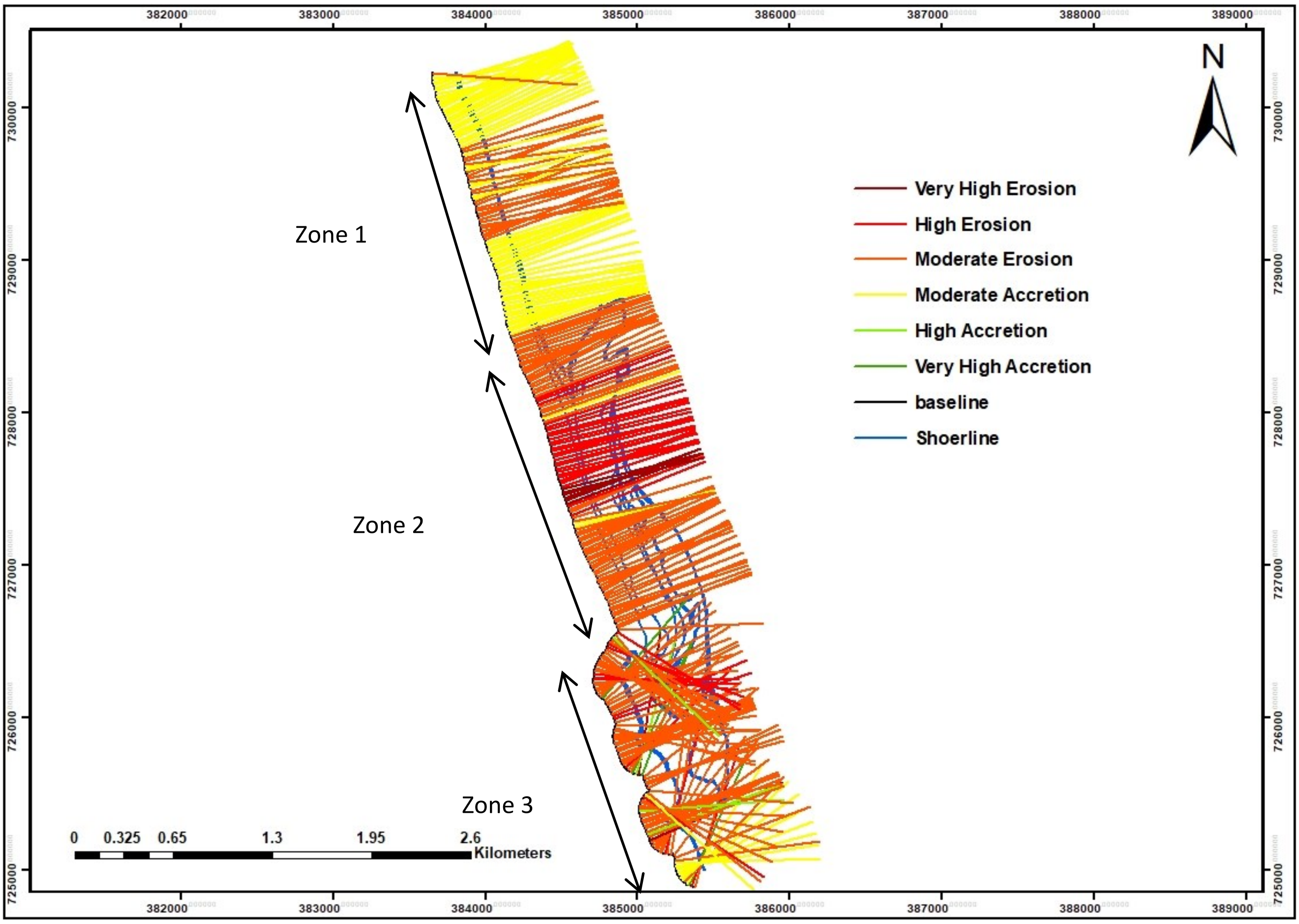


Figure 10: Identifying erosion and accretion using LRR method (Linear Regression Rate)
Source: Prepared by authors based on Google Earth Pro data, 2021

By employing the Linear Regression Rate (LRR) mechanism as explained above, the study was able to quantitatively assess the erosion and accretion rates along different segments of the coastal belt. This information is invaluable for understanding the dynamic changes taking place in coastal areas and aids in developing effective management strategies to address erosion and protect vulnerable regions from further damage.

More importantly, Figure 10 and Figure 11 provide a detailed representation of the erosion and accretion patterns along the coastal belt using the LRR mechanism. The visualization of different sections with varying erosion and accretion rates helps researchers gain insights into the complex dynamics of the coastal environment, enabling them to make informed decisions for coastal management and conservation efforts.

The Transect line method was employed to calculate shoreline changes over the specified time period. This method involves drawing lines perpendicular to the coastline at regular intervals, and measurements are taken along these lines to assess the changes in the shoreline position.

