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Geotechnical Characterization of Coastal Erosion in Kalutara Coastline, Sri Lanka

*S.M. Rupasinghe, H.L.A. Hewaarachchi, W.G.D.D. Nimnajith, K.H.Cheshani Kaumadi Peiris

Faculty of Technology, University of Sri Jayewardenepura
*sanduni2000rupasinghe@gmail.com

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Abstract: The coastal zone of Sri Lanka serves as an important key component for the sustainable development of the country. Its significance spans various dimensions, including economic activities, biodiversity, tourism, and cultural heritage. However, the persistent challenge of coastal erosion poses a long-term threat to the integrity of this vital zone, necessitating a sophisticated and comprehensive approach. The coastline of Kalutara, Sri Lanka, has experienced increased vulnerability to erosion, attributed to a complex interplay of environmental changes stemming from both natural processes and human activities, notably climate change. This study is primarily focused on the geotechnical characterization of coastal erosion in Kalutara coastline, a location of significant economic and environmental value located in Sri Lanka's southwest coast, by emphasizing the erosion process and vulnerability assessment, considering the geotechnical aspects of erosion processes affecting the beachside and also by specifying the certain factors that related to the coastal region such as wave dynamics, sediment transport, and coastline changes. Additionally, the study will explore the identification and evaluation of mitigation and adaptation strategies along the coastline, coupled with the analysis of climate changes and future trends of the erosion of the coastline.

Index Terms: Coastal Erosion, Geotechnical Characterization, Google Earth Images, Kalutara Coastline

1 INTRODUCTION

Sri Lanka possesses a diverse and vibrant coastline zone that runs along the Indian Ocean for nearly 1,700 kilometers. This stretch of coastline is not only geographically noteworthy but also economically and biologically important to the island nation[1]. In Sri Lanka, the coastal region has become essential to sustaining people's livelihoods and serving as a base for social and economic activities. However, despite their significance, these coastal are notably susceptible to the adverse impacts of coastal erosion. The most severe effects of climate change are anticipated to be experienced in Sri Lanka's densely populated and highly productive coastline region.

In various regions of Sri Lanka's coastal zones, coastal erosion has emerged as a significant environmental concern that is driven by both natural and human actions. This phenomenon is significantly impacted by natural factors such as sea level rise, sediment transport, wave dynamics, and shoreline changes. The vulnerability to coastal erosion is simultaneously caused by human activities, including high population density, urbanization, and intense tourism along Sri Lanka's southwest and southern coastal districts[2].

The Southwestern Monsoon exerts a significant influence on the Kalutara coastline, contributing to coastal erosion dynamics in this region. The coastline is subjected to increased wave action and rainfall during the monsoon season, which is characterized by prevailing winds from the southwest. These climatic conditions can contribute to increased erosion, with wave-driven processes eroding coastal sediments and impacting coastline stability. Strong winds, elevated wave energy, and increased precipitation can all result in sediment removal from the coastline and transport along the coast. Furthermore, the Southwestern Monsoon may contribute to variations in sea level and storm surges, causing the Kalutara coastline's susceptible to erosion[3]. Coastal erosion in Kalutara Beachside has an unbreakable link to geotechnical

variables that determine the coastal landscape's stability and resilience. Soil composition, sediment transport, subsurface condition, shear strength and stability, wind-induced factors, and climate change will all have an impact on coastal erosion[4]. The key factors such as sea level rise, changing storm patterns, increased intensity of extreme weather events, altered precipitation patterns, loss of coastal vegetation is also contributing to the coastal erosion in Sri Lanka.

2 EROSION PROCESS AND VULNERABILITY ASSESSMENT

Coastal erosion is a natural process of transportation or removal of sediment and any material at the shoreline. Coastal erosion occurs due to wave action, geological factors, sea-level rise, and human activities in that area. Coastal erosion can be analyzed according to coastline changes, soil composition, sediment transport data, etc.

2.1 Wave Dynamics

There are two monsoon conditions affecting Sri Lanka. They are the southwest monsoon from May to September and the southeast monsoon from December to February[3]. The waves in the Indian Ocean can grow strong in the monsoons, expanding the amount of wave power that affects the shoreline. Kalutara receives heavy rainfall during the Southwest Monsoon. Along Sri Lanka's south to northwest shores, the southwest monsoon generates high-energy sharp waves. During the southwest monsoon, the high-energy waves reduce beach width and flatten the intertidal zone of the coast face. As Kalutara is a low-laying coastal zone it has soft sediment deposition which is more erodible with the wave action. from the two ways of sediment transport which are long-shore and cross-shore, in Kalutara can be mainly observed long-shore sediment transport [5].

