J. Res. Technol. Eng. 6 (1), 2025, 30-40

Journal Of Research Technology & Engineering
www.jrte.org

Assessing the Morphological Dynamics and Coastal Processes of the Kalu Ganga Estuary at Calido Beach, Kalutara, Sri Lanka: Implications for Sustainable Estuarine Management

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Received:22 Sep 2024; Revised:25 Nov 2024; Accepted: 03 Jan 2025; Available online: 20 Jan 2025

Abstract: The Kalu Ganga estuary at Calido beach, Kalutara, Sri Lanka, has experienced significant morphological changes due to both natural processes and human activities. High population density, urban development, and thriving economic activities, particularly tourism, have contributed to its vulnerability. Analysis of changes from 2016 to 2024, using Google Earth imagery and published studies, highlights the influence of seasonal monsoons, sediment transport, tidal flows, river management, and urbanization. Notably, the estuary mouth expanded after the 2017 floods but subsequently narrowed over the years, reflecting the dynamic interplay between natural and anthropogenic factors. To mitigate further changes and promote stability, integrated coastal management strategies are crucial. Sustainable solutions include beach nourishment to counter erosion, mangrove restoration to enhance shoreline stability and biodiversity, and controlled dredging to manage sediment transport. These measures, combined with adaptive management practices, can help balance ecological preservation with the socio-economic benefits of the estuary, addressing the challenges posed by environmental stressors and human interventions.

Index Terms: Calido Beach, Coastal Erosion, Google Earth Images, Morphological Changes

1 INTRODUCTION

Coastal regions are increasingly impacted by both regional and global environmental changes, placing major strain on shorelines, which serve as the transitional border between land and marine ecosystems. Due to both natural and man-made factors, this dynamic habitat is extremely vulnerable to changes in shape and position. These regions are under more stress due to intensifying coastal development, which has led to serious risks like coral bleaching, coastal erosion, and saltwater intrusion. One of these, coastal erosion, is a major worldwide issue that jeopardizes the stability of coasts everywhere. To prevent additional deterioration of coastal ecosystems, infrastructure, and populations, effective management and mitigation measures are desperately needed [1].

Coastal erosion, which is caused by both natural and human activity, has become a major environmental concern in many parts of Sri Lanka's coastal zones. Natural elements like coastline alterations, wave

dynamics, sediment transport, and sea level rise have a big influence on this occurrence. Human activities such as urbanization, high population density, and heavy tourism along Sri Lanka's southern and southwest coastline regions all contribute to the vulnerability of these areas to coastal erosion [2].

The southwest monsoon significantly affects the patterns of coastal erosion in Kalutara district. During this season, the prevailing southwest winds force wave energy directly into the coast, resulting in enhanced wave activity and heavy rains. The shoreline's stability is weakened by this seasonal climatic pattern, which speeds up erosion by moving and mobilizing coastal sediments. Increased precipitation, higher wave energy, and faster wind all contribute to the removal of silt from the shore, which is then redistributed along the coast and makes certain coastal regions more vulnerable. Furthermore, the Kalutara coast is more vulnerable to erosion due to storm surges during the monsoon season and temporary changes in sea level [3].

The stability and resilience of the Kalutara coastline are closely linked to a number of geotechnical factors that affect its physical and structural integrity. Soil composition, sediment transport dynamics, and subsurface conditions play a critical role in determining the shoreline stability. Factors such as soil shear strength, sediment cohesion, and the overall stability of the underlying layers contribute to coastal erosion susceptibility. Climate change exacerbating these challenges by altering storm patterns, increasing the frequency of extreme weather events, and altering precipitation trends, all of which increase the intensity of coastal erosion events. Additionally, loss of coastal vegetation reduces the natural barriers that protect the coast from wave and sediment displacement, further reducing the resilience of these landscapes [2].

Coastal erosion in Kalutara and other areas of Sri Lanka highlights the urgent need for integrated management that takes into accounts both natural and anthropogenic causes. This dual approach is critical to strengthen coastal resilience, protect ecosystems and safeguard the communities and infrastructure that depend on these vulnerable areas. The interplay of monsoonal influences, geotechnical conditions and human development highlights the complexity of coastal erosion processes and the urgent need for sustainable interventions to mitigate current and future risks [2].

