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Research Article

Analysis of Coastal Erosion using Linear Regression Rate and End Point Rate Approaches Case Study: Southern Coastal Line, Sri Lanka Weligama Bay

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ABSTRACT

The coastal zone is defined as the area bounded by the band of ocean and the adjacent strip of land. This zone, in Sri Lanka, extends up to 300 m inland along the 1760 km coast. Various developmental projects have been installed in the coastal area of Sri Lanka, placing a considerable pressure on it, leading to various coastal hazards such as coastal erosion, seawater intrusion, coral bleaching, and temporal and long term shoreline changes. With the main objective of assessing the displacement of the coastline on the landward side by the forces of waves and currents which is known as the coastal erosion, this study was conducted for a part of Southern coastal line of Sri Lanka.

In order to calculate the Linear Regression Rate (LRR) and End Point Rate (EPR) of the erosion and to identify the key erosion hotspots of the study area, Digital Shoreline Analysis System (DSAS) tools were used in the GIS application. Temporal shore lines for different time periods were generated from the process of digitizing of Google Earth images which were taken in the years of 2006, 2010, 2014, 2017, 2018, 2019, 2020 and 2021. Further, 1:5,000 map prepared by the Survey Department of Sri Lanka and Landsat images extracted from USGS website were taken as the base map for the study. The erosion or the accretion regimes for 50 m orthogonal transects along the coastline were calculated based on the baseline and shorelines data. Finally, the coast line was classified as high erosion, moderately erosion, low erosion, stable, low accretion, moderately accretion and high accretion, using the resulting rates.

According to the results of the study, it can be identified that Weligama Bay shoreline exhibits a significant variation in the EPR value over the course of the relevant study period. Based on EPR, Weligama bay shows the maximum accretion rate as 2.3 m/year and the maximum erosion rate as -1.93 m/year. The results show that the area of the study is experiencing anthropogenic-caused coastal erosion due to the significant changes in the environment and shoreline. Human activities rather than natural events like climate change, sea level rise, and natural disaster conditions are the main cause of coastal erosion in the area under study.

Keywords: GIS; Erosion; Shoreline; LRR; EPR

INTRODUCTION

With the collision of the land, sea and atmosphere, the coastal zone can be considered as the most distinctive feature on the surface of the Earth [1]. The extent of the coastal zone depends on the environmental conditions and industrial and economic purposes it serves. The United Nations Environment Program report in 2022 revealed that approximately 45% of the global population is concentrated in the coastal zone [2]. It further reveals that the population density in this zone has been changed at an alarming rate (from 77 people per km^2 in 1990 to 87 in 2000) and predicts to increase up to 134 in 2050 [2]. Coastal region provides the home for one third of the total population of the country and it performs a very important role for the economical growth of the country.

Generally, the coastal zone performs a number of key activities under three categories: Regulation tasks such as maintaining biological and genetic diversity, regulating the chemical composition of sedimentary and water, storing and recycling nutrients and human waste, User-Production tasks such as providing space for agriculture, navigation, transportation, and tourism and Information tasks such as providing a variety of information about aesthetic, historical, cultural, and scientific aspect [3]. The zone is responsible for nearly 80 percent of the fish production and 70

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percent of the industrial output.

The coastal environment varies with a range of natural resources such as estuaries, lagoons, salt marshes, sandy beaches, coral reefs, mineral resources, and wildlife. Coastal locations are crucial for humans in their economical, social and cultural activities. These locations provide a proof for international trade between different countries. The expansion of fishing and tourism in the coastal area gives limitless benefits to the economy of the coastal public. It has a huge impact on the economic progress of the particular country. Changes in the shoreline attract more attention as one of the most important environmental indicators that have a direct impact on economic development and land management in the region.

The coastal environment of Sri Lanka can be considered as a famous tourist destination among the locals and tourists. It is surrounded by the Indian Ocean extending 1600 km long shoreline approximately [4,5]. General public and tourists use scenic coastal areas for different purposes such as viewing and feeling the natural environment, releasing the mental stress, recreation, and gathering for cultural activities. Further, it can be emphasized that the most of the road networks are centered along the coastal line and, hence, cities are developed and expanded parallel to i. This situation puts an unnecessary pressure on the coastal area with high level of urban expansion and population growth, specially in coastal urban areas. This would be, further, enhanced by the tourism industry which serves a greater contribution to the economy of Sri Lanka. By considering these trends, it can be concluded that the coast line of Sri Lanka is in a greater threat due to these natural and man-made pressures on it.