These monsoons affect the ocean's current circulation and tidal waves. Southwest monsoon mainly affects the west and .south coastal area and in that duration wave condition of the west coastal zone is higher than the wave condition of the east coastal zone in the northeast monsoon. High tides leads to more significant erosion. [2] Other than that, long-term causes of coastal erosion in Kalutara and other parts of the world include global sea level rise. Erosion may be made worse by increased coastal flooding brought on by rising sea levels. Human activities also engage with the process of coastal erosion. The most affected human activity in the Kalutara coastal zone is cutting off the sand bar in Calido beach to increase the width of the river mouth as a solution for heavy flood situations in 2017. And buildings along the shore, such as hotels and resorts, can obstruct the movement of natural sediment and worsen erosion. Deforestation and inappropriate land use in river catchments can worsen sedimentation at river mouths, which can impact coastal erosion [6]. Anyhow, like in many other coastal regions, coastal erosion is a dynamic and continuing process in Kalutara. It is crucial to enlist specialists in geology, oceanography, climate science, and social development to undertake a thorough risk assessment and design efficient solutions for managing coastal erosion in Kalutara, Sri Lanka.

2.2 Sediment Transport

The Southwest Monsoon has a considerable influence on sediment movement along the coastline in Sri Lanka, notably along the southern coastline, contributing to coastal erosion. The prevailing winds during the Southwest Monsoon season are from the southwest, resulting in significant wave action and greater rainfall. The southwest winds generate powerful waves which impact the coastline, contributing to coastal erosion. Furthermore, increasing rainfall during the monsoon increases runoff, transporting sediments from inland areas to the coast. The combined effect of wave action and sediment-laden runoff causes sand and soil displacement along the southern coastline.

Understanding and preventing coastal erosion in this region requires an understanding of the particular dynamics of sediment transport controlled by the Southwest Monsoon. It emphasizes the significance of geotechnical studies and erosion management measures tailored to climatic circumstances in contributing to Sri Lanka's sustainable coastal development[7].

2.3 Soil Composition

The geological composition of the coastal soil significantly impacts its erodibility. Sandy soils, prevalent in coastal areas, are more susceptible to erosion compared to cohesive soils. Understanding the specific soil types and their geotechnical properties is crucial for assessing erosion vulnerability. Coastal locations frequently have a variety of geological features, such as sedimentary formations formed by weathering and sedimentation processes. Fine-grained sediments, such as silts and clays, are more erodible, especially

when exposed to wave action and storm surges. Furthermore, the mineralogical composition, organic content, and presence of cementation all contribute to coastal soil stability or vulnerability. Understanding these geological elements is critical for establishing successful solutions for managing coastal erosion and increasing resilience to environmental change.[8]

Bog and half-bog soil, low humic gley soil, alluvial soil found in basins and back swamps, and regosols are the main soil types in the Kalutara coastline. Sand regosols characterize the coastal sand belt. The fine-grained surface sand has a median size range of 0.6 to 0.7 mm and is well-sorted. Geologically, there are two types of regosols: first one, the sandy regosols found in coastal dunes and elevated beaches, and medium-textured regosols found on freshly formed erosion products such as slope colluvium[9]. Despite the fact that they are typically dry, sandy regosols may have a variable water table at medium or shallow depths. The degree of weathering of the sand influences the differentiation of these regosols. Young beach and dune regosols are yellowish in color and include a significant amount of weatherable minerals. Others are mostly quartz sand, which can be bleached and colorless or have red to yellow colors due to a thin ferruginous layer around individual grains, similar to latosol regosols[2].

The Kalu River (Kalu Ganga) is the main sediment source in the Kalutara coastal zone. It carries a significant amount of sediment from its catchment areas. Wave energy has a substantial impact on sediment movement. The Southwest Monsoon helps in the erosion of the Kalutara coastal zone and transports sediment along the coastal zone. sediment deposits along the coastal zone. The pattern of sediment deposition changes according to the monsoons. In the southwest monsoon, which occurs from May to September, sediment transports to the south, and at the same time, the other side faces erosion. In the northeast monsoon, which occurs from December to February, the transport of sediment may be reversed.