Fig. 1. Kalu ganga river basin

2. METHODOLOGY

2.1 Study Area

The study area is located around the river mouth and estuary area of Kalu Ganga in Kalutara district in the southwestern coastal belt of Sri Lanka. The landscape of the study area is influenced by both fluvial, synthetic and marine forces, with significant seasonal variations due to the southwest monsoon (May to September) and the northeast monsoon (December to February). The study area is located at north latitude 6˚ 35” and east longitude 79˚ 57”. The total length of the study area is approximately 3.15km.

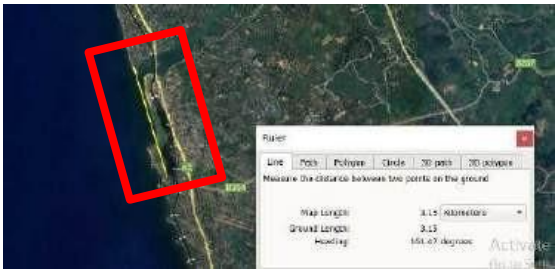

Fig. 2. Study Area (Calodo beach – Kalutara)

2.2 Data Collection

Both primary and secondary data were collected for this study. As primary data, Google Earth Images data was collected for the comparison. Previously published articles and other published sources were considered as the secondary data for this study.

2.3 Expansion of the Kalu Ganga Estuary

The historical analysis from Google Earth Pro imagery (7.3.6.9796 (64-bit)) shows significant variations in the width of the Kalu Ganga river mouth. During the monsoon seasons, the river mouth often expands due to increased runoff, while contraction is observed in drier months. Human activities such as dredging may also contribute to periodic expansions.

2.4 Loss the Sand layer

The analysis shows a gradual reduction in the sand layer along Calido Beach, particularly near the mouth of the estuary. This loss is more pronounced after heavy rainfall or storm events, suggesting that hydrodynamic forces play a role in sand displacement. Seasonal trends indicate that sand accumulation occurs after the monsoon, but is often temporary.

2.5 Coastal Erosion

Coastal erosion along Calido Beach has been significant, with recessions of up to several meters per year occurring in some areas. This erosion correlates with natural hydrodynamics and human interventions such as estuarine management and land reclamation.

2.6 Land Use and Land Cover (LULC)

Changes in land use and land cover (LULC) can increase or decrease an area's vulnerability, which can be assessed using LULC maps. Changes in agricultural, residential, abandoned and aquaculture lands have affected the Coastline, moving it inland [2]. To examine these changes, LULC maps were developed using Google Images from 2016 and 2024. The visual interpretation method was used to classify different LULC types in the study area.

3. RESULTS

3.1 Kalu Ganga River Mouth Expansion

According to the table 01, the data reveals significant fluctuations in the width of the Kalu Ganga river mouth over recent years, with the narrowest measurement recorded at 72.83 m in 2017 and the widest at 317.79 m in 2019. These variations reflect a highly dynamic estuarine system in which periods of expansion and contraction alternate at the river mouth. Significant expansions were noted in 2018, 2019, and 2023, with thickness increasing significantly, likely due to increased flow velocities or sediment removal processes, either naturally or through anthropogenic activities. In contrast, contractions occurred in 2017, 2020, and 2021, potentially due to increased sediment deposition or reduced river flow (Fig. 03).

Table 1. Kalu Ganga river mouth expansion in 2016 - 2024

Year	River mouth open (m)	Observation
2016	183.51	Stable width
2017	72.83	Significant contraction
2018	221.71	Expansion
2019	317.79	Peak width, likely high flow
2020	133.29	Narrowed, sediment accumulation
2021	97.90	Continued narrowing
2022	189.66	Moderate expansion
2023	233.01	Expanded width
2024	213.74	Slight reduction

Fig. 3. Calido Beach in 2016 – 2024 Years Which Shows a Changes of Kalu River Mouth

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In 2017, severe flooding affected over 10,000 people in Kalutara and Ratnapura districts, particularly

Ratnapura which is about 100 km from the coast, and Kalutara, about 40 km away. This flooding event led to widespread landslides triggered by heavy monsoon rain [12]. During this period, the width of the river mouth decreased to 72.83 m, contributing to reduced water discharge velocity, which in turn may have exacerbated the effects of flooding by hindering efficient drainage.

