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AN ANALYSIS OF CAUSES OF COASTAL EROSION IN CALIDO BEACH, KALUTARA, WEST COAST OF SRI LANKA

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ABSTRACT

The coastal zone is key to sustainable development of a country. However, coastal erosion has been identified as a major natural hazard in the world for a long time. Coastal erosion is mainly affected to damage or destroy the various structures along the coast. This can also be a huge problem for the tourism industry of the country because the beaches play a vital role in attraction of tourists. In Sri Lanka, Kalutara is one of the most critically eroded coastal areas of the country. Therefore, it is needed to identify the spatial distribution of the eroded areas, causes and impacts of coastal erosion as well as suitable protection and mitigation measures.

Therefore, the aim of the study is to analyze the coastal erosion of Calido beach in Kalutara. The specific objectives of the study are mainly two folds' identification of spatial distribution of beach erosion in Calido beach, and the causes for coastal erosion in Calido beach. The study is based on qualitative analysis. Google Earth Pro is used for the completion of research objectives. Rainfall, wave climate, river flow, shoreline changes and sediment transport are the main data that was collected. The spatial distribution of eroded area could be classified as high, medium, and low by the direct observation method. The results of the study revealed that the cut of sand bar in May, 2017 is the main cause of coastal erosion in Calido beach. Accordingly, the total extent of the eroded area of the beach was approximately 0.45 km^2. Further, the results of the study revealed that the length of the eroded area was approximately 3 km and the perimeter was about 5.52 km. Therefore, this study was recommended to identify suitable protection and mitigation measures for the coastal erosion in Calido beach.

KEYWORDS: *Coastal Erosion, Calido Beach, Spatial Distribution, Shoreline, Sustainable Development, Google Earth*

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1. INTRODUCTION

The coastal area is subjected to an increased pressure by regional alterations and global changes. The shoreline also called as the coastline, is a boundary in between the land and the sea. Due to the dynamic environmental circumstances, coastline being carried out in the coastal areas is constantly changing its location and shape. Diverse development projects have been set up along the coast, putting a great deal of pressure on them, leading to various coastal threats such as seawater intrusion, coastal erosion, and coral bleaching. Among them, coastal erosion is a critical problem affecting all the countries in the world having a shoreline.

Particularly, coastal erosion can be defined as a natural process that break down the rocks and the sediments at the shoreline. Taranaki Regional Council (2009) defines coastal erosion as "the process of episodic removal of material at the coastline leading to a loss of land as the coastline retreats landward". Coastal erosion happens due to a result of the action of waves, tidal action, wind, storm surge, ice, rain, and surface runoff (Centers for Disease Control and Prevention, 2016; Atlantic Climate Adaptation Solutions Association, 2011). In addition to that, there are three possible factors to affect coastal erosion, such as Sea Level Rise (SLR), change of monsoon/ storm climate, and human interference (Taranaki Regional Council, 2009).

Beach erosion involves a redistribution of sand from the beach face to offshore. Stormy waves have higher energy. Therefore, the backwash is stronger leading to erode the beach. Whereas during the calm weather, beaches are not eroded since weaves have lower energy and therefore backwash is not stronger. This phenomenon suggests that wave energy plays an important role in beach erosion (Braatz, Fortuna, Broadhead and Leslie, 2007; Kennedy, Mcinnes and Ierodiaconou, 2010; Short, 2012). Certainly, strong wind is necessary to generate stormy waves that lead to erosion (Lindgreen and Lindgreen, 2004).

There are many methods to study the coastal erosion. As an example, to analyze the coastal/ beach erosion, Synthetic Aperture Radar (SAR) is used as satellite radar to capture shoreline details, while aerial digital photography is used to get three-dimensional (3D) details through photogrammetric study (Jena, Kumar and Kintada, 2017).

Especially, soft and hard engineering structures are developed to mitigate coastal erosion. According to Hunt, Sample and Carlson (2014), the previous attempts in the 1950s and 60s to prevent sea erosion is mainly focused on "hard" engineering measures but more recently consideration has moved to apply "soft" engineering measures that are regarded to be more effective on coastal erosion control. Some of the soft measures can be identified as beach nourishment, stabilizing coastal beaches, planting coastal vegetation (i.e. littoral plants), planting mangroves, maintaining healthy fringing reefs and barrier coral reefs, protection and restoration of sea grass and algal ecosystems, and maintaining a healthy reef island and islets.

