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Breached sandbar and changing coastal systems: interpreted and perceived impacts of flood-control interventions at Calido Beach, Sri Lanka

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ABSTRACT

Calido Beach, located on the southwestern coast of Sri Lanka, has experienced substantial environmental and socio-economic change in recent years. These changes have coincided with flood-control interventions implemented in 2017, including partial removal of a sand spit barrier and widening of the Kalu River mouth. However, the extent to which observed changes can be attributed to these interventions remains uncertain due to the inherently dynamic nature of coastal systems.

This study integrates qualitative interpretations and comparisons of satellite imagery with community-based survey data to examine environmental transformations and associated livelihood impacts. Google Earth imagery from 2010 to 2024 was analysed to identify broad changes in shoreline configuration, sandbar morphology, and adjacent landforms. In parallel, structured face-to-face surveys were conducted with 70 individuals engaged in fisheries, tourism, small businesses, and sand mining activities to assess perceptions of environmental and socio-economic change.

Satellite imagery interpretation indicates substantial modification of the sandbar and associated mangrove cover. Changes include erosion, landward migration, and transformation into lagoonal and vegetated features.

Survey results show that 73% of respondents expressed dissatisfaction with flood-control measures, while 40% attributed observed erosion to a combination of natural processes and human interventions. Fisher Exact Tests identified significant associations between perceptions of environmental change and duration of residence, as well as between satisfaction with interventions and income source ($p < .001$). These relationships should be interpreted cautiously given the small sample size and uneven subgroup distribution.

Overall, the findings highlight the importance of integrating community perceptions with scientifically robust coastal analysis. The results support the need for participatory and evidence-based approaches to coastal management, while underscoring the limitations of qualitative geomorphological assessment for establishing causal relationships.

1. Introduction

1.1. Coastal processes and human intervention

Coastal systems are dynamic environments shaped by interactions among waves, currents, sediment transport, and human activities. These systems provide critical ecological, economic, and social services, supporting biodiversity, coastal protection, and livelihoods (Neumann et al., 2017; Temmerman et al., 2013). However, coastal zones are increasingly under pressure from both climatic and anthropogenic drivers.

In addition to sea-level rise and climate-related extreme events (Nicholls and Cazenave, 2010), fluvial sediment supply and river dynamics play a key role in shaping shoreline morphology. It is estimated that between 80% and 95% of beach sediment originates from fluvial sources (Boye et al., 2019; Deng et al., 2017). Consequently, human interventions such as river damming, channel modification, and flood-control measures can disrupt sediment transport pathways and affect coastal equilibrium.

A growing body of research demonstrates that poorly designed or implemented coastal and river engineering interventions can result in unintended geomorphological changes, including accelerated erosion

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and altered shoreline configurations (Angnuureng et al., 2025; Warrick et al., 2023). These effects highlight the complexity of coupled river-coast systems and the need for integrated approaches to coastal management.

1.2. Coastal dynamics in Sri Lanka

Sri Lanka's coastline extends over approximately 1700 km and includes a range of geomorphological features such as beaches, dunes, estuaries, and lagoon systems (Lakmali et al., 2017). The coastal ecosystem is rich in biodiversity and hosts a wide array of natural resources (Balasuriya, 2018; Gunatilleke et al., 2008). As an island nation, surrounded by coast, Sri Lanka heavily relies on its coastal zones for key economic activities such as fisheries, tourism, and transportation. These sectors collectively contribute approximately 40% of the country's Gross Domestic Product (GDP), underscoring the immense value of coastal resources (World Bank, 2017).

At the same time, Sri Lanka is subject to frequent flooding events associated with monsoon systems, particularly in river basins such as the Kalu River (Wickramasooriya and Walpita, 2021). These hazards have led to the implementation of flood-control measures, which may interact with coastal processes in complex and sometimes unintended ways. The southwestern coastal zone, in particular, is characterised by strong monsoonal wave climates, high rainfall, and significant riverine sediment inputs, making it highly dynamic and susceptible to change (Perera and Ranasinghe, 2021). Rapid urbanization, increasing human activities, and developmental pressures have led to serious human and environmental challenges (Jayathilaka et al., 2023).

Coastal erosion has been identified as a major environmental and socio-economic issue in Sri Lanka, especially in areas where human interventions have modified natural coastal processes (Coast Conservation and Coastal Resource Management Department, 2024; Jayathilaka et al., 2023; Kirishanthan, 2022; Punniyarajah, 2022). Hard-engineering approaches such as groins and seawalls have, in some cases, disrupted longshore sediment transport and exacerbated erosion in adjacent coastal areas (Jayathilaka et al., 2023).

Recognising these challenges, national coastal management strategies increasingly emphasise integrated coastal zone management (ICZM) approaches that incorporate ecological processes and stakeholder participation (Coast Conservation and Coastal Resource Management Department, 2024; Cioffi et al., 2024). The recent significantly revised Sri Lanka Coastal Zone and Coast Conservation and Coastal Resource Management Department, 2024 - 2029 to conserve and sustain its coastal zones and associated resources (Amarasinghe, 2020) is the first such plan of any tropical country, based on evidence from peer-reviewed research and developed in consultation with community representatives.