At the same time, sea level rises day by day, mainly, due to increasing the rate of melting processes of glaciers and ice caps continuously as a result of the global warming effect as well as the occurrence of El-Nino and stormy even [6,7]. In addition to that, the impact of the pressure created by the larger waves such as Tsunami, on the coast line, is very dangerous. Though these extreme events are not frequent, their impact is very harmful to the general public, their properties and natural environment [8]. As the result of this natural and human-induced phenomenon, the shoreline is eroding at an alarming rate. This current trend has been converted into a burning issue for the low lying coastal areas in Sri Lanka. These coastal hazards are making problems for the people who have made permanent structures in the areas closer to the shoreline and, continuously, affected by the erosion and wave attacks.

Coastal vulnerability can be considered as a spatial concept. And the assessment of coastal vulnerability identifies the people and the places that are exposed to affect resulting from coastal hazards. In the process of vulnerability analysis, specially for coastal hazards, it needs to consider all the physical, economic, and social systems in order to get a meaningful result. As well as, to mitigate the impact of coastal hazards, identification and analyze the vulnerability and assessment of risks are much important. Hence, it can predict the damage of the hazard earlier and can make proper precautions to minimize the impact.

Southern coastal area experiences a high population concentration and trend is there to increase the coastal erosion in certain areas drastically. It is, therefore, necessary to identify the factors and effects of coastal erosion in Sri Lanka in order to mitigate the impact. The main goal of this study was to assess the long-term shoreline changes along the coastline of Weligama bay to identify and quantify erosion and accretion areas using Linear Regression Rate (LRR) and End Point Rate (EPR) prediction models associated with the Digital Shoreline Analysis System (DSAS) tools in the Geographical Information Systems (GIS) environment as well as figuring out the main hot-spots for coastal erosion. Weligama beach is famous all over the world because of Weligama Bay and the number of beach hotels are situated near the shoreline. Developments are still going on in many areas of Weligama bay, even though it is restricted by the environmental acts and regulations introduced by the government. Preservation of the coastal assets is vital and highly needed for the future generations. In this study, integrated approach of Remote Sensing and GIS Technology was implemented with the views of experts.

The most popular statistical techniques for calculating shoreline change rates are end point rate calculations and linear regression rate-of-change statistics. LRR is the statistical method most frequently used to express shoreline movement and calculate rates of change. LRR can be calculated by fitting a least squares regression line to all shoreline points for a specific transect obtained from the analysis and EPR can be calculated by dividing the distance of shoreline movement by the time between the earliest and latest measurements.

MATERIALS AND METHODS

A number of research studies have been conducted everywhere in the world giving more priority for the study areas such as assessing the coastal erosion, modelling the temporal and long term coast line changes and analyzing the natural and physical vulnerability of coastal public for coastal disasters. These studies suggested that the erosion in the coastal zone depends on different natural characteristics and human interventions in the particular coastal zone. Natesan et al. [9] identified urbanization, mineral extraction, illegal sand and coral mining, and industrialization as the main human activities and strong waves in the North-East and South-West monsoon seasons as the main natural reason responsible for the change Tamil Nadu, India coast line. Samanmali et al. [10] identified unplanned human settlements as the predominant reason for coastal erosion in Kalpitiya Peninsula in Sri Lanka, after investigating the shoreline changes over a 50 year time period. Further, Samanmali et al. [10] emphasized that human factors, natural phenomena such as speed and direction of wind and speed and direction of waves change the coastal line in a greater extent.

Gunasekara et al. [11] also identified beach profile of Ratmalana in Colombo, Sri Lanka, is subjected to change, significantly, due to the reduction of sand volume during the South Western monsoon period from May to September. This was further proved by Baig et al. [12] in the study of Vishakhapatnam coastal profile of Andhra Pradesh, India. Vivek et al. [13] used Landsat satellite images in order to identify the spatial differences of the coast line in Lake Mouth Chilika, Odisha, India.