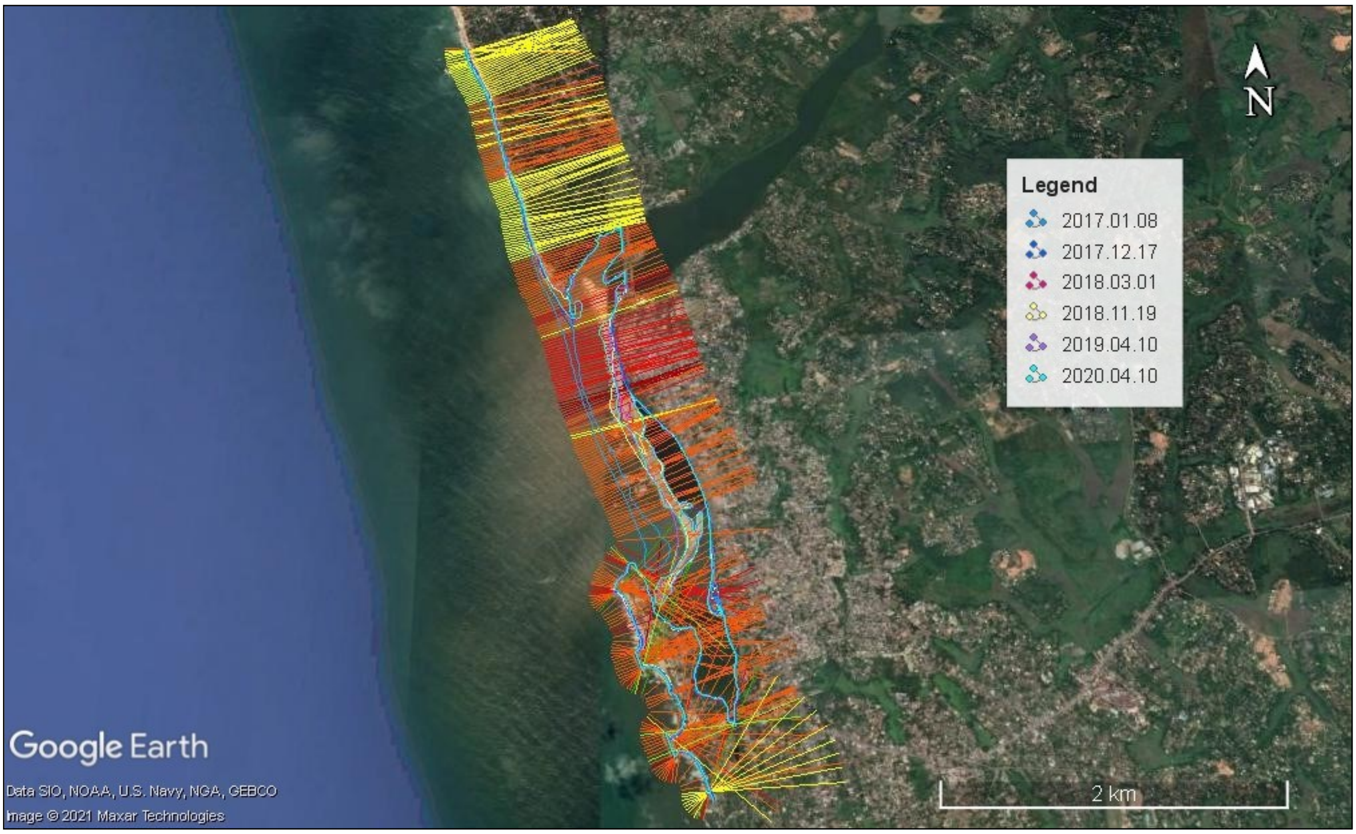


Figure 11: Overlaying erosion & accretion detected by LRR on the Kalu River estuary
Source: Prepared by Authors based on Google Earth Pro data, 2021

The calculated values can be either negative or positive. A negative value indicates erosion, which means that the shoreline has retreated or moved landward, resulting in the loss of coastal land. On the other hand, a positive value signifies accretion, indicating that the shoreline has advanced or moved seaward, leading to the deposition of sediment and the expansion of coastal land. According to the calculations, the highest rate of erosion recorded during the time period from 2017 to 2020 was -53.9 meters. This suggests a significant retreat of the shoreline over that specific period. On the other hand, the highest rate of accretion observed during the same time frame was 165.66 meters, indicating substantial sediment deposition and coastal land expansion.

Furthermore, the resultant map (see, Figure 10) was divided into three zones, presumably based on specific geographic or administrative divisions. This zoning allows for a more detailed analysis of shoreline changes within different areas of the map, enabling researchers to identify variations in erosion and accretion rates in distinct regions.

By employing the Transect line method and interpreting the calculated values, the study was able to gain valuable insights into the dynamics of coastal change, including the areas most susceptible to erosion and the regions where accretion is prevalent. This information is crucial for coastal management and decision-making, as it helps identify areas at risk and informs strategies to mitigate erosion and protect valuable coastal resources (Raj et al., 2019).