When focused on Sri Lanka, the coastal belts are one of the important elements for the sustainable development. There is approximately 1600 km of coastline across the country. The coastal region is gorgeous, and it is rich in biodiversity and wide diverse natural resources. However, coastal erosion has become a problem. With population growth, the pressure on the resource base of the coastal zone has also proportionately increased. It creates new stresses on the coastal environment, and it can become a hazard in the future. Further, the lack of understanding of the dynamic nature and complex interrelationship among ecosystems and human activities in the coastal zone result in an escalation of coastal problems (Senevirathna, Edirisooriya, Uluwaduge and Wijerathna, 2018). Especially, there is a high concentration of population in the southwest coast and western coastal areas, which will expand the coastal erosion in specific areas.

However, coastal erosion is an acute problem today. Accordingly, many coastal areas in the southwest coastal zone in Sri Lanka are highly vulnerable to coastal erosion. In this zone, coastal erosion of Calido beach in Kalutara is a very huge problem today. Especially, coastal erosion is mainly affected to damage or destroy various structures along the coast. Therefore, the buildings along the coastline are highly vulnerable to coastal erosion in this area. This can also be a huge problem for the tourism industry because the Calido beach in Kalutara plays a vital role in attraction of tourists. Hence, coastal region has been very popular among foreigners. The economic and social demand previously received from this area has been reduced today due to this situation. Therefore, understanding this issue and contributing to mitigate coastal erosion will be useful in the future.

Present study is focused on analyzing the coastal erosion and identifying the causes of coastal erosion in Calido beach, Kalutara. The specific objectives of the study are mainly two folds; 1) to identify spatial distribution of beach erosion in Calido, and 2) to identify the causes for coastal erosion in Calido beach.

2. METHODOLOGY

Description of study area

Kalutara is located in the Western province and it covers an area of 1,598 square kilometers in Sri Lanka. It is situated on the coast at the estuary of Kalu River. Accordingly, this study is mainly focused on Calido beach in Kalutara.

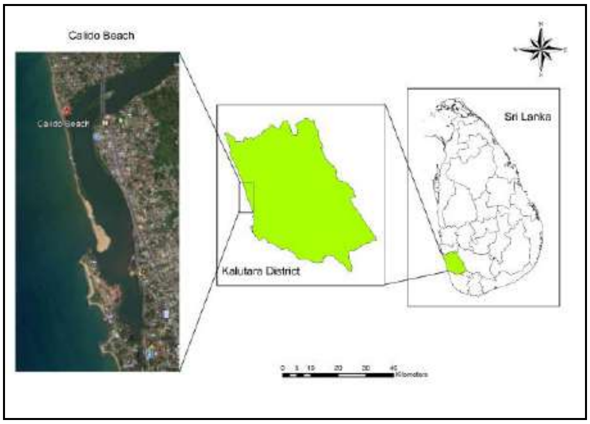

Figure 1: Location of the study area

Calido beach locates in Kalutara district in the Western province of Sri Lanka (Figure 1). It is also located in the wet zone and the Southwest coastal belt of Sri Lanka. The study area is located at the coordinates between 6° 34′ 59.16″ N and 79° 57′ 33.48″ E. The average annual temperature of the coastal zone is around 24 °C - 30.5 °C. Calido beach is the belt of beach that lies between the Kalu River estuary and the Indian Ocean. It is a usually straight beach extending in the south direction.

There are two main monsoon periods in Sri Lanka, namely Southwest monsoon (from May to September) and Northeast monsoon (from December to February). Accordingly, rainfall in the study area is mainly received during the southwest monsoon. High energy steep waves are produced by the southwest monsoon along the south to northwest coastlines of Sri Lanka. The high-energy steep waves decrease the beach breadth and flatten the intertidal shore face during the southwest monsoon (Ratnayake, Ratnayake, Azoor, Weththasinghe, Seneviratne, Senarathne, Premasiri and Dushyantha, 2019).