In 2021, a severe storm, Cyclone Tauktae, brought heavy rainfall of up to 250 mm in 24 hours, with a peak of 336 mm recorded in Agalawatta in Kalutara District [13]. After this event, the mouth of the Kalu Ganga showed a widening to 97.90 m, which was probably due to the increased water discharge from the river during the storm event, which temporarily widened the mouth.

3.2 Loss the Sand layer

The Kalu River (Kalu Ganga) serves as the primary source of sediment for the Kalutara coastal zone, carrying substantial sediment loads from its catchment areas. Wave energy significantly influences sediment movement along this coastline, with the southwest monsoon intensifying coastal erosion in the Kalutara region and transporting sediment along the shore. Sediment deposition patterns change with the seasonal monsoons, during the southwest monsoon (May to September), sediment generally moves southward, while erosion occurs on the opposite side. In the Northeast Monsoon (December to February), sediment transport may reverse, allowing deposition on previously eroded areas.

Low tides and gentler currents facilitate sediment accumulation, while high tides and strong currents contribute to erosion. The sediment carried by the Kalu River plays a key role in shaping the shoreline of the Kalutara coast. During the Southwest Monsoon, high tides and increased erosion drive the shoreline inland, whereas in the northeast monsoon, enhanced sediment deposition pushes the shoreline seaward [5].

Since 2017, significant shoreline changes have been observed at Calido Beach in Kalutara, largely due to the removal of a sandbar. This area, the most eroded section of the Kalutara coast, previously showed minimal shoreline variation. However, comparisons of Calido Beach in 2017, 2018, and 2019 reveal not only ongoing erosion but also areas of new sediment deposition. This deposition is linked to increased sediment supply from the river as its flow intensifies. Deposited linked, in 2020 to 2024 time period settle around the Calido beach and Estuary area (Fig. 4).

Fig. 4. Sand Layer Losses and Changes at Calido Beach

3.3 Land use and land cover (LULC)

Comparing the Kalu Ganga river basin, Calido Beach, and Kalu Ganga Estuary between 2016 and 2024 shows a significant increase in synthetic environments developed with human infrastructure or altered landscapes, such as urban expansion, tourism hotels, road networks, and industrial sites (Fig 05). This intensification of synthetic environments has introduced significant ecological and geomorphological consequences. The increase in built-up areas around the Kalu Ganga basin has reduced the natural vegetation cover, leading to an increase in surface runoff and the erosion of riverbanks and coastal zones. The lack of natural vegetation and the corresponding loss of root systems along the river and coast have destabilized the soils and made the region more vulnerable to erosion from both river currents and wave action.

Fig. 5. Land Use and Land Cover Changes in 2016 and 2024 Years

This expansion of synthetic environments has also accelerated sedimentation processes in the Kalu Ganga and estuary. The eroded sediments are carried downstream, where they accumulate in the river mouth and estuarine areas, altering natural flow dynamics and sediment deposition patterns. This sediment accumulation can partially block water outflow and cause the river mouth to narrow especially during dry seasons when river flow is low. Reduced flow capacity in the estuary due to sediment deposition can also exacerbate flooding during periods of high rainfall, as excess water is less easily discharged to the sea.

Additionally, the increase in synthetic environments has contributed to coastal erosion along Calido beach and surrounding areas. Urban infrastructure disrupts the natural transport of sediment along the coast, while hard surfaces reduce the infiltration of rainwater into the soil, increasing the speed and volume of runoff that reaches the coast. During the monsoons, this increased runoff combined with wave energy results in faster erosion of coastal sediments. The sediment removed from these coastal areas can in turn be deposited unevenly, causing shoreline irregularities and instability in beach profiles.

Environmental sustainability in the Kalu Ganga Estuary and Calido Beach region has subsequently

declined. Increasing rates of sedimentation and erosion have disrupted local ecosystems and impacted flora and fauna that rely on stable shorelines and sediment distributions. For example, estuarine vegetation, which is crucial for buffering wave action and providing habitat is becoming increasingly degraded, further weakening natural defenses against erosion. In addition, changes in sediment deposition impact aquatic habitat in the estuary, affecting fish spawning grounds and other sediment that support biodiversity.

The cumulative effects of synthetic environmental expansion increased erosion, sedimentation imbalance, and reduced environmental resilience underscore the urgent need for integrated coastal and riverine management strategies. These should focus on mitigating erosion, restoring natural vegetation buffers, and managing sediment flows to ensure long-term ecological and geomorphological stability.