1.3. Environmental change at Calido Beach

Calido Beach, located in the Kalutara District on the southwestern coast of Sri Lanka, represents a coastal system influenced by both fluvial and marine processes. The site is situated at the mouth of the Kalu River and historically included a sand spit barrier that separated the estuary from the open ocean (Perera and Ranasinghe, 2021; Rupasinghe et al., 2023).

Previous studies have highlighted the sensitivity of such sand spit systems to both natural variability and human intervention (Perera and Ranasinghe, 2021; Tinh et al., 2020). In May 2017, a major flood event in the Kalu River basin resulted in significant loss of life and widespread damage, affecting over 180,000 people (Amaratunga et al., 2021; International Organization for Migration, 2017).

In response, authorities implemented flood-control measures that included widening the river mouth and removing a portion of the sand spit barrier to facilitate water discharge. While these interventions were designed to reduce flood risk, previous reports and studies suggest that they may also be associated with changes in coastal morphology, including shoreline retreat, altered sediment transport, and changes in ecosystem structure (Asia Pacific Alliance for Disaster Management, 2024; Gamage and Kumara, 2025; Hettiarachchi et al., 2021).

However, coastal environments are inherently dynamic, and observed changes may also reflect the combined influence of natural processes such as monsoon forcing, wave action, and river discharge variability. As such, establishing causal relationships between specific interventions and environmental outcomes remains challenging.

1.4. Study aims and research focus

While previous research has examined coastal erosion and flood management in Sri Lanka, fewer studies have integrated environmental observations with community perceptions in specific local contexts. Understanding how local communities perceive environmental change is particularly important, as their livelihoods are directly affected by coastal processes and management interventions (Perera et al., 2025).

A range of anecdotal evidence and grey literature supported the need for this research - relevant parliamentary reports and information from government institutions, including the Disaster Management Centre (Disaster Management Centre, 2025); information relevant to Kalutara, such as the Land Use Policy Planning Department-Kalutara (Land Use Policy Planning Department, 2025), the Kalutara Divisional Secretariat Office (Srilanka-Places.com, 2026) and the Ministry of Defence (Jayatillake, 2020). Additional sources included community-based surveys (not in English language), newspaper articles (e.g. Gomes (2022) and Lankadeepa Editorial Board (2018)); videos (including LankaAnews (2018) and Newsfirst Sri Lanka (2018)). These sources strongly suggested that environmental changes that coincided with the Kalu River flood mitigation project, have inadvertently led to negative socio-economic repercussions for the local communities such as reducing drinking water quality, clogging roads and drainage networks with sand, limiting access to the beach, and negatively impacting the livelihoods for those who depend both directly and indirectly on fisheries and tourism activities as a source of income or economic activity. While the project was intended to alleviate disaster risks, the possibility of unintended broader and long-term negative ecological and socio-economic consequences highlight the need for integrated coastal management strategies. Prior to this study, community members' experiences and perceptions of the environmental and socio-economic repercussions of this project had not been formally researched.

This study seeks to address this gap by combining analysis of satellite imagery with community-based survey data. Specifically, the study aims to:

1. Describe observable changes in coastal morphology at Calido Beach using qualitative satellite imagery analysis
2. Examine community perceptions of environmental and socio-economic impacts associated with coastal change
3. Explore relationships between socio-demographic characteristics and perceptions of flood-control interventions

Rather than attempting to establish causal relationships, the study adopts an integrated socio-environmental perspective to examine how environmental change is observed and experienced within a dynamic coastal system.

2. Materials and methods

2.1. Study area

The study was conducted at Calido Beach, located in the Kalutara District on the southwestern coast of Sri Lanka, near the mouth of the Kalu River (Fig. 1). This coastal system is characterised by interactions between fluvial sediment discharge, wave-driven longshore transport,