Table 3: Some measurements of nearby areas of Kalu river estuary

Zone	Description
1	Located north of the estuary of Kalu River (Length of the Zone is 1.8 km)
2	Coastal area near the Kalu River mouth (Length is 2 km)
3	Located South of the estuary (Length is 1.8 km)

Especially, the LRR analysis provides valuable insights into the dynamics of shoreline changes in each zone. The pronounced erosion in Zone 2 highlights the significance of the pre-existing sand reef in coastal protection, underscoring the importance of preserving and restoring natural coastal defenses. The mixed patterns in Zones 1 and 3 emphasize the complexities of coastal processes and the need for context-specific management strategies to mitigate erosion and enhance the resilience of these coastal areas.

In Figure 12, the process of identifying erosion and accretion using the End Point Rate (EPR) method is illustrated. The EPR method is another approach for analyzing shoreline changes over a specific period. The EPR method involves measuring the positions of the shoreline at two distinct endpoints in time, such as the beginning and end of the study period. By comparing the shoreline positions at these two endpoints, researchers can determine whether erosion or accretion has occurred. If the shoreline position at the end of the study period is located landward (closer to the coast) compared to its position at the beginning, it indicates erosion. This means that the shoreline has retreated, resulting in the loss of coastal land.

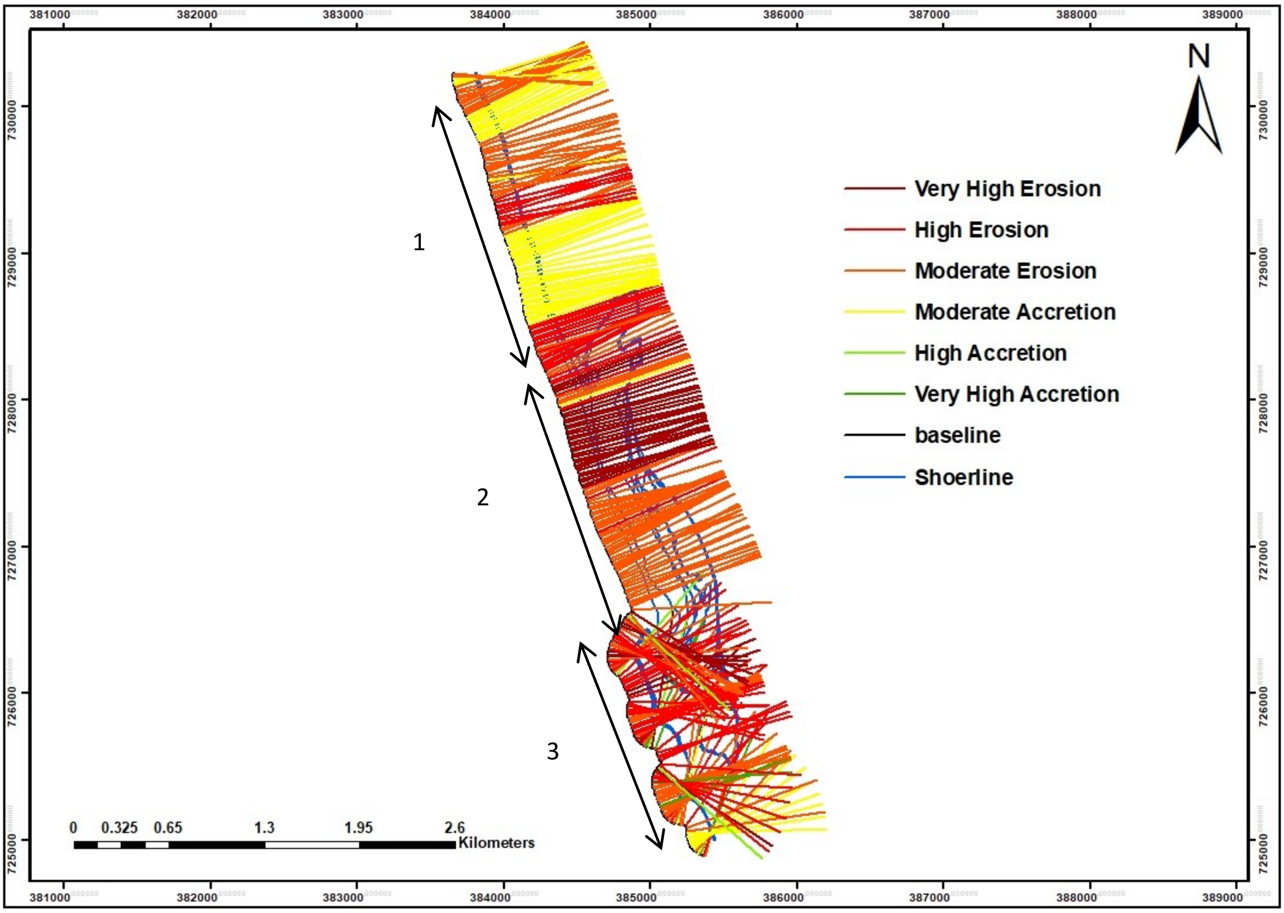


Figure 12: Identifying erosion & accretion using EPR
Source: Prepared by surveyors based on Google Earth Pro data, 2021