4. DISCUSSION

The Kalu Ganga River Estuary and the surrounding Kalutara coastal system have undergone significant changes between 2016 to 2024 due to a combination of natural hydrological events, monsoon influences, and human activities (construction activities and urbanization). Notable expansions of the river mouth in 2018, 2019, and 2023 are accompanied by high river discharge, possibly from monsoon rains and storm surges, which can widen the mouth by increasing water flow and flushing out sediments. In contrast, years such as 2017 and 2021 experienced contractions due to sediment deposition, revealing that estuaries are sensitive to climate and flow fluctuations.

Following the removal of a natural sandbar in December 2017, Calido Beach experienced increased erosion, destabilized the shoreline. The monsoon system drives this erosion, particularly during the southwest monsoon, where sediment transport heads southward, causing inland movement of the shoreline. During the northeast monsoon, sediment transport may reverse and restore some eroded areas. However, the absence of the sandbar makes the beach more vulnerable to erosion.

Human activities around the Kalu Ganga basin, such as urbanization, tourism and industrial expansion, have exacerbated these issues. The growth of synthetic environments has led to a reduction in vegetation cover, which naturally stabilizes soils and minimizes erosion. Loss of vegetation increases susceptibility to erosion from river currents and wave action, and sediment buildup at the river mouth decreases drainage, raising flood risks during heavy rain. Urban infrastructure also disrupts the natural flow of sediment along the coast, increasing coastal erosion and destabilizing shorelines.

Ecologically, these changes have significant impacts on estuarine and coastal habitats, as reduced vegetation lowers natural wave barriers and leaves shorelines unprotected. In addition, shifts in sediment deposition threaten aquatic habitats in the estuary and affect fish spawning and biodiversity. Combined, these human and natural factors have accelerated erosion, sediment imbalance, and habitat degradation,

highlighting the need for sustainable management strategies. Measures to control urban expansion, restore vegetation, and manage sediment flows could help stabilize the region, preserve biodiversity and increase the resilience of the Kalutara coastal zone.

For effective and long-lasting protection against seasonal coastal erosion, an integrated strategy combining hard engineering, soft engineering, and sustainable behaviors is needed. By controlling sediment flow and stabilizing the coastline, hard engineering solutions offer instant relief. While offshore breakwaters disperse wave energy before it reaches the beach, groins and other structures can retain sand and lessen damage brought on by longshore drift. During periods of high energy, seawalls and revetments serve as strong barriers to protect the shore. Dredging can also be used to disperse sediment, reducing erosion hotspots and guaranteeing balanced deposition.

For efforts to preserve and restore the coastal environment, sustainable solutions and soft engineering work in combination with natural processes. Beach nourishment replaces degraded shorelines, providing a buffer against waves, whereas coastal restoration, which includes planting flora and building sand barriers, stabilizes the coast and improves natural resilience. Mangrove restoration and the planting of salt-tolerant plants are examples of nature-based solutions that help bind soil and disperse wave energy, so decreasing erosion and increasing biodiversity. Living shorelines provide long-term protection while maintaining biological balance by integrating features like salt marshes and oyster reefs. By moving infrastructure away from susceptible places, managed retreat reduces the likelihood of future erosion and allows the shoreline to develop naturally.

Seasonal differences in coastal erosion must be addressed by monitoring and adaptive management. Regular assessments of shoreline alterations give insights into the efficacy of adopted solutions, allowing for revisions depending on changing conditions. The long-term viability of these measures is ensured by including local populations in conservation initiatives and limiting destructive activities like sand mining. Coastal preservation measures can strike a balance between protecting infrastructure and maintaining natural ecosystems by integrating ecological and community-driven methods with hard engineering.

5 CONCLUSIONS

This study explores how natural forces and human activities combine to shape the Kalu Ganga estuary and the Kalutara coastal zone. Seasonal monsoon cycles play an important role in shifting sediment transport, with the southwest monsoon increasing erosion and the northeast monsoon favoring deposition. The growth of synthetic environments around the Kalu Ganga basin has increased erosion and sediment deposition as reduced vegetation cover does not effectively stabilize riverbanks and coastal zones. This sediment accumulation in the estuary reduces drainage efficiency and increases flood risk, while coastal infrastructure disrupts sediment dynamics, worsens shoreline erosion and impacts coastal ecosystems. The study highlights the need for sustainable management strategies that mitigate erosion, restore

vegetation and regulate development. By considering both human and natural influences, these strategies can improve ecological resilience, support biodiversity and ensure environmental sustainability in the Kalu Ganga Estuary and Kalutara Coastal Area amid ongoing environmental change.