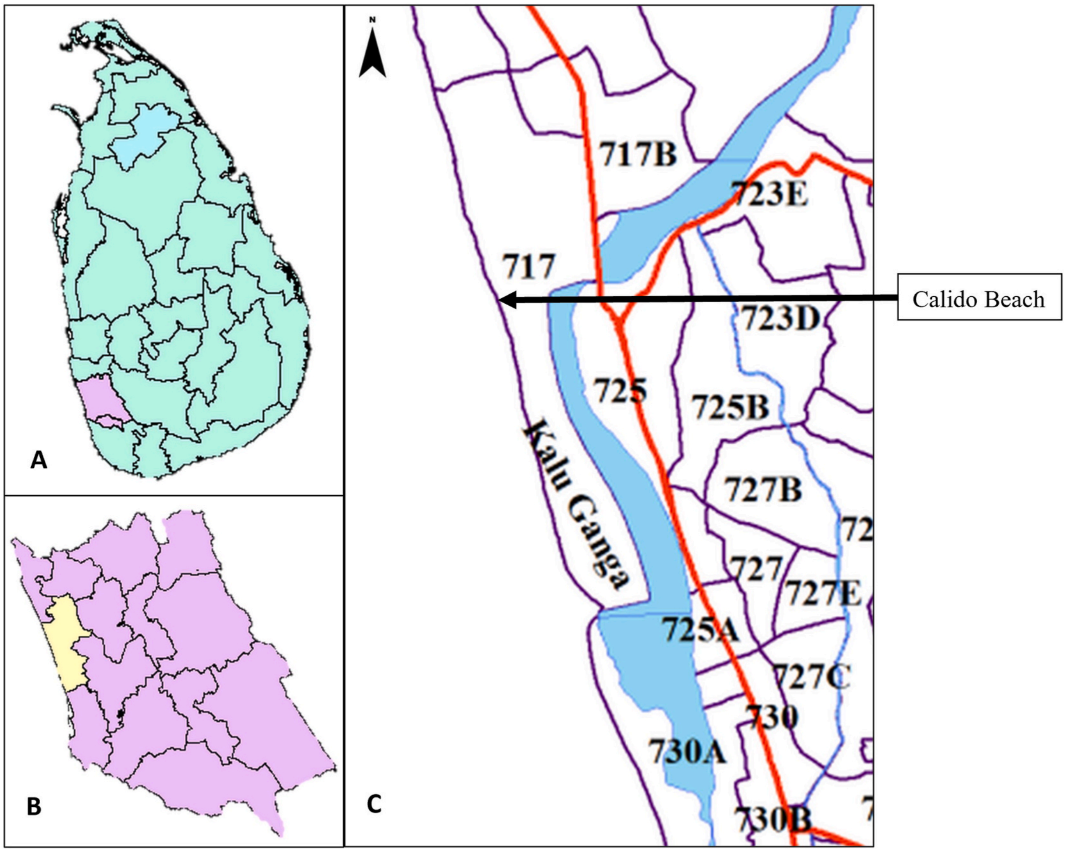

Fig. 1. Location of the study site. (A) Map of Sri Lanka showing the location of Kalutara District along the southwestern coastline. (B) Administrative divisions within Kalutara District, indicating the broader study region. (C) Detailed map of the Kalutara North Grama Niladhari Division, showing the location of Calido Beach relative to the Kalu River estuary and adjacent coastal features. Note: Maps are based on publicly available spatial data sources and are intended for locational reference.

and seasonal monsoon dynamics, which play a key role in shaping shoreline processes (Deng et al., 2017; Warrick et al., 2023). The region surrounding Calido Beach spans approximately 38 ha and has a total population of over 2300 across approximately 800 households as per the latest statistics (Pavithra, 2024) and is also a popular tourist destination known for its cultural and religious sites, including the renowned Kalutara Bodhiya.

The area includes a sand spit barrier that historically separated the river estuary from the Indian Ocean. Such sand spit systems are known to be highly dynamic and sensitive to both riverine and coastal forcing mechanisms (Tinh et al., 2020).

The region experiences a tropical monsoon climate, with mean annual rainfall between 3000 and 4000 mm and temperatures ranging from approximately 24°C to 30.5°C. Seasonal variability in river discharge and wave energy contributes to a naturally dynamic shoreline environment (Perera and Ranasinghe, 2021). Sixteen significant flood events were recorded in the Kalu River basin between 2001 and 2020, with a major flood occurring in May 2017 (Amarakoon et al., 2024).

2.2. Study population and sampling

The study population comprised adult residents whose livelihoods are directly linked to coastal and estuarine resources, including fisheries, tourism, small-scale trade, and sand mining. These sectors are widely recognised as key components of coastal economies in Sri Lanka (Jayathilaka et al., 2023).

Participants were recruited using purposive convenience sampling in key economic locations such as markets, fishing areas, and tourism sites. This approach is appropriate for exploratory socio-economic studies where target groups are defined by livelihood characteristics (Ponto, 2015). Ethics approval was obtained from the University of Colombo to collect data from these adult residents, and each participant provided their consent to participate.

A total of 70 participants were included in the study. The high proportion of male respondents (91%) reflects local workforce structures in fisheries and coastal industries, as well as the outward migration of women for overseas employment, which is a documented trend in Sri Lanka (Harper et al., 2024).

No participants declined to participate in the survey. Given the non-random sampling approach and relatively small sample size, findings are not intended to be statistically representative but rather to provide exploratory insights into community perceptions.

2.3. Data collection

Data were collected using a mixed-methods approach combining satellite image interpretation, field observations, and survey-based data.

2.3.1. Satellite imagery analysis

Google Earth Pro imagery from 2010 to 2024 inclusive was used to conduct visual comparison of coastal morphology over time. Images were examined at multiple time points (beginning, middle, and end of each year) to identify broad patterns of shoreline change, sandbar configuration, and landform transformation. This type of remote sensing approach has been used in previous studies to identify general coastal dynamics where detailed geospatial data are unavailable (Perera and Ranasinghe, 2021; Tinh et al., 2020).

However, no georeferencing or digitisation, of shoreline change was conducted. Observations are therefore interpretive and intended to identify general trends rather than precise rates of erosion or sediment transport. Bathymetric changes were not assessed, consistent with the limitations of satellite-based imagery without in situ measurements.