Pussella et al. [14] also could identified several reasons such as unplanned human settlements in the coastal regions, nature of living styles of coastal public, economical activities, lack of natural barriers, unplanned human implemented rock barriers, and sea level rise for the coastline changes in the North Western coast of Sri Lanka. And further, they emphasized the necessity of studies about the coastal area and analyze the properties of sea waves and currents such as speed and direction, temporal changes of meteorological factors such as temperature and rainfall, and beach characteristics such as land use and land cover type before implementing rock barriers at hot spots for coastal erosion.

Abeykoon et al. [15] studied about the capability of hard artificial structures for coastal protection and a sensitive study was recommended in order to identify a suitable type of structure. Geeganage and Warnasuriya [16] also identified the higher vulnerability rate of the Southern coast of Sri Lanka due to higher rate of land use and land cover change, human constructions, economical activities, sand mining and mangrove destruction. Gunasena attempted to introduce a new civil engineering based approach: artificial near-shore reef barrier using rock armors, to Weligama bay of Sri Lanka with the aim to reduce the coastal erosion of the area which is highly vulnerable for the erosion due to the shape of the bay where the water pressure and under currents are very high and strong.

Zahir et al. [17] attempted to identify the major reasons for the shoreline changes in the Eastern coastline of Sri Lanka and concluded that the human and natural interventions such as seasonal monsoon changes, unplanned human settlements and constructions are responsible greatly for the coastal erosion. Further, Lin and Pussella [18] concluded that the beach profiles such as sandy and rocky beaches are subjected to severe erosion in the South Western coastal line of Sri Lanka than others due to the impact of monsoons, natural disasters such as tsunami and other human activities. Lakmali et al. [19] used Google Earth images to identify the changes of the coast line due to seasonal monsoon patterns.

Natesan et al. [9] used ortho-rectified MSS, TM, ETM+, and OLI Landsat images acquired from 1978 to 2014 to assess the rate of coastal erosion. Gunasekara et al. [11] used GNSS and satellite images to collect the data in order to prepare a numerical model to evaluate the coastal erosion scenario. In order to track the coast line changes in the Eastern coast line of Sri Lanka, Perera et al. [20] used Quick Bird, Worldview and Google Earth images. Baig et al. [12] have used satellite data such as Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 ETM+ to analyse shore line changes of Vishakhapatnam, India from 1991 to 2018. Abeykoon et al. [15] used integrated approach of satellite data and GPS data to collect the data to obtain coast line changes.

Geeganage and Warnasuriya [16] also used Landsat satellite images obtained from 1976 to 2014 to examine the shoreline changes. Lakmali et al. [19] used satellite images in a GIS environment in order to understand about the coastal erosion by considering the wet-dry line as the coast line boundary. Samanmali et al. [10] used visual interpretation approach in remote sensing and DSAS extension in GIS software package to analyze the changes of the shoreline for a long time period (from 1956 to 2014) for Kalpitiya peninsula of Sri Lanka taking indexes such as NDVI, NDII and SAVI to demarcate the coastal line on the satellite images. Perera et al. [20] also conducted a study to map the changes along the coastline of Pottuvil, Sri Lanka from 1987 to 2018 using Net Shoreline Movement (NSM) and End Point Rate (EPR) tools in DSAS extension in GIS software.

Baig et al [12] obtained the final decision matrix for coastline change and categorized the coast line with the erosion rate Vishakhapatnam, India. Pussella et al. [14] attempted to model the vulnerability for the coastal erosion using several factors such as rate of shoreline erosion, mean wave height, mean tidal change, dune height, relative sea-level change, geomorphology, land use pattern, beach type, coastal slope and barrier type by considering the wet-dry line as the coastal boundary. In this model, DSAS tools in GIS environment and Analytical Hierarchical Process approach were used in order to enrich the model with statistical parameters. Karadana and Nuwan [21] predicted the shoreline of North Western part of Sri Lanka using EPR, JKR and LLR tools in DSAS extension. Hasanuzzaman et al. [22] predicted the rate of erosion and accretion in the Ganga River bank of India using EPR model to calculate the rate and LRR model for predicting the rate. The importance of using GIS, Remote Sensing, and Digital Shoreline Analysis System (DSAS) techniques to detect shoreline changes in the coastal zone is also emphasized by Perera et al. (2020).