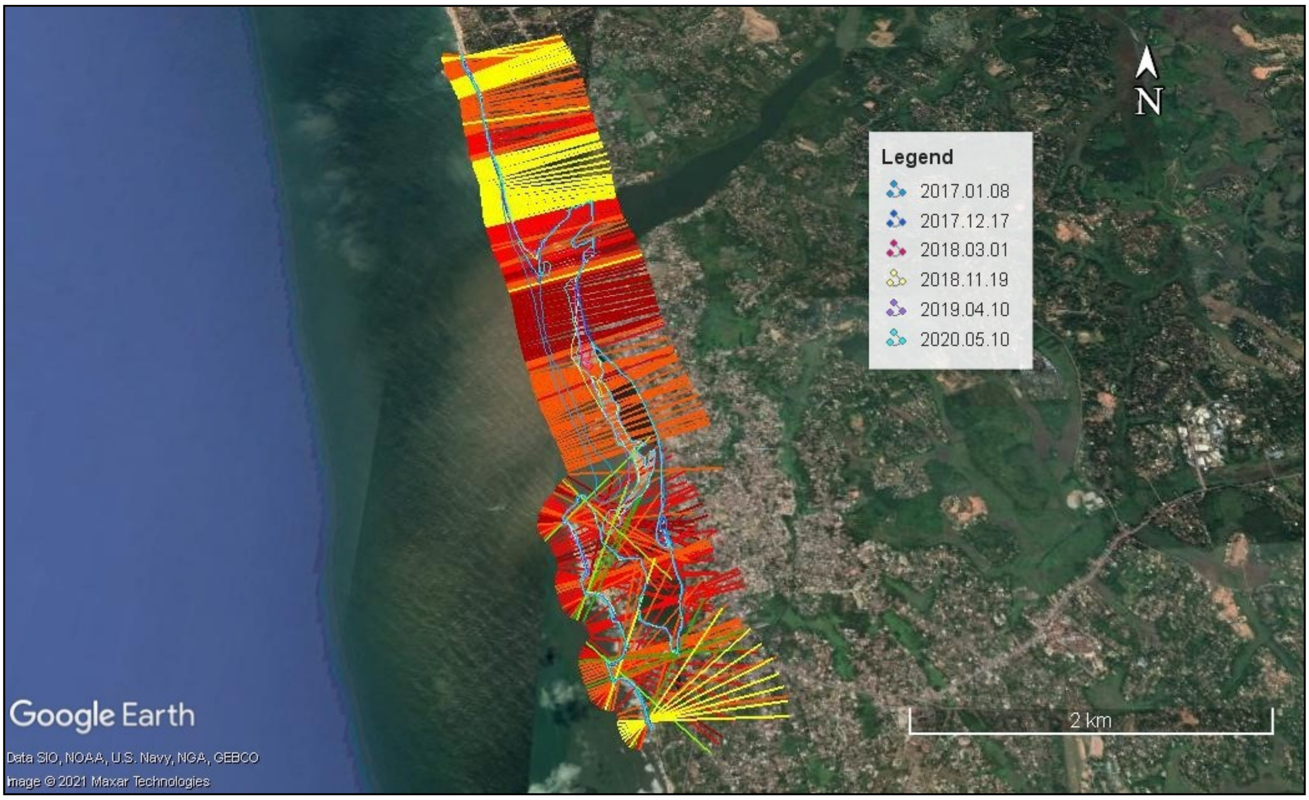


Figure 13: Overlaying erosion and accretion detected by EPR on the Kalu River estuary
Source: Prepared by surveyors based on Google Earth Pro data, 2021

Conversely, if the shoreline position at the end of the study period is located seaward (further away from the coast) compared to its position at the beginning, it indicates accretion. This means that sediment has been deposited, leading to the expansion of coastal land. Figure 12 visually demonstrates how the EPR method is applied to identify erosion and accretion. It likely includes two maps or images representing the shoreline positions at different points in time, along with the calculated EPR values for each section of the coast (e.g., Nassar et al., 2019).

The EPR method is useful for obtaining a quick snapshot of shoreline changes over a specific time interval, making it a valuable tool for initial assessments and comparisons across different coastal regions. When combined with other methods, such as the LRR, transect line, or historical analysis, the EPR method provides a comprehensive understanding of coastal dynamics and assists in the development of effective coastal management strategies.

A negative value resulting from this calculation indicates erosion, meaning that the shoreline has retreated over time. Conversely, a positive value indicates accretion, signifying that sediment has been deposited, leading to the expansion of the coastal land. According to the data from the figure 12, the highest rate of erosion observed is -61.49 meters per year, suggesting a significant rate of shoreline retreat. On the other hand, the highest rate of accretion is 124.23 meters per year, indicating substantial sediment deposition and coastal land expansion.

Figure 14 presents the outcomes of the Shoreline Change Envelope (SCE) method, which is a technique used to assess and visualize the extent of shoreline changes over a specific period. The SCE method involves creating a "change envelope" around a series of shorelines from different time periods. This envelope represents the maximum shoreline extent observed during the study period. By plotting the shorelines from various time points within the envelope, researchers can gain insights into the overall changes that have occurred along the coastline.