Especially, sediments are carried with the water to the face of the beach until it consumes its energy and it begins to rush back offshore. Water carries offshore due to gravity and therefore, it usually does not follow the same path to the beach unless it is moving towards the shore. Hence, sediment is transported downdrift in a zig-zag pattern, not backward and forward. Along shore current is generated in the breaker zone by waves breaking at an angle to the shoreline (O'Neill, 1985; National Oceanic Atmospheric Administration, 2015). Longshore and onshore-offshore sediment transport based on wave direction and strength (Figure 2).

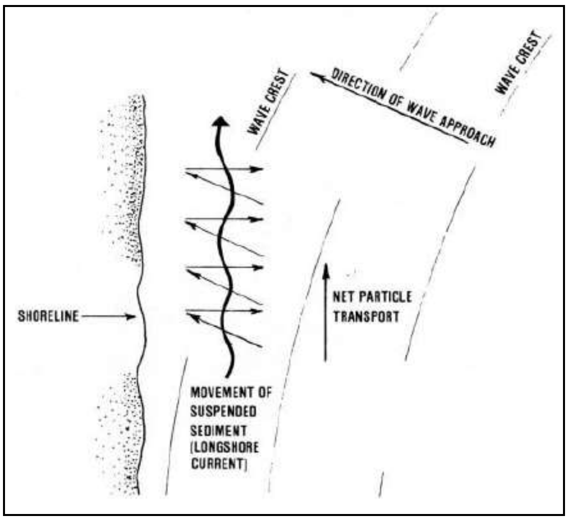

Figure 2: Sediment Transports phenomenon
Source: O'Neill, 1985

Wind waves are set up as a consequence of the wind action on the surface of the water. Wind waves depend on the height, length, period, and direction at which they are striking the shore (Figure 3).

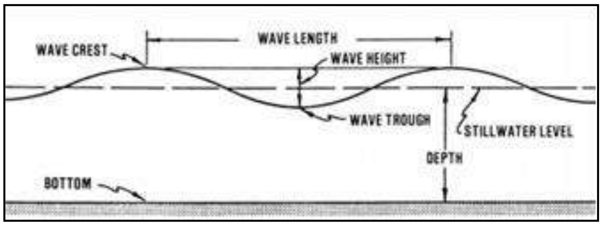

Figure 3: Wave characteristics (Source: O'Neill, 1985)

Data collection

The study was mainly based on secondary data. Wave climate, river flow, rainfall, shoreline changes, and sediment transport data were collected for analyzing the coastal erosion in the Calido beach, Kalutara. Monthly river flow and rainfall data were obtained from the Department of Irrigation and the Department of Meteorology, Sri Lanka. Monthly river flow data were collected for a period of 30 years from 1990 to 2020 at Putupaula gauge station. Monthly rainfall data were also collected for a period of 30 years from 1990 to 2020 at Kalutara rain gauge station.

Further, 22 historical Google earth images were collected for the study during the period from 2004 to 2020. Those images were collected for the months of January, February, March, April, May, August, October, November, and December.

Cross-shore profiles were used for Sediment transport calculations. Further, wave data was obtained from Beruwela. Other sources of data including video, newspapers, and journals were also collected to gather information related to the study.

Data analysis

This study was based on qualitative analysis. Sediment transport map was created using LITPACK model. Rose plot diagrams were generated by MIKE Zero. Furthermore, the past and recent Google earth satellite images were used to examine the spatial distribution of beach erosion and accretion trends in the study area. Accordingly, satellite images in 2004, 2005, 2009, 2010, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, and 2020 were used to identify the shoreline changes for analyzing the level of eroded coastal area as high, medium, and low.

To examine the behavior of the coastline and to identify the land use patterns of the study area, satellite imagery by using Google Earth Pro were used. MS Excel was used to analyze the collected rainfall and discharge data.

3. RESULTS AND DISCUSSION

Analysis of the spatial distribution of beach erosion

According to the analysis of shoreline changes between 2004 and 2020, it has been classified the eroded area as high, medium, and low (Figure 4).