2.3.2. Survey data collection

Primary data were collected through structured face-to-face surveys conducted between July and September 2024, with a follow-up site inspection in August 2025.

The survey instrument included:

- Likert-scale questions (e.g., levels of agreement or satisfaction)
- categorical variables (e.g., age, gender, occupation, duration of residence)
- structured questions relating to environmental change, water quality, and economic impacts

Structured survey designs incorporating Likert scales are widely used in socio-economic and perception-based coastal research to quantify attitudes and responses (Ponto, 2015).

The questionnaire was developed in English and translated into the local language. A pilot study was conducted prior to data collection to ensure clarity, cultural appropriateness, and feasibility of the survey instrument. Any qualitative responses were translated back to English.

2.4. Data analysis

Data analysis was conducted using IBM SPSS Statistics 23. Descriptive statistics (frequencies and percentages) were used to summarise respondent characteristics and perception patterns.

Given the small expected cell counts in contingency tables, Fisher's Exact Test was used to assess associations between categorical variables. This test is appropriate for small sample sizes and when expected frequencies are low (Cleophas and Zwinderman, 2016).

Results are reported using p-values ($p < .001$ where appropriate), and relationships are interpreted as indicative rather than definitive. Measures of association (Cramer's V) are reported to provide insight into effect size where applicable.

Due to the limited sample size and uneven subgroup distributions (e.g., gender), statistical findings should be interpreted with caution. The analysis does not establish causation but instead identifies patterns in community perceptions and reported experiences.

3. Results

3.1. Changes in coastal morphology Based on satellite imagery

Visual interpretations and comparisons of satellite imagery from 2010 to 2024 suggest substantial changes in the morphology of the sandbar at Calido Beach (Fig. 2). Prior to 2017, imagery indicates the presence of a relatively continuous sand spit that functioned as a barrier separating the river estuary from the open ocean. Seasonal variability in sandbar shape and vegetation cover is evident, consistent with a dynamic coastal environment influenced by monsoonal processes and sediment transport (Deng et al., 2017; Warrick et al., 2023).

Following the 2017 flood event and subsequent river mouth modification, imagery shows a marked alteration in the form and continuity of the sandbar. By late 2017, the sandbar appears fragmented, with sections reduced in width and continuity. Over subsequent years, portions of the former sandbar appear to have shifted landward and merged with adjacent land, contributing to the formation of low-lying lagoon-like areas and vegetated zones.

By 2024, only limited remnants of the original sand spit structure are visible. The river mouth appears wider and positioned differently relative to earlier imagery, although interpretation is limited by the qualitative nature of the analysis. These observations suggest a substantial reconfiguration of the coastal system; however, the relative influence of natural processes and human interventions cannot be determined from the available data (Tinh et al., 2020; Perera and Ranasinghe, 2021).