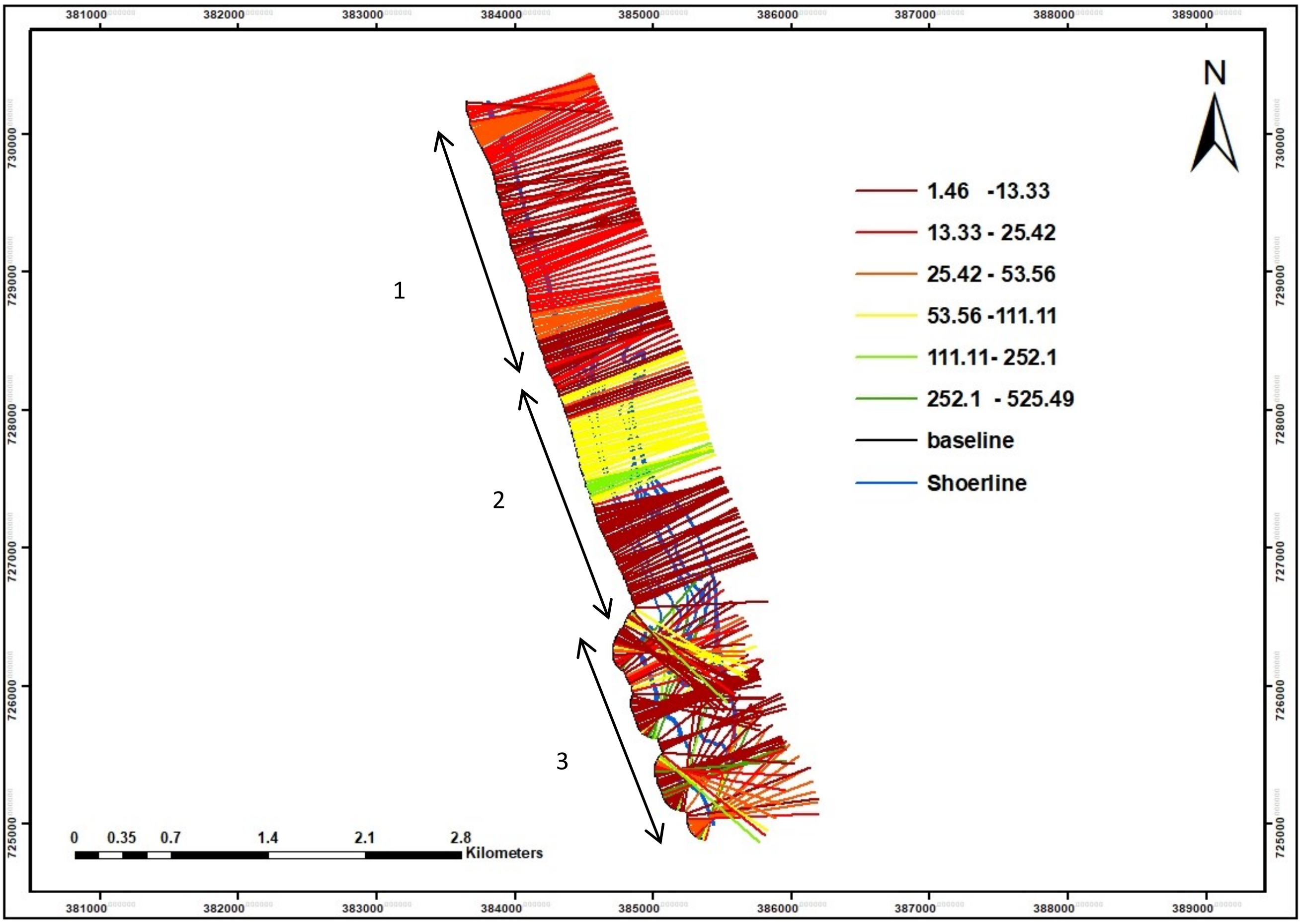


Figure 14: Identifying erosion and accretion rates and patterns using SCE mechanism.
Source: Prepared by authors based on Google Earth Pro data, 2021

The SCE method is particularly useful for identifying areas of high erosion and accretion and for understanding the overall spatial patterns of shoreline dynamics. It allows for the visualization of the historical range of shoreline positions and provides a broader perspective on coastal changes. In Figure 14, you may see a series of shorelines plotted from different time points, such as the oldest shoreline to the most recent one. The envelope surrounding these shorelines delineates the maximum extent that the shoreline has occupied during the study period. By analyzing the shape and width of the envelope, researchers can determine the magnitude and variability of shoreline changes over time.

Based on the results revealed in Figure 14, the farthest distance represents the highest value, indicating the highest accretion observed during the study period. The figure also shows that the longest distance recorded is 525.49 meters, which corresponds to the highest accretion observed along the coastline. In Zone 2, the highest accretion is predominantly concentrated in the center of the zone, with additional localized accretion occurring in various places. The highest accretion value falls within a range of 252.1 to 525.49 meters, indicating a significant expansion of coastal land in those areas.