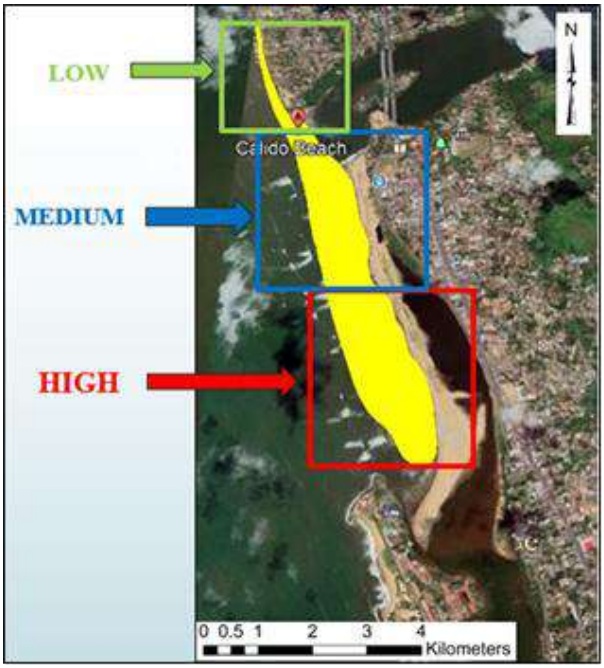

Figure 4: Spatial distribution of beach erosion in Calido

Therefore, the study was revealed that the total extent of the eroded area of the Calido beach was approximately 0.45 km^2. Also, the length of the eroded area was approximately 3 km, while the perimeter was about 5.52 km.

Identify the causes of coastal erosion

1. Removal of the sand bar

The sand bar in Calido beach has been cut off to widen the river mouth as a solution to drain the water during the heavy flood situation of May in 2017. When considering to the condition of the Calido beach before the sand bar is cut and after the sand bar is cut (Figure 5), it could be identified that the Calido beach has continued to erode by December, 2017. It was a serious problem for the people who live in this area.

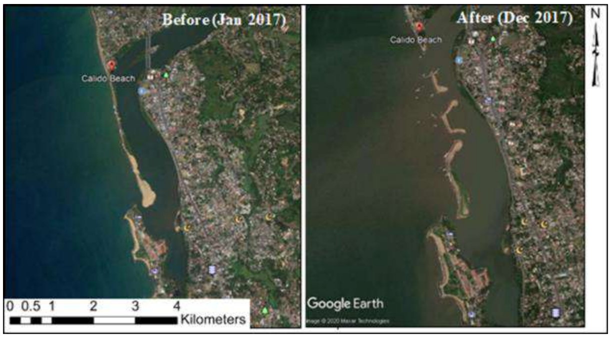

Figure 5: Satellite images of sand bar in Calido beach in January 2017 and December 2017

2. Changes in rainfall pattern & river flow

The climate is one of the facts influence coastal erosion. There were variations between rainfall and discharge of the study area at the Putupaula gauge station over about 20 years (Figure 6). Although, there was no significant change from 1995 to 2016, however, there was a significant increase in rainfall and discharge by 2017 and 2019.

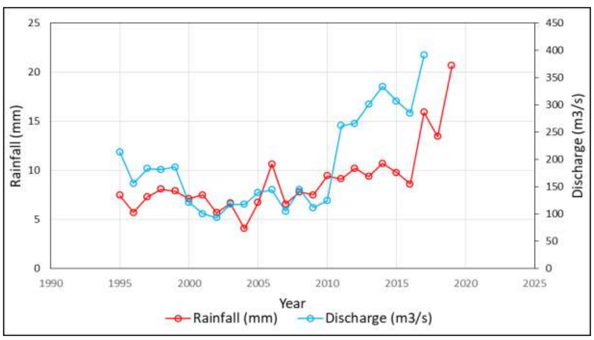

Figure 6: Variation of annual rainfall and river flow at Putupaula

Furthermore, it could be identified that there were significant variations of monthly rainfall at Kalutara from 2016 to 2020 (Figure 7) by considering the rainfall seasons as Northeast (NE) monsoon, First-inter monsoon (IM1), Southwest (SW) monsoon and Second-inter monsoon (IM2). According to those variations, a significant increase in rainfall has occurred during the southwest monsoon.