6 REFERENCES

[1] Cooper, J.A.G, & McKenna, J. (2008). Social justice in coastal erosion management: The temporal and spatial dimension. *Geoforum*, 39, 294-306.

[2] Kirishanthan, P. (2022). Physical and social vulnerability to coastal erosion: An assessment of Kalutara Coastal Belt, Sri Lanka. *IOP Conference Series: Earth Environmental Science*, 1109(1), https://doi.org/10.1088/1755-1315/1109/1/012077.

[3] Gunasinghe, G.P., Ratnayake, N.P., Ratnayake, A. S., Samaradivakara, G. V. I., Dushyantha, N.P., Jayaratne, R., Dinusha, K.A., & Silva, A. (2022). Monsoon-Driven Geomorphological Change Along the West Coast of Sri Lanka: A Combined Approach Utilizing 'CoastSat' and Google Earth Engine. *Ocean Science Journal, 57(3), 475-492, https://doi.org/*10.1007/s12601-022-00081-z.

[4] Rekha Nianthi, K.W.G. (2003). Recent trends of climate change in Sri Lanka. *Journal of Geo- Environment, Rajshahi University, Bangladesh*, (3), 37-4.

[5] Rupasinghe, S.M., Hewaarachchi, H.L.A., Nimnajith, W.G.D.D., & Peiris, K.H.C.K., (2023). Geotechnical Characterization of Coastal Erosion in Kalutara Coastline, Sri Lanka. *Journal of Research Technology & Engineering*, 4(4), 272-277.

[6] Samarasinghea, S.M.J.S., Nandalalb, H.K., Weliwitiyac, D.P., Fowzed, J.S.M., Hazarikad, M.K., & Samarakoon, L. (2010). APPLICATION OF REMOTE SENSING AND GIS FOR FLOOD RISK ANALYSIS: A CASE STUDY AT KALU- GANGA RIVER, SRI LANKA. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Kyoto Japan*, 38(8), 110-115.

[7] Samarasekara, R.S.M., Sasaki. J., Jayaratne, R., Suzuki, T., Ranawaka, R.A.S., & Pathmasiri, S.D. (2018) Historical changes in the shoreline and management of Marawila Beach, Sri Lanka, from 1980 to 2017. *Ocean Coast Management,* 165, 370–384. https://doi.org/10. 1016/j.ocecoaman.2018.09.012.

[8] Perera, K. R. L., & Ranasinghe, D. P. L. (2021). An Analysis of Causes of Coastal Erosion in Calido Beach, Kalutara, West Coast of Sri Lanka. *KDU Journal of Multidisciplinary Studies*, 3(1), 69–79.

[9] Gunasinghe, G. P., Dinusha, K. A., Ratnayake, N. P., Samaradivakara, G. V. I., & Ratnayake, A. S. (2019). Review of Impacts on Coastal Zone Due to Poor Riverine Flood Controlling Mechanism: A Case Study in Kalutara Coastal Zone, Sri Lanka. *Built Environmental Spatial Science*, 78.

[10] Jayathillake, D. (2020). Mount Lavinia beach nourishment project successful—DG Coastal Conservation Department. http://www.defence.lk/Article/view.article/1679. Accessed 07 May 2021.

[11] Batugedara, B.D.I.M., & Senanayake, S.A.M.A.I.K. (2022). PLANKTON DIVERSITY IN COASTAL WATERS NEAR KALU GANGA RIVER MOUTH; SRI LANKA. KDU Journal of Multidisciplinary Studies (KJMS), 4 (2), 7-20. http://doi.org/10.4038/kjms.v4i2.47.

[12] CNN. (2017). HEAVY RAIN AND FLOODS IN SRI LANKA LEAVE 91 DEAD. CNN. SRI LANKA FLOODS: 91 DEAD, MORE THAN 100 MISSING, GOVERNMENT SAYS | CNN

[13] Disaster Management Center. (2021). *Sri Lanka situation report*. Disaster Management Center.