The information presented in Figure 14 highlights the areas with the most substantial sediment deposition and coastal land expansion. This data is crucial for understanding the spatial distribution of accretion along the coastline and identifying regions where natural or anthropogenic factors may be contributing to enhanced sediment deposition. By identifying the zones with the highest accretion rates, coastal managers and policymakers can focus their efforts on preserving and enhancing these areas to maintain their protective and ecological functions. Furthermore, understanding the factors contributing to the observed accretion can help develop sustainable coastal development practices and conservation strategies to safeguard coastal ecosystems and communities. Overall, Figure 14 provides valuable insights into the dynamics of shoreline accretion and is a valuable tool for coastal management and conservation efforts.

In Figure 15, the results of the Net Shoreline Movement (NSM) method are presented. The NSM method is a technique used to calculate the overall change in the position of the shoreline over a specific time period, taking into account both erosion and accretion. The NSM method involves comparing the positions of the shoreline at the beginning and end of the study period. By subtracting the initial shoreline position from the final shoreline position, researchers can determine the net movement of the shoreline. A positive value for the NSM indicates a net shoreline advancement or accretion, meaning that the shoreline has moved seaward, and sediment has been deposited, resulting in the expansion of coastal land. On the other hand, a negative value for the NSM suggests a net shoreline retreat or erosion, indicating that the shoreline has moved landward, leading to the loss of coastal land.

Figure 15 likely shows a visual representation of the NSM results, with the NSM values calculated for different sections or segments along the coastline. It may include a map or graph depicting the shoreline positions at the beginning and end of the study period, along with the calculated NSM values for each segment.

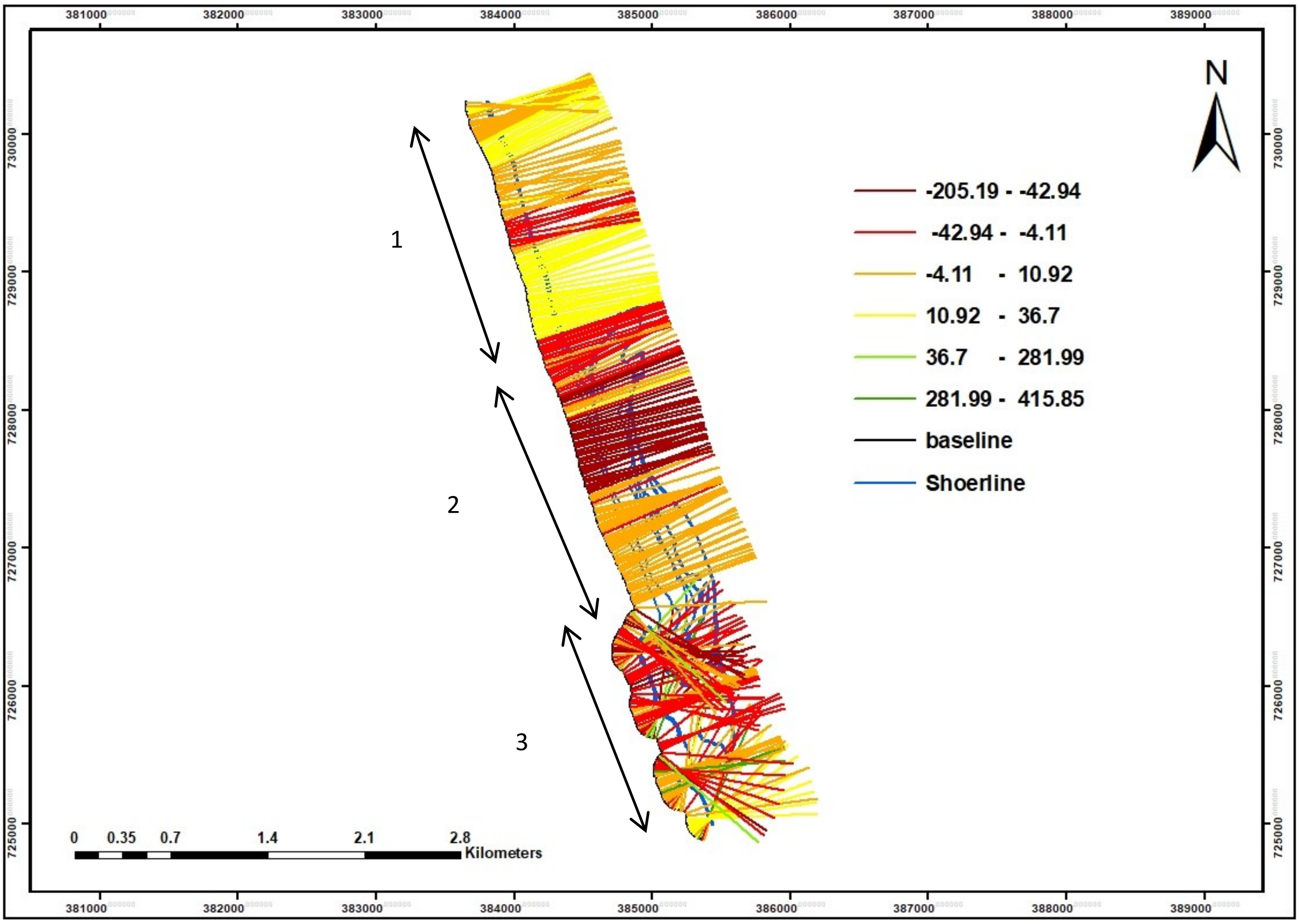


Figure 15: Identifying erosional and accretional process and patterns using NSM mechanism
Source: Prepared by surveyors based on Google Earth Pro data, 2021