In addition to changes in sandbar morphology, qualitative

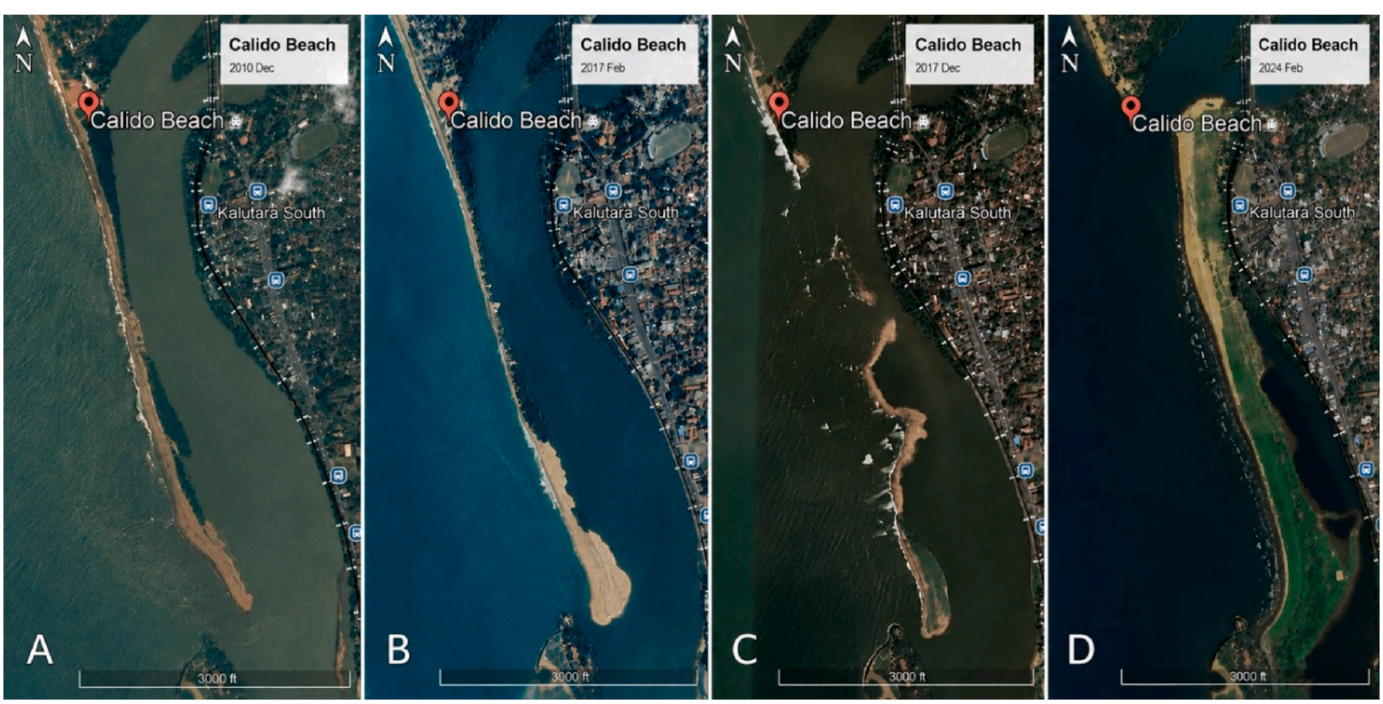

Fig. 2. Temporal changes in sandbar morphology at Calido Beach derived from satellite imagery. (A) December 2010, showing a continuous sand spit barrier separating the Kalu River estuary from the Indian Ocean. (B) February 2017, prior to major flood events and river mouth modification. (C) December 2017, following flood-related interventions and alteration of the river mouth. (D) 2024, showing significant transformation of the sandbar and surrounding coastal morphology. Images illustrate qualitative changes in shoreline configuration and sandbar structure over time. Note: Images are sourced from Google Earth Pro (2024) and are used for qualitative visual comparison only; no geospatial digitisation or quantitative shoreline change analysis was conducted.

interpretation of satellite imagery suggests a shift in the spatial distribution of mangrove vegetation in the study area. Mangrove cover appears to have expanded in certain low-lying and newly formed lagoonal areas following the reconfiguration of the sandbar and river mouth. This apparent increase in vegetated areas is most noticeable in the years following 2017, where previously unvegetated zones show signs of colonisation. However, these observations are based on visual image interpretation and were not quantitatively validated through vegetation mapping or field-based ecological surveys.

3.2. Sample characteristics

A total of 70 respondents participated in the survey. Participants were engaged in fisheries (40%), tourism (27%), small-to medium-scale businesses (23%), and sand mining (10%). The majority of respondents were male (91%), reflecting the gendered structure of coastal livelihoods in Sri Lanka (Harper et al., 2024). Ninety-six percent were educated to at least grade 8, 50% were aged between 50 and 60 years old and 83% were married.

Approximately 41% of respondents reported living in the area since birth, while equal proportions of 24% each had been residing there for 6-10 years or more than ten years respectively. Most respondents (76%) lived within 500 m of the river, indicating close proximity to the coastal and estuarine environment.

3.3. Perceptions of coastal change

All respondents reported awareness of coastal erosion at Calido Beach. When asked about causes, 40% identified a combination of natural processes and government interventions, while 39% attributed erosion primarily to government activities. Half acknowledged that some beach damage may have begun more than 10 years prior due to natural factors alone. Ninety percent of those individuals employed in sand mining did not perceive significant changes in sand quality or quantity following beach erosion, suggesting that such changes may be gradual or localized.

The majority of respondents (94%) were aware of the flood-control interventions implemented in 2017, and 73% expressed dissatisfaction with these measures. These findings align with previous reports highlighting community concerns regarding coastal interventions in Sri Lanka (Jayathilaka et al., 2023).

3.4. Perceived changes in water quality

Perceptions of water quality varied depending on the source of drinking water (Fig. 3). Among respondents who relied on tap water, most (71%) reported no noticeable changes. In contrast, over half (56%) of respondents relying on well water reported increased salinity, which may reflect increased seawater intrusion into coastal aquifers (Gamage and Kumara, 2025; Punniyarajah, 2022).

Fisher's Exact Test indicated a significant association between water source and perceived changes in water quality ($p < .001$, Cramer's $V = .648$). No significant relationship was found between proximity to the river and perceptions of water quality ($p = .711$).

3.5. Infrastructure impacts

Most respondents (93%) reported damage to infrastructure associated with coastal change with 38% of the participants perceiving government and private properties as being the most affected. Roads and bridges were only seen by 3% of respondents as being impacted, despite sand accumulation on roads (Fig. 4), and blockage of drainage systems, and reduced accessibility to coastal areas (Fig. 5) being evident during research site inspections. Participants reported that the government's allocation of around USD 5-7 million for a sand-pumping project and installation of sea walls to reduce coastal erosion after the removal of the sandbar, these mitigation measures were deemed ineffective as the sand rapidly returned to the sea. Similar challenges associated with hard-engineering interventions have been noted in other coastal contexts (Angnuureng et al., 2025).