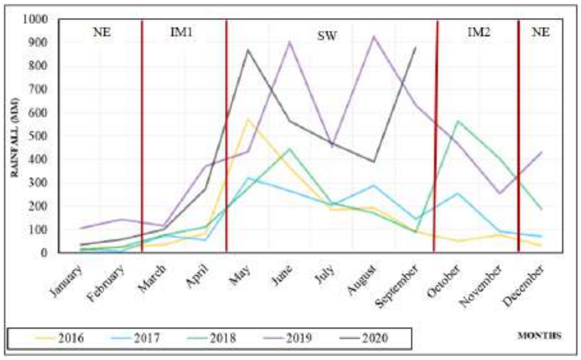

Figure 7: Monthly rainfall variation at Kalutara

3. Sediment Transport

Sediment transport can be identified as the movement of sediments due to wave action and currents in the nearshore area. There are two ways of sediment transport. They are longshore transport (which is parallel to the shore) and onshore-offshore transport (which is perpendicular to the shore). These two types of sediment transport cause either erosion or deposition according to the physical characteristics of the shore and the waves. Generally, less steep, long-period waves move sediment onshore, while steep waves with shorter periods tend to transport sediment offshore (O'Neill, 1985). In addition to that, water stirs bottom sediments when the break of the waves.

Accordingly, at Kalutara coastal area, Longshore and cross-shore sediment transport directions can be identified (Figure 8). The longshore drift and its direction are mainly controlled by the southwest and northeast monsoon wind and waves of Sri Lanka. The cross-shore transport of the coastal profile consists of onshore and offshore sediment transport components and is generated by a variation of waves and water level conditions along the adjacent coast. According to the study, longshore transport of sediment, value is greater than the cross-shore transport of sediment value from Kalu River. A careful study of this map shows that the supply of sediment from the Kalu River is higher than other rivers around Sri Lanka. Although, sand deposition in other river estuaries is a problem, sand deposition at this location is very advantageous. According to that, it can be assumed that the coast will develop at a higher rate.

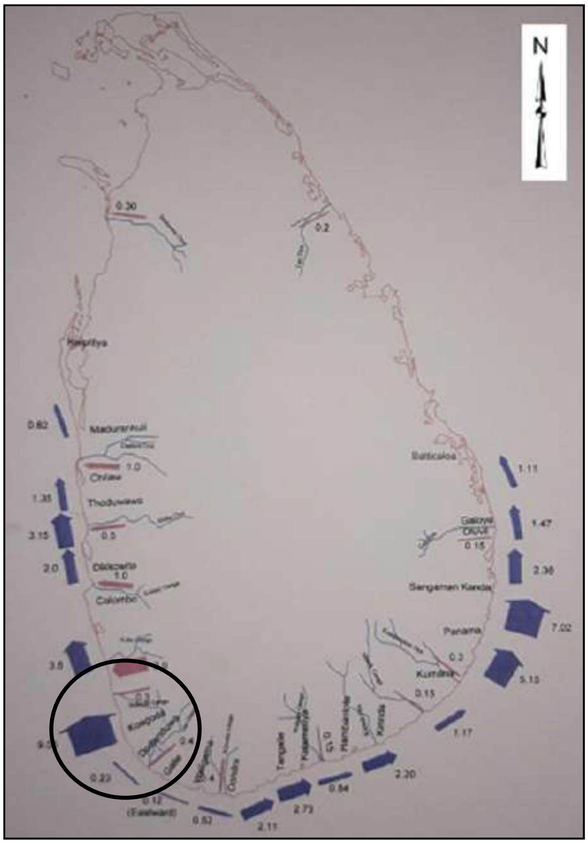

Figure 8: Annual net sediment drift along the shoreline and River discharges (Values are in 100,000 m3/ yr)