Table 4: Some measurements of nearby areas of Kalu river estuary

	LRR (m/y) (Meter per year)	**EPR (m/y)**	**SCE (m)**	**NSM (m)**
Mean	0.2669	0.5341	37.8957	1.7822
Lowest Value	-53.9	-61.49	1.46	-205.19
Highest Value	165.66	124.23	525.49	415.85

Source: Authors' calculations, 2021.

The information provided in Table 4 and Figure 15 highlight its crucial role in presenting the total amount of shoreline distance changes from 2017 to 2020, considering both erosion and accretion. As mentioned, a negative value in Figure 15 represents erosion, indicating that the shoreline has retreated or moved landward over the specified time period (2017 to 2020), resulting in the loss of coastal land. Conversely, a positive value in Figure 15 represents accretion, indicating that sediment has been deposited, and the shoreline has advanced or moved seaward, leading to the expansion of coastal land. Based on the results depicted in Figure 15, it is evident that Zone 2 experienced the highest amount of erosion from 2017 to 2020. This implies that this area of the coast suffered significant shoreline retreat and erosion during the study period.

On the other hand, Zone 3 exhibited the highest amount of accretion during the same time frame, indicating that this coastal region experienced substantial sediment deposition and the expansion of coastal land. The data presented in Figure 15 is of critical importance for understanding the overall trends in shoreline changes within each zone over the specified period. It helps identify areas that are more susceptible to erosion and those that are more resilient with higher accretion rates. By recognizing the zones with the highest rates of erosion and accretion, coastal management authorities can focus their attention and resources on implementing appropriate measures. For Zone 2, efforts might be directed toward erosion control and coastal protection, while for Zone 3, there may be opportunities for sustainable coastal development and habitat restoration.

5. CONCLUDING REMARKS

The research relied on six Landsat satellite images to investigate and track alterations in the river estuary and sand reef, with a specific focus on the impact of the estuary cutting event. By leveraging satellite imagery from various time points, the study achieved a comprehensive understanding of the estuary's dynamics before and after the critical event. The utilization of Landsat data highlighted the significance of remote sensing in environmental research and contributed to the robustness of the findings.

According to the calculations and analysis conducted, various results have been revealed, taking into account different criteria for each calculation. The study area was divided into different zones based on village service domains, and erosion and accretion patterns were observed in each zone. In Zone 2, moderate to high erosion was predominantly observed, indicating that this area experienced significant shoreline retreat and loss of coastal land. The highest erosion was recorded in 725 Kalutara South, and neighboring areas, including the bordering regions of 725 Kalutara South and 717 Kalutara North, also exhibited high erosion rates. Zone 3, which includes 730 Wettumakada and 730A Kalapuwa, showed moderate erosion levels. On the other hand, accretion was identified in 717 Kalutara North and Zone 3. These areas experienced moderate accretion, with Zone 3 exhibiting both high and very high accretion rates.

The overall accretion observed in the study area was mostly moderate, with only slight instances of very high accretion. From these findings, it can be concluded that the Kalu River estuary's changes have had a significant impact on the nearby beaches and coastline from 2017 to 2020. The erosion and accretion patterns observed in the study area indicate that the estuary's landform changes have influenced the adjacent coastal areas in the short term. This highlights the interconnected nature of coastal systems and underscores the importance of understanding estuarine dynamics to effectively manage and protect coastal environments. The research findings have implications for coastal management and planning, as they provide valuable information about vulnerable areas prone to erosion and the potential for sediment deposition and accretion. By considering these changes in the estuary and the related coastline, authorities can implement appropriate measures to mitigate erosion, enhance coastal resilience, and promote sustainable coastal development practices. Ultimately, understanding and monitoring the interactions between Kalu River mouth estuaries and adjacent coastlines are vital for ensuring the long-term health and sustainability of coastal ecosystems and communities of Sri Lanka. Future research foci can be aligned with the researching and investigation of the erosional patterns along the Sri Lankan coastal belt. In accordance with our personal understanding, this need has importantly been come to the fore due to the adverse impacts of ongoing climate change impasses.

REFERENCES

Abou Samra, R.M. and Ali, R.R., (2020). Applying DSAS tool to detect coastal changes along Nile Delta, Egypt. *The Egyptian Journal of Remote Sensing and Space Science*. Available at: https://scholar.google.com/scholar (Accessed 26 Nov. 2020).