Study area

Weligama Bay in the Southern Coast of Sri Lanka was selected as the study area of this research work. This region is situated at latitudes 5°55' and 9°51' N and longitudes 79°41' and 81°53' E in the Weligama west area of the Matara district of Sri Lanka. This particular area was chosen, since it is highly vulnerable to both natural and man-made hazards, including coastal erosion, excavation of sand dunes, sea level rise and tsunamis. Due to the physical characteristics of the area, the damage of Tsunami- 2004 was significant. Fishing and tourism are the main source of income of the residents in this area. Also, the area is well popular among tourists as a destination as shown in Figure 1.

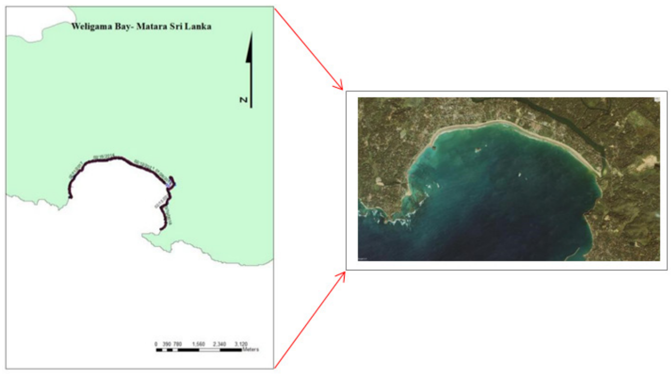

Figure 1: Location map of study area, Weligama Bay, Matara District, Sri Lanka.

Data requirement and preparation

In order to achieve the main objectives of the study, the study required, mainly, temporal shore lines for different time periods. They were generated from the process of digitizing of Google Earth images taken in 2006, 2010, 2014, 2017, 2018, 2019, 2020 and 2021. In selecting these images, cloud free images taken on approximately closer dates were taken into account. Further, 1:5,000 map prepared by the Survey Department of Sri Lanka and Landsat images extracted from USGS website were taken as the base map for the study. The shorelines for the years from 2006 to 2021, were manually digitized using the Google Earth Pro digitizing tool and saved as KML files separately. After that, these files were imported into layers in GIS environment. Since the projected coordinate system of the layers was WGS84 and its geographic coordinate system was GCS WGS1984, digital layer files were Geo-referenced. Then, these layers were exported as Shape files to be used in GIS.

In the process of work with DSAS tools to assess the erosion rate of the coastal area, it needs to define a baseline firstly. In this, the oldest coast line would be taken as the baseline normally. Therefore, in this study, the line extracted from the 2006 image, was considered as the baseline. Then the baseline and other shorelines were inserted into a Geodatabase in the GIS. After that, transacts were digitally drawn for each and every shoreline with 50 m intervals using the tools in the DSAS tool kit. There are a few particular requirements in the attribute fields for the analysis. These fields were manually created and saved in baseline and shoreline attribute fields prior to the analysis. Width of transects, Smoothness of transects and the range of detecting shorelines were selected to improve the accuracy and the precision of the output data. The misleading transects were removed for better results. Using the "Rate Calculate" button, the End Point Rates and the Linear Regression Rates were calculated. DSAS tools were further used to overlay the vector layers of shorelines and calculate the erosion or the accretion rates at 50 m intervals along the coast line of the study area as shown in Figure 2.

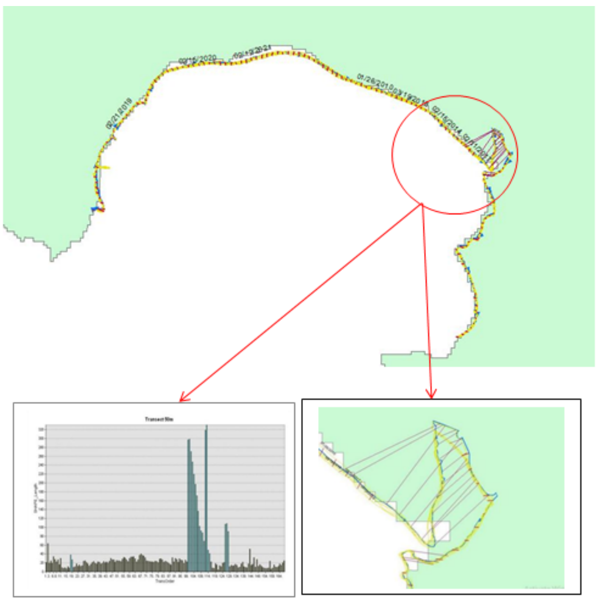

Figure 2: DSASv5 Transect Layer (50 m).