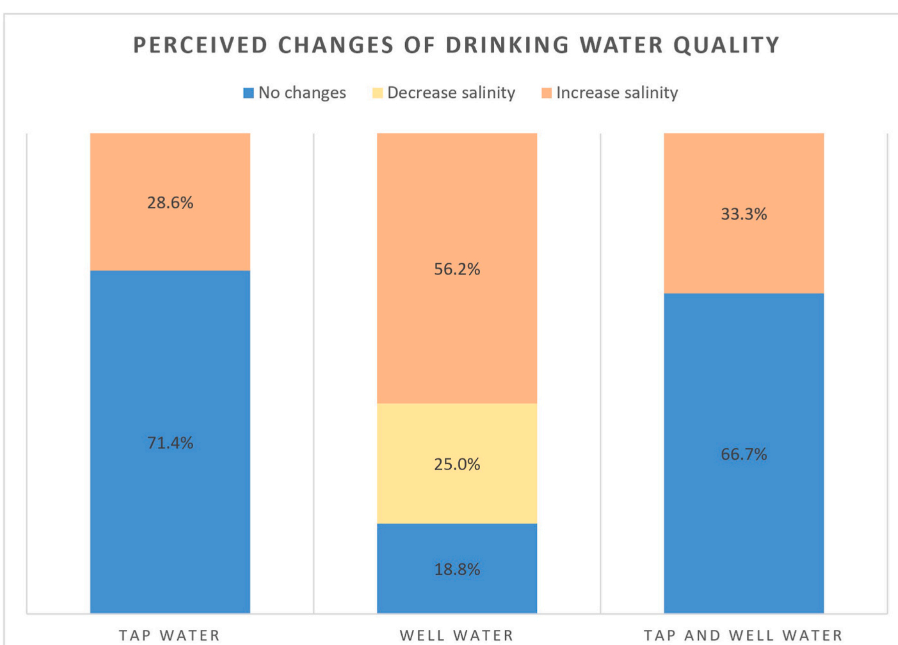

Fig. 3. Community perceptions of changes in drinking water quality by water source. Bar chart showing the proportion of respondents reporting increased salinity, decreased salinity, or no change in water quality for tap water, well water, and combined sources. Results indicate variation in perceived water quality change depending on water source, with higher reported salinity changes among well water users. Note: Data represent perceived changes reported by survey participants ($n = 70$) and do not reflect measured water quality parameters.

Fig. 4. Example of infrastructure impacts associated with sand accumulation at Calido Beach. Photograph showing sand deposition on access roads and within drainage channels following coastal change and mitigation efforts. Sand accumulation has reduced accessibility and disrupted drainage function in the study area. Note: Image captured during field visit in 2025.

Fig. 5. Current coastal conditions at Calido Beach following erosion and mitigation efforts. (A) Stone wall structures installed along the shoreline, limiting beach access. (B) Accumulation of sand and sediment across beachfront areas, affecting usability of the beach and infrastructure. The images illustrate the combined effects of erosion, sediment redistribution, and coastal stabilisation interventions. Note: Photographs taken during field observations in 2025.

3.6. Community perceptions and satisfaction

Statistical analysis indicates that perceptions of the causes of environmental change are associated with duration of residence ($p < .001$, Cramer's $V = .877$), suggesting the importance of long-term experiential knowledge (Meetiyagoda et al., 2024). Long-term residents largely blamed government activities for the beach damage. Interestingly, only small business owners expressed satisfaction with the flood control methods following the sandbar removal.

Satisfaction with flood-control measures was significantly associated with income source ($p < .001$, Cramer's $V = .903$), with sand mining and fishing workers being more satisfied than business and tourism workers. Gender differences were observed with 100% of female participants expressing satisfaction compared to only 15% of male participants who indicated that they were satisfied with flood control measures; however, interpretation is limited by the small number of female respondents ($n = 6$).

3.7. Tourism and livelihood impacts

Respondents reported a decline in tourism activity following coastal changes, particularly due to reduced beach accessibility and environmental quality. According to participants, coastal and estuary changes have severely impacted the local economy and livelihoods dependent on tourism. What was a popular destination for both locals and tourists - widely used for leisure and recreational activities, including kite flying, kite festivals and New Year celebrations, and for small-scale business vendors to sell handicrafts, food, and clothing – has largely disappeared. Participants reported that nearly 100 guest houses/hotels in the area are no longer operational due to the lack of a safe and attractive beach and the bad odor from stagnant water in a newly formed water body. Previous studies have similarly identified coastal erosion as a key driver of reduced tourism revenues and local economic disruption (Alexandrakis et al., 2015).

Impacts varied across sectors, with fisheries, tourism, and small businesses perceived as negatively affected, while sand mining activities were reported as largely unchanged.

3.8. Environmental awareness

Most respondents reported noticeable changes in coastline position and mangrove distribution. According to the participants, the area which was lost included a sandbar and a beach stretching for over 2 km, from where the Indian Ocean could be seen on one side and the Kalu River on the other - a unique coastal stretch, considered one of the most beautiful beaches in the Western Province.

While satellite imagery suggests localised expansion of mangroves in some areas, respondents perceived an overall decline in mangrove cover, indicating potential differences between observed spatial redistribution and community interpretation. Respondents' concern about a decline in mangroves is reasonable, as mangroves are known to play a critical role in coastal stability and ecosystem functioning (Alongi, 2015; Barbier et al., 2011).