Anon, (2002). Coastel Erosion Chapter 2, UNDP pp.27-45. Available at: http://www.dmc.gov.l k/ ha zar d /hazard/Report/UNDP (Accessed 24 June 2020).

Al-Zubieri, A.G., Ghandour, I.M., Bantan, R.A. and Basaham, A.S., (2020). Shoreline Evolution Between Al Lith and Ras Mahāsin on the Red Sea Coast, Saudi Arabia Using GIS and DSAS Techniques. *Journal of the Indian Society of Remote Sensing*, *48*(10), pp.1455-1470. Available at: https://scholar.google.com/scholar (Accessed 26 Nov. 2020).

Arieep, Y., (2018). Death toll expected to rise; 99 missing. *Sunday Observer.*

Bheeroo, R.A., Chandrasekar, N., Kaliraj, S. and Magesh, N.S., (2016). Shoreline change rate and erosion risk assessment along the Trou Aux Biches–Mont Choisy beach on the northwest coast of Mauritius using GIS-DSAS technique. *Environmental Earth Sciences*, *75*(5), p.444. Available at: https://scholar.google.com/scholar (Accessed 14 Aug. 2020).

ChenthamilSelvan, S., Kankara, R.S. and Rajan, B., (2014). Assessment of shoreline changes along Karnataka coast, India using GIS & Remote sensing techniques. Available at: https://scholar.google.com/scholar (Accessed 26 Nov. 2020).

Himmelstoss, E.A. (2009). “DSAS 4.0 Installation Instructions and User Guide” in: Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Ergul, Ayhan. Available at: https://cmgd s. mari ne . u sgs. g ov/publicati on s/DSAS (Accessed 24 Jun e 2020).

Foti, G., Barbaro, G., Bombino, G., Fiamma, V., Puntorieri, P., Minniti, F. and Pezzimenti, C., (2019). Shoreline changes near river mouth: case study of Sant’Agata River (Reggio Calabria, Italy). *European Journal of Remote Sensing*, *52*(sup4), pp.102-112. Available at: https://scholar.google.com/scholar (Accessed 24 June 2020).

Karunarathne, A., & Andriesse, E. (2018), Social Policy Legacies and the Contemporary Development Trajectory of Sri Lanka, *Institute of Indian Studies-Journal of South Asian Studies,* 24(1), pp. 57-95.

Karunarathne, A.Y. and Lee, Gunhak (2019a). Traditional social capital and socioeconomic networks in response to flood disaster: A case study of rural areas in Sri Lank, International Journal of Disaster Risk Reduction, 41, pp. 101279.

Karunarathne, A.Y., & Lee, G. (2019b). Estimating hilly areas population using a dasymetric mapping approach: A case of Sri Lanka’s highest mountain range. ISPRS Int. J. Geo-Inf. 2019, 8, 166. doi:10.3390/ijgi8040166.

Karunarathne, A.Y. and Lee, Gunhak (2020a). Developing a multi-facet social vulnerability measure for flood disasters at the micro-level assessment, International Journal of Disaster Risk Reduction, 49, 101679.

Karunarathne, A. Y. and Lee, Gunhak (2020b). The geographies of the dynamic evolution of social networks for the flood disaster response and recovery, Applied Geography, 125, 102274.

Karunarathne, A.Y., (2021). Geographies of the evolution of social capital legacies in response to flood disasters in rural and urban areas in Sri Lanka, International Journal of Disaster Risk Reduction, 102359.

Karunarathne, A. Y., (2022). Community resilience to mass flooding event of 2017: a case of severely inundated local admin areas in Kuruwita DSD, Sri Lanka. KALAM International Research Journal, 15(1), pp. 19-28.

Karunarathne, A. Y., Gress, D.R., (2022). The role of organizational networks in ameliorating flood disaster impacts: A case study of flood inundated rural and urban areas in Sri Lanka. International Journal of Disaster Risk Reduction, 71, 102819.

Karunarathne, A. Y., & Lee. G., (2022). How do urban reciprocal support network legacies matter to improve the resiliency of urban informal livelihoods?, Sustainable Cities and Society. 2022, 77: 103528.

Mujabar, P.S. and Chandrasekar, N., (2013). Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. *Natural Hazards*, *69*(3), pp.1295-1314. Available at: https://scholar.google.com/scholar (Accessed 14 Aug. 2020).

Nassar, K., Mahmod, W.E., Fath, H., Masria, A., Nadaoka, K. and Negm, A., (2019). Shoreline change detection using DSAS technique: Case of North Sinai coast, Egypt. *Marine Georesources & Geotechnology*, *37*(1), pp.81-95. Available at: https://scholar.google. C om / sc holar (Accessed 24 June 2020).

Raj, N., Gurugnanam, B., Sudhakar, V. and 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*, *10*(3), pp.205-212. Available at: https://scholar. google. co m/scholar (accessed 24 June 2020).

Tanaka, H.I.T.O.S.H.I., (2006). Monitoring of short-term morphology change at a river mouth. In *Proceedings of the Vietnam-Japan Estuary Workshop* (pp. 1-6). Available at: https://scho l ar. google.com/scholar (Accessed 24 June 2020).