While low tides and softer currents may facilitate sediment deposition, high tides and powerful currents may cause erosion. The sediment transport of Kaluganga may contribute to the shoreline changes. Kalutara coast faces hide tides during the southwest monsoon, and with that erosion increase, shoreline comes inland. As opposed to this, during the northeast monsoon, deposition increases, and shoreline moves towards the sea. A significant shoreline change can be seen in Calido Beach, Kalutara, after 2017[5]. It occurs due to the removal of sand bar. Calido Beach is the most eroded area in that zone. Earlier, there was not that kind of significant shoreline change. When comparing Calido Beach in 2017, 2018, and 2019, not only erosion but also a few new depositions can be seen (figure 01). It is due to the sediment supply from the flow of the river increases when the river flow is increased[5]

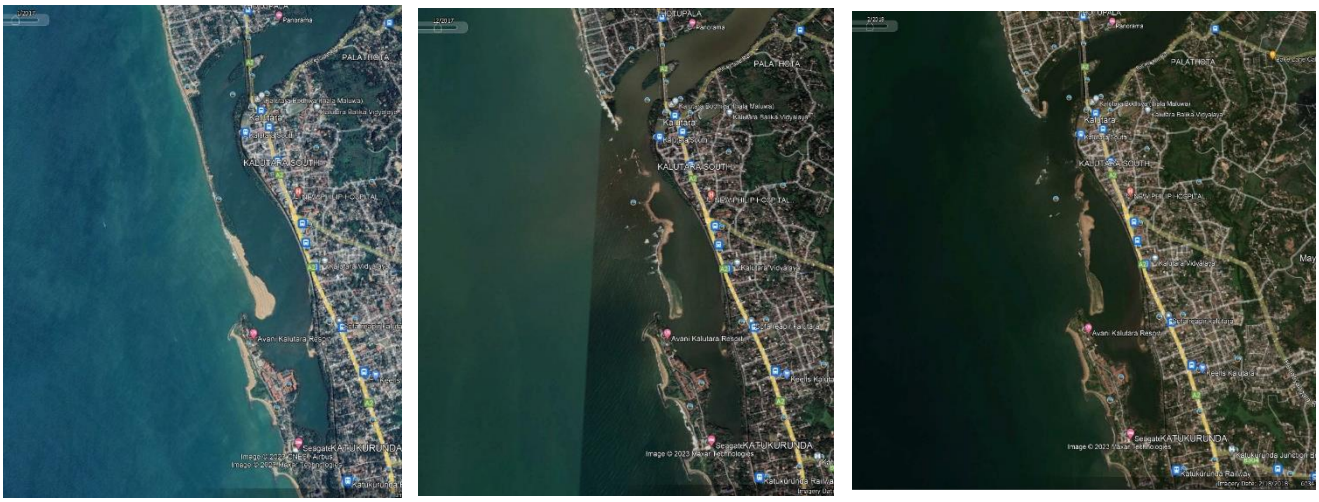

Figure 01: Calido Beach in 2017-, 2018-, and 2019-years which shows a deposition along the coastline.

Another vulnerable situation about water quality occurred in the lagoon area of Calido. That was due to garbage being released into that lagoon area (figure 02). As a result, there is a lack of clean water in this area. The water is cleaned here before flowing into the sea before the sand bar is removed. The after-effect is therefore greater than the before-effect[6]. periodic tracking of the movement of sediment, coastal erosion, and accretion is necessary for choices to be made for the betterment of the coastal area.

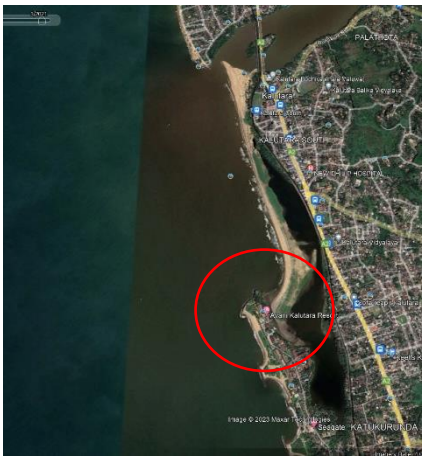

Figure 02: Lagoon area of Calido

3 Mitigation and Adaptation Strategies

Controlling coastal erosion will need a combination of mitigation techniques and adaptive measures. There are hard and soft mitigation methods such as seawalls, bulkheads, revetment, groins and etc. Normally soft options like sand bypassing, sand fencing, are not that cost effective. With the advancement of technology things like green belts, sand filled polyene bags, concreate reef balls, and artificial coral reef started to be used. Low-cost coastal protective structures are now being used in Sri Lanka.