4. Wave Climate

Waves are two types as short waves which are wave periods less than nearly 20s and long waves which are wave periods between 20-30s and 40 min. Furthermore, short waves can be divided as sea waves and swell waves. In general, sea waves are steep and are often both irregular and directional and these are generated and conducted by the local wind field. Sea waves can be destructive for the coastal zone because sea waves are generated an offshore motion of sediments, which effects a normally flat shoreface and a steep foreshore. Swell waves can be identified as waves that are generated by wind fields far away. Also, they have carried long distances over deep water away from the wind field and their propagation direction is not the same as the local wind direction (Goodwin, Stables and Olley, 2006; Hemer, Church and Hunter, 2007; Hughes, 2016). Furthermore, swell waves can be developed from the coastal profile to a steep shoreface (Mangor, Drønen, Kærgaard and Kristensen, 2017).

The combination of ocean currents and tidal waves increases coastal land erosion. Two rainfall seasons are mainly affected by ocean current circulation in Sri Lanka. Those two different rainy seasons are Southwest monsoon from May to September and the Northeast monsoon from December to February in Sri Lanka.

Accordingly, it is dominant for the south and west coasts during South-west monsoon. This is also one of the fact contributing to the increase in coastal erosion on the southwest part because of the wave conditions on the west coast during the southwest monsoon are more severe than the wave conditions of the east coast during the northeast monsoon (Senevirathna et al., 2018).

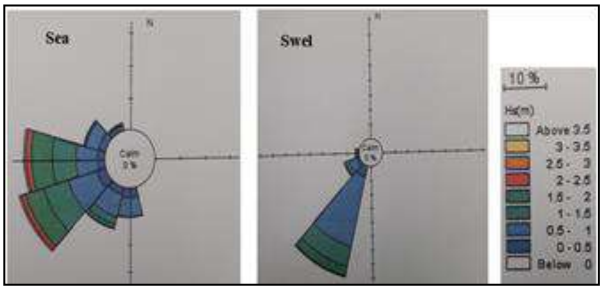

Figure 9: Annual wave roses in Beruwala

Rose petals indicate the direction of the wave and these different colors indicate the wave height. Waves are generated by the nearshore and offshore winds, which blow over the sea surface. Then, their energy is transferred to the water surface. Therefore, it can be observed that the sea waves strike in different directions than swell waves (Figure 9). Furthermore, the wave height of the sea waves is more than swell waves.

The southwest monsoon is characterized by sea waves with higher wave heights than the northeast monsoon (Figure 10).

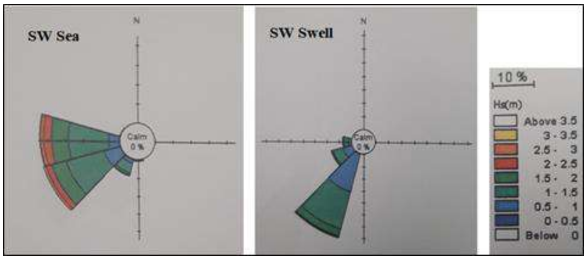

Figure 10: Southwest seasonal wave roses in Beruwala

However, waves strike in a different direction during the northeast monsoon. Also, it can be seen that waves strike generally in the same direction when comparing swell waves of southwest and northeast monsoon. Therefore, sea waves are more affected waves than swell waves. It affords increasing transport for incidence angles from 0°- 45° while decreasing transport from 45°- 90°. It seems that more waves incidence angles from 0°- 45° during the northeast season. Therefore, sediment transport is increasing during the northeast season (Figure 11).

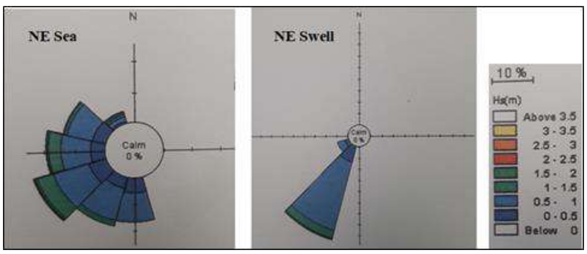

Figure 11: Northeast seasonal wave roses in Beruwala

5. Shoreline Changes

Shoreline position changes can affect coastal currents during monsoon periods. Cut the sand bar in 2017 is the main reason for shoreline position changes in Calido beach.