The erosion or the accretion regimes for 50 m orthogonal transects along the coastline were calculated based on the baseline and shorelines. Finally, the coast line was classified using the erosion and accretion rates (Table 1).

Table 1: Shoreline Classification based on EPR and LRR.

Section No	Rate of shoreline Changes EPR/ LRR (m/year)	Shoreline Classification
1	≤ -2	High Erosion
2	>-2 to ≤ -1	Moderate Erosion
3	>-1 to <0	Low Erosion
4	0	Stable
5	>0 to <1	Low Accretion
6	1 ≤ to <2	Moderate Accretion
7	2 ≤	High Accretion

RESULTS AND DISCUSSION

According to the results of the study, the shoreline of Weligama Bay exhibits a significant variation in the EPR value over the course of the relevant study period. Based on EPR analysis, it shows a maximum accretion rate of 2.3 m/yr (Transect ID 96) and maximum erosion rate of 1.93 m/yr (Transect ID 148). Figure 3 shows the erosive patterns along the study area. High and moderate rates of erosion along the coast were observed from Transect ID 4 to 8, 52 to 68, and 136 to 151. The construction of ports and harbours along these coasts has resulted in severe erosion, and the placement of sea protection structures like seawalls and groynes reduces the supply of beach sediment to other areas by trapping sediment along the protection structure.

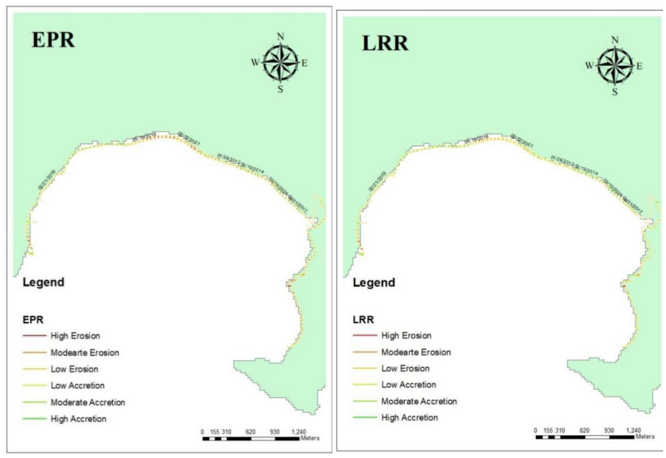

Figure 3: Erosion and Accretion rates along Weligama Bay. **Note:** (—) High erosion rate (—) Moderate erosion rate (—) Low erosion (—) Low accretion (—) Moderate accretion (—) High accretion

Consequently, these shoreline changes may be caused primarily by various development activities that physically alter shorelines, seasonal changes, additional anthropogenic interventions, and the impact of the implemented hard coastal protective structures. Geometrical processing was used to improve the satellite data, and accuracy assessment was carried out using the map of Matara District of Sri Lanka and the Google Earth image of the area. The shorelines and baselines in the current data set were defined using the digitization technique in GIS. It was obtained from Google Earth Pro Application. It was discovered that, the Weligama Bay experienced both erosion and accretion over the course from 2006 to 2021. The degradation of coastal vegetation and the absence of rock barriers are the primary causes of land-use changes, which lead to coastal erosion.

Tsunami disaster in 2004 has been caused many acres of vegetation bio shield to be destroyed, the offshore wave climate has changed over past years (from 2006 to 2021), changing the coastline due to tidal fluctuation and sea level rise. Anthropogenic activities have destroyed or altered mangroves, coconut plantations, and coastal vegetation over past 15 years. Unfortunately, the erosion and sedimentation issues in the harbour currently make it difficult to manage even fishing operations. It is obvious that additional research should be conducted in order to stabilize and eventually achieve sustainable development of the coastal area of Weligama Bay. Unfortunately, the erosion and sedimentation issues in the harbour currently make it difficult to manage even fishing operations. It is obvious that additional researches should be conducted in order to stabilize and eventually achieve sustainable development of the Weligama Bay coastal area as shown in Figure 4.