The government has primarily employed hard coastal protection techniques (revetments, groins, offshore breakwaters, gabion walls, coves, and immediate rock beddings), which allow the shore to behave naturally without the use of any constructive protection measures (designated as a restricted area), as well as soft coastal protection techniques (beach nourishment and dune construction). The government has primarily employed hard coastal protection techniques (revetments, groins, offshore breakwaters, gabion walls, coves, and immediate rock beddings), which allow the shore to behave naturally without the use of any constructive protection measures (designated as a restricted area), as well as soft coastal protection techniques (beach nourishment and dune construction). With the assistance of nongovernmental organizations, Sri Lanka's Department of Coast Conservation and Coastal Resource Management constructed coastal protective structures. These buildings serve as a temporary fix for costal irritation. This is not a sustainable solution because the structures tend to move the erosion along the coastal zone due to the effect of longshore sediment transport. Mostly used structures are breakwater, revetments, groins, and coves. A revetment is a construction or barrier placed along the banks of rivers, coasts, or other bodies of water to stop erosion or guard against flooding. It is often formed of rocks, concrete, or other materials. The purpose of revetments is to reduce the erosive impact of flowing water on the soil or structures behind them by absorbing and deflecting the energy of the water. They are essential for protecting riverbanks and coastal areas[10].

4 Climate Change Impacts and Future Trends

During the southwest monsoon, which occurs from May to September, and during convectional-cyclonic-depression events, this southwest coastline experiences the highest levels of precipitation. The southwest monsoon is characterized by prevailing winds from the southwest, bringing moist air over the land, leading to increased rainfall. Convectional-cyclonic-depression events further enhance precipitation, contributing to the overall climatic dynamics of the southwest coastline. This pattern underscores the importance of understanding seasonal variations in weather phenomena for effective climate and environmental management in the region[9].

Climate change is having a significant impact on the Kalutara coastline in Sri Lanka, needing a full geotechnical characterization to identify and manage emergent concerns. Change of sea levels pose a severe danger to coastal soil stability which causes the erosion. Changes in precipitation patterns contribute to soil saturation, influencing coastal terrain erodibility. The region is also vulnerable to increased

frequency and severity of extreme weather events, which amplifies the dynamic pressures acting on the coastline.

Geotechnical characterization, which includes sedimentary structure, mineral composition, and organic content, is critical for understanding the evolving nature of Kalutara's coastal soil. Grain deposition proved the West Coast's significantly high energy deposition environment. As a result, the impact of southwest monsoon currents on landform changes in Sri Lanka is more prominent. Furthermore, these statistical factors indicated that the west coast of Sri Lanka is more vulnerable to coastal erosion than the east coast, which includes the Kalutara coastline. The geological features of the coastal landscape, such as dunes and estuaries, may change, affecting overall geomorphology[8].

8 CONCLUSION

This review emphasizes the critical importance of geotechnical characterization in addressing and analyzing coastal erosion along Kalutara coastline Sri Lanka. The dynamic interaction of geological factors, such as soil composition, sediment transport, subsurface condition, shear strength, and stability, contributes to coastal erosion. Rising sea levels, changing precipitation patterns, and extreme weather events, all exacerbated by climate change, pose significant risks to coastal soil stability. The geotechnical investigations have explained the specific geological composition of the Kalutara coastal soil, which includes bog and half-bog soil, low humic gley soil, and regosols. This deep understanding emphasizes the need for specialized geotechnical solutions to solve the distinct problems given by the region's different soil types. Because these soil types are susceptible to varying degrees of erosion and weathering, a nuanced and site-specific approach is required in the creation of successful coastal protection and sustainable land use policies.

The study of Erosion Processes and Vulnerability Assessment has revealed how the coastline has eroded in Kalutara as a result of the southwest monsoon season and convectional-cyclonic-depression events. Geotechnical studies have revealed variable soil and grain composition, including bog and half-bog soil, low humic gley soil, and regosols. This comprehensive understanding emphasizes the need for specific solutions to reduce the erosion process posed by these various kind of soil types.

The section on Mitigation and Adaptation Strategies emphasizes the significance of taking proactive actions to safeguard the Kalutara coastline. Tailoring strategies to the specific geological conditions is imperative, ranging from nature-based solutions to innovative engineering approaches. The focus on sustainable coastal resilience emerges as an essential component.

Examining the Impacts of Climate Change and Future Trends sheds light on the interrelated concerns of coastal erosion and climate change. Rising sea levels, changing precipitation patterns, and extreme weather events are all contributing to coastal erosion in Kalutara. Geotechnical studies play an important role in identifying and forecasting these impacts, laying the groundwork for effective adaptation methods.

This literature evaluation will serve as a foundation for future research as navigate the dynamics of Kalutara's coastal erosion. The integration of global and local perspectives on geotechnical characterization advances the understanding of the issues faced by coastal erosion in Kalutara Beachside. Moving forward, it is critical to incorporate these findings into sustainable coastal development plans that combine environmental conservation with the region's socioeconomic demands.

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