The movement of material along the coast is associated with natural forces such as longshore and cross-shore currents, waves, tidal movements, and wind waves. Wave and current processes, sediment supply, coastal geology and morphology, and human mediation are primary factors that can change shoreline position (Chand & Acharya, 2010). The waves generated by the wind are one of the most important energy transfer agents along the Calido coastline. These waves emancipate their energy by striking the coast and setting up the erosion of cross-shore and alongshore. There is no significant change of shorelines in the early years. It is a regular pattern. However, shorelines are significantly changing yearly after the year 2017 (Figure 12).

Figure 12: Annual shoreline changes in Calido beach

Accordingly, it can be observed that the sand deposition is higher on December 28 than it was on December 17. In January, it was even more so. According to these figures, it can be concluded that predominantly sand deposited during the northeast season (Figure 13).

In February, it can be seen that the sand deposition was even higher. The formation of the sand bar changed after the southwest monsoon period. The southwest monsoon may have contributed to this change, as heavy rainfall and higher wave height of waves occur during this monsoon.

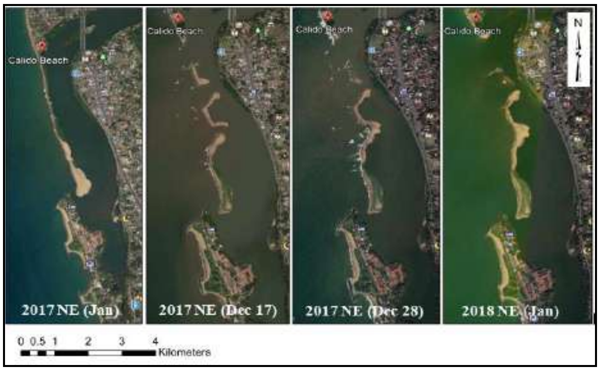

Figure 13: Seasonal shoreline changes during 2017 & 2018

Comparision of these images indicates that some areas are newly deposited, and some areas are eroded. Constructive waves can cause to erode some areas because their strong backwash will result in beach erosion. Also, cross-shore sediment transport and alongshore sediment transport may cause the new deposition. Because of increasing the river flow, the sand supply from the river is increased (Figure 14).

Figure 14: Seasonal shoreline changes during 2018 & 2019

These images clearly show that the direction in which the new sand is deposited is the same as that on the sediment transport map around Sri Lanka. By considering all these figures, it can be concluded that the developing rate of sand bar is less during the southwest monsoon and predominantly sand deposited during the northeast monsoon. Hence, the southwest monsoon and northeast monsoon are the critical seasons. However, these are only seasonal changes. It gets recovered and deposited after the season (Figure 14).

Another important fact that can be seen in the study area is the sediment cell developing in the sand bar (Figure 15).

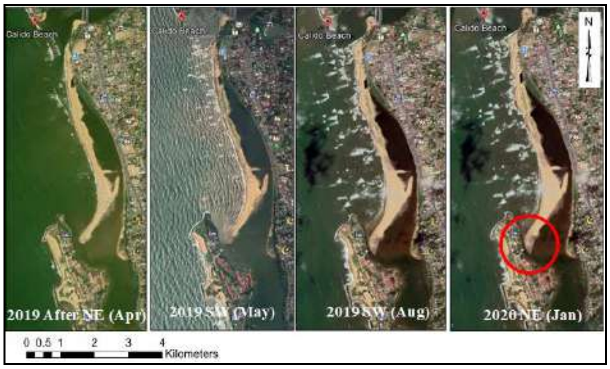

Figure 15: Seasonal shoreline changes during 2019 &2020

Sediment cells are the movement of material that is largely self-contained. Also, if the dune in the lagoon area (the area surrounded by red color in the fourth image) is covered, another huge problem will arise. It can occur water quality problems because people who live in this area normally put garbage in the water and no circulation if it is closed.