Participants' perceptions of morphological estuarine change, due to either natural or anthropogenic activities, were less pronounced, suggesting spatial variability in awareness of environmental processes. This is despite studies in the area, such as Gamage and Kumara (2025), which have recently reported such morphological changes to the Kalu estuary.

4. Discussion

4.1. Interpreting coastal change

The findings suggest substantial changes in coastal morphology at Calido Beach, particularly in relation to sandbar configuration and shoreline position. Such transformations are consistent with previous research highlighting the sensitivity of sand spit systems to both natural variability and human intervention (Tinh et al., 2020). These transformations represent not only a loss of natural beauty and habitat but also the weakening of the natural buffer against tidal surges and storm events, consistent with global concerns regarding coastal resilience loss due to human interventions (Lakmali et al., 2017).

However, the absence of quantitative shoreline analysis limits the ability to determine rates of change or sediment dynamics. Coastal systems are inherently dynamic, influenced by fluvial sediment supply, wave climate, and storm events (Deng et al., 2017; Warrick et al., 2023).

While the observed changes coincide with flood-control interventions, causality cannot be established. Similar complexities have been documented in studies of coastal engineering impacts globally (Angnuureng et al., 2025).

The observed changes in mangrove distribution may reflect ecological stress – ecological responses to altered hydrological and sedimentary conditions within the estuarine system. Mangroves are highly sensitive to changes in salinity, sediment supply, and water flow regimes, and can rapidly colonise newly formed or stabilised substrates (Alongi, 2015; Temmerman et al., 2013). Their destruction compromises the ecological integrity and biodiversity of the area.

The apparent expansion of mangrove cover in the recently formed lagoon-like environments at Calido Beach may therefore indicate localised increases in habitat suitability following morphological change. Mangroves serve as vital stabilizers of coastal zones, protecting against erosion and serving as breeding grounds for marine life (Barbier et al., 2011). In Sri Lanka, and other nations, mangrove ecosystems are also an important source of medicines and foods, especially for traditional and low-income communities (United Nations Sri Lanka, 2024). This could be promising for retaining biodiversity, as Athukorala and Karunarathna (2020) noted that while Sri Lanka is generally doing better than its neighboring countries in meeting the Sustainable Development Goals, there has been a concerning decline in biodiversity and other environmental measures in the last few decades.

It must be noted that shifts in mangrove location - rather than uniform expansion - may reflect spatial redistribution driven by changing environmental conditions. Without quantitative vegetation analysis, it is not possible to determine whether total mangrove area has increased or decreased. Nevertheless, these observations highlight the interconnected nature of geomorphological and ecological processes in dynamic coastal systems.

4.2. Socio-economic implications

Survey findings indicate that local communities perceive significant negative impacts on livelihoods, particularly in tourism and fisheries. These findings align with broader literature demonstrating that coastal erosion can reduce economic activity and increase vulnerability in coastal communities (Jayathilaka et al., 2023; Alexandrakis et al., 2015). However, these results are based on perception data and may also reflect broader socio-economic trends.

Both measured and perceived impacts of human interventions and grey infrastructure (e.g., sand walls) highlight the need for more sustainable coastal management approaches. Increasingly, this has reinforced the importance of nature-based solutions, such as mangrove rehabilitation and dune restoration, which support long-term ecological resilience and the sustainability of fishing, small business, and tourism livelihoods (Enríquez-Hidalgo et al., 2025). In contrast, sand mining—an environmentally contentious activity (Jayathilaka et al., 2023)—appears to have continued largely unaffected, raising ethical concerns regarding the prioritisation of industrial interests over community resilience.

These findings are consistent with earlier research showing that fragmented or short-term coastal management strategies can exacerbate environmental degradation and increase the vulnerability of both ecosystems and marginalised communities (Amaratunga et al., 2021). Reports from community members regarding the ineffectiveness of costly mitigation measures, such as USD 5–7 million sand-pumping projects, further point to systemic shortcomings in policy implementation, transparency, and long-term planning. Similar governance challenges have been documented both in Sri Lanka (Jayathilaka et al., 2023) and globally (Angnuureng et al., 2025).

Taken together, the findings suggest an urgent need to reconsider flood control and erosion management strategies in the Kalu River Estuary and at Calido Beach. This supports previous critiques of Sri Lanka's current approach to coastal erosion management (Jayathilaka et al., 2023). Rather than relying solely on large-scale, high-cost interventions, more sustainable approaches should integrate a combination of measures, including beach nourishment, dune restoration, mangrove rehabilitation, and carefully designed coastal defence structures, supported by robust cost-benefit analyses.

However, all interventions involve trade-offs. Hard engineering solutions such as stone walls and groins are expensive, can disrupt sediment transport, and may intensify erosion in adjacent areas. Soft approaches, including beach nourishment, often require ongoing maintenance and may provide only temporary relief. In addition, both hard and soft interventions can alter coastal habitats, landscapes, and the aesthetic and recreational value of beaches (Angnuureng et al., 2025).

Given these constraints, alternative funding mechanisms may be necessary to support coastal protection. Beyond government investment, financial support could be generated through tourism-related revenues, user fees, or municipal taxes applied to coastal businesses (Alexandrakis et al., 2015).