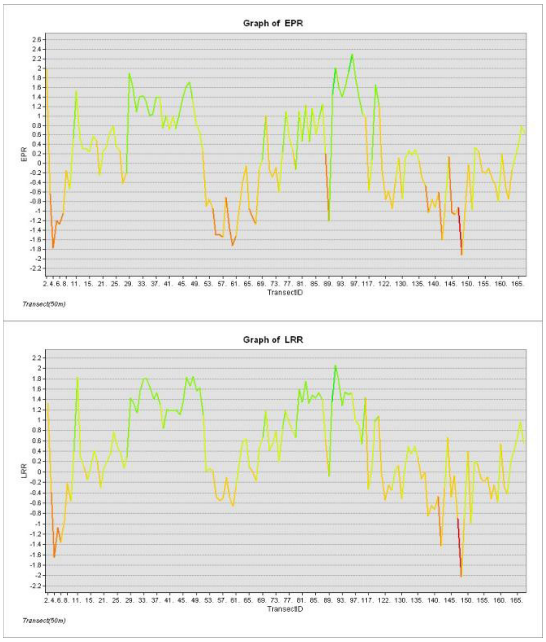

Figure 4: Erosion and Accretion rate Graph. **Note:** (—) High erosion rate (—) Moderate erosion rate (—) Low erosion (—) Low accretion (—) Moderate accretion (—) High accretion

Below figures represent erosion regimes along the Weligama bay (Figure 5, Figure 6 and Figure 7)

Figure 5: Transect ID 4 to 8 Area

Figure 6: Transect ID 52 to 68 Area.

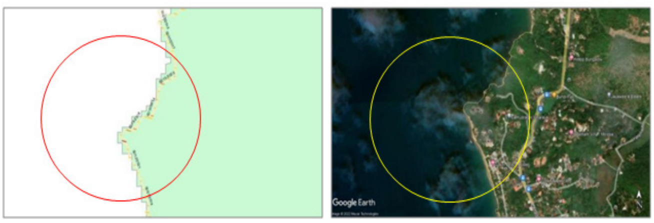

Figure 7: Transect ID 136 to 151 Area.

CONCLUSION AND RECOMMENDATION

The results shows that the study area experiences significant changes to the environment and shoreline. Also, natural events such as climate changes, sea level rise, and natural disaster conditions are the main cause for coastal erosion in the area. Though the vegetation line has not been changed over the past 15 years compared to the wet dry line, the study uses wet dry line through the digitization process of the shoreline. The solution that is least able to control coastal erosion over a large area is the application of hard structures. Additionally, it is crucial to accurately identify the shoreline's dynamic nature, which is brought on by wave patterns and coastal currents, and to consider mandatory subsidies for the management and conservation of the coastal zone, as well as the buffering effect of natural coastal ecosystems and coastal-based industries.

This research is mainly focused on the shoreline changes. Using Google Earth Pro satellite imagery, this study is crucial for revealing the evolution of shoreline change in Weligama Bay from the year 2006 to 2021. Calculated EPR and LRR for the Weligama bay and the erosion/accretion maximum and minimum rates were carried out. The accuracy of the study can be increased by the use of high resolution images. If low resolution images are used, the vegetation line must be used to extract the shoreline. Low resolution images used for wet dry line extraction tend to cause more errors. For more accurate results, a large area should be chosen when making the selection.

For this study, the EPR and LRR were divided into high, moderate, and low sections, with accretion/erosive rates ranging from -2 m/year to +2 m/year. The range can vary from one study area to another, with erosion rates of -2 m/year to 0 m/year and accretion rates of 0 m/year to +2 m/year. The transect gap can be altered to either reduce or add more data, but transect width should be determined by the objectives of the study and the purpose as well.

According to the study, rock structure is the most simple and direct method to prevent erosion. Mangroves can be grown to prevent erosion as well. Beach nourishment programs are nonetheless a highly suggested solution, despite the fact that they are challenging to implement due to their high cost and dearth of resources. While building a revetment wall, breakwaters, and sea walls are some hard structure methods to protect the shorelines, beach nourishment, beach filling, and green belts are some soft solutions. Sandbags, rock dumps, and stone barriers can be used as emergency protection to reduce erosion as well.

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