Therefore, no fresh water is available in this region. This causes health problems for the people living in this area. Also, marine habitat already exists in this lagoon area. Before cutting the sand bar, the water is purified and the water flows into the sea from this region. Therefore, the side effect after cutting is more than before cutting.

When considering to the seasonal shoreline changes during in 2017 and 2018 of the river mouth area, it can be identified a sand formation after cutting the sand bar. It creates a major effect on salinity intrusion. The site where the sand bar was cut (Figure 16). It can be identified that the sand bar was developed gradually during the NE season. However, after the southwest monsoon in 2018, this sand bar has eroded (Figure 16 & 17). Furthermore, Sand is deposited gradually increased near the river mouth area . However, it is also another severe problem because the dune can adjoin with the island. This situation can be clearly shown in southwest season in 2019 (Figure 18).

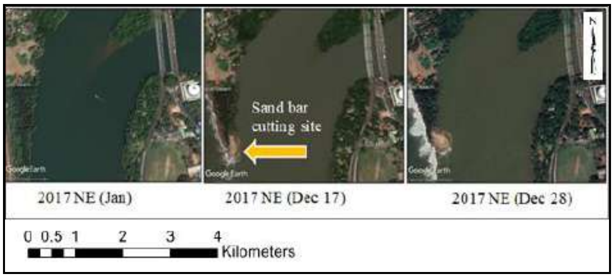

Figure 16: Seasonal shoreline changes in 2017

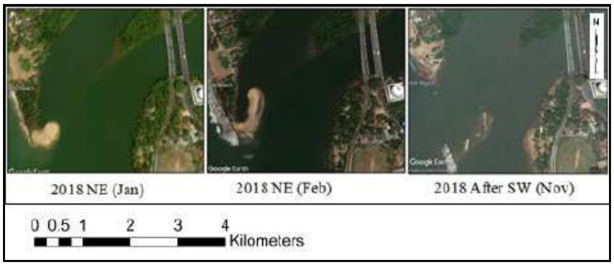

Figure 17: Seasonal shoreline changes in 2018

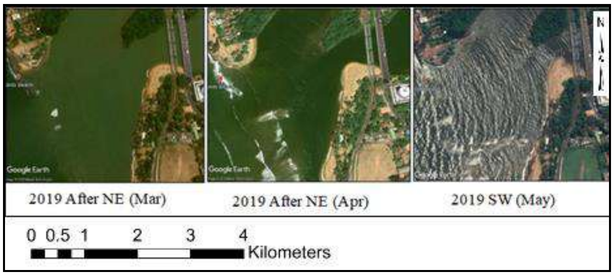

Figure 18: Seasonal shoreline changes in 2019

Although, the gradual expansion of the sand bar toward the sea can be identified in northeast season in 2020 (Figure 19). However, it is a serious problem as it is more difficult to drain the water from the mouth of the river. Then again this area will be eroded.

Figure 19: Seasonal shoreline changes during 2019 & 2020

4. CONCLUSIONS

In Sri Lanka, the coastal zone is key to the sustainable development of the country. However, coastal erosion has been identified as a major natural hazard for a long time. Kalutara is one of the most critically eroded coastal areas in the country. The goal of the study is to analyze the spatial distribution of beach erosion of Calido beach in Kalutara. This study was based on qualitative analysis. Google Earth Pro was used for the completion of research objectives. Rainfall, river flow, wave climate, sediment transport, and shoreline changes are the main data that were collected.

According to the analysis, the cut of sand bar in May, 2017, was the main cause of coastal erosion in Calido beach. The spatial distribution of eroded area was classified as high, medium, and law beach erosion. The results of the study revealed that the total extent of the eroded area was approximately 0.45 km^2. Further, the results of the study revealed that the length of the eroded area was approximately 3 km and the perimeter was about 5.52 km. Therefore, this study was recommended to identify suitable protection and mitigation measures for the coastal erosion in Calido beach. The study also recommended the further studies as design the structure of wave analysis for the return period of about 25-100 years, perform the proper Environmental Impact Assessment and Feasibility Analysis, and apply the most suitable flood control system to the Kalu River.

5. ACKNOWLEDGEMENTS

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