4.3. Community perceptions and knowledge

Community feedback indicates a predominantly critical view of government-led flood-control initiatives, particularly among individuals whose livelihoods are most directly dependent on the coastal ecosystem, including fishermen, tourism operators, and small-scale vendors. Community members and water experts also reported perceived political influence in decisions to remove the sandbar without a proper environmental impact assessment, raising concerns about governance transparency and accountability. These observations support the argument that environmental policy in Sri Lanka often fails to adequately incorporate local knowledge and lived experience (Priyanthika Jayawardena et al., 2024). Although Sri Lanka's Coastal Zone Management Plan (2024-2029) emphasises community participation, the extent to which this will be effectively operationalised at sites such as Calido Beach remains to be seen.

The statistically significant relationship between length of residence and perceptions of beach degradation highlights the importance of local ecological knowledge. Long-term residents often develop detailed observational understanding of environmental change through lived experience (Meetiyagoda et al., 2024), which is frequently associated with a stronger sense of place and a greater willingness to engage in environmental management. However, variability in perceptions - particularly the limited awareness of estuarine changes - suggests uneven access to environmental information. This supports previous findings that Sri Lankan communities require improved access to local environmental data and more comprehensive environmental education to achieve sustainable development (Athukorala and Karunarathna, 2020; Nirmani, 2024). It also reinforces the importance of integrating scientific data and modern technologies with traditional ecological knowledge in coastal management practices (Perera et al., 2025).

Gender differences in satisfaction with flood and coastal management measures further indicate uneven exposure to environmental and economic risk. While women may be less directly involved in certain livelihood activities, they remain affected by broader social, infrastructural, and household impacts. Similar differences in how men and women perceive environmental, social, economic, and governance outcomes of coastal management have been documented by Nagabhatla et al. (2019). These findings highlight the need for more equitable and gender-responsive coastal management strategies that support biodiversity conservation, sustain fisheries and tourism, and promote the well-being of all community members.

Expert perspectives suggest that alternative, lower-impact interventions - such as selective modification of the sandbar at the southern end - could potentially reduce flooding without causing extensive environmental damage. More broadly, these findings emphasise the need for a participatory, inclusive, and evidence-based approach to coastal management, in which community perspectives are systematically incorporated into decision-making processes.

4.4. Methodological limitations

This study has several limitations. First, satellite imagery analysis was qualitative and did not include geospatial quantification. Second, the sample was relatively small and non-random. Third, statistical associations should be interpreted cautiously given uneven subgroup sizes.

Finally, the study relies on perceived rather than measured environmental changes. These limitations are consistent with challenges identified in mixed-method coastal studies (Cleophas and Zwinderman, 2016).

4.5. Implications for coastal management

Despite these limitations, the findings provide important insight into community responses to coastal change, particularly from those most directly affected by coastal management policies and interventions. They support the need for integrated coastal zone management (ICZM) approaches that incorporate both scientific evidence and stakeholder perspectives, while simultaneously addressing ecological sustainability, disaster risk reduction, and socio-economic resilience (Cioffi et al., 2024).

Future interventions should be developed through participatory planning processes that actively engage local stakeholders - including both men and women - at all stages of decision-making. Meaningful engagement of affected communities is essential to ensure that participants feel safe, valued, and able to contribute to environmental governance. Such inclusion enhances the legitimacy of decisions and increases the likelihood of sustainable outcomes, making stakeholder participation a critical component of effective coastal zone management (Perera et al., 2025). Multi-stakeholder approaches can incorporate diverse perspectives, enhance transparency, foster cooperation, build capacity and trust, minimise conflict and facilitate its resolution, support equitable resource allocation, and improve program implementation and monitoring.

Nature-based solutions, such as mangrove reforestation and dune restoration, can complement engineered approaches and contribute to long-term coastal resilience (Temmerman et al., 2013; Nagabhatla et al., 2019). In addition, the establishment of long-term monitoring systems that combine satellite imagery with community-based observations is essential for evaluating environmental change and the effectiveness of interventions over time. Such systems can also improve access to environmental data and support community education.

Finally, effective coastal governance requires strong coordination among key agencies and stakeholders, particularly those involved in environment, disaster management, fisheries, and tourism, to ensure coherent and sustainable policy implementation.

5. Conclusion

This study highlights substantial changes in coastal morphology and mangrove cover, many of which are supported by community perceptions, at Calido Beach. While these changes are associated with flood-control interventions, they likely reflect a combination of natural and anthropogenic processes.

The findings emphasise the importance of combining qualitative and quantitative approaches in coastal research, and the need for participatory, evidence-based management strategies (Perera et al., 2025).

Future research should incorporate quantitative shoreline analysis and long-term environmental monitoring to better understand coastal dynamics and intervention outcomes.

CRediT authorship contribution statement

H.C. Thulani: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft. **A.D. Ranaweera:** Investigation, Software, Visualization, Writing – original draft, Writing – review & editing. **J. Trafford:** Formal analysis, Supervision, Writing – original draft, Writing – review & editing. **D. Wickramasinghe:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare no competing conflicts of interest.

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Data availability

Data will be made available on request.

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