

Analyzing the Impact of Artificial Beach Nourishment on Shoreline Dynamics: A Case Study of Calido Beach - Kaluthara

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Abstract: Sandy beaches face a significant threat due to coastal erosion worldwide. Artificial beach nourishment has become an emerging approach to overcoming this threat. However, empirical assessments of nourishment effectiveness, particularly in data scarce regions, are essential for evidence based coastal management. This study assesses the impact of the artificial beach nourishment conducted in 2017 to 2020 in the Calido Beach area of Kalutara, Sri Lanka, in mitigating shoreline erosion. A multi decadal shoreline change analysis was conducted using Landsat 5, 7, and 8 imagery (1992 - 2017) and Sentinel 2 imagery (2021 -2024). The Modified Normalized Difference Water Index (MNDWI) was used for shoreline extraction and shoreline change rates were calculated using the Digital Shoreline Analysis System (DSAS). Results indicate a marked transformation in shoreline behavior following nourishment. Pre nourishment, 36.65% of transects exhibited erosion with an average End Point Rate (EPR) of -1.18 m/yr, while 63.35% showed accretion averaging 2.21 m/yr. Post nourishment, erosional transects declined to just 9.77% (average -0.89 m/yr), while accretional transects increased to 90.23% (average 6.74 m/yr). The overall average EPR increased from 0.96 ± 0.07 m/yr to 6.00 ± 2.83 m/yr, and the Shoreline Change Envelope (SCE) decreased from 60.10 m to 20.87 m, indicating enhanced shoreline stability. The findings demonstrate that the artificial beach nourishment at Calido Beach has been highly effective in reversing historical erosion trends and promoting sustained accretion. This study provides critical empirical evidence for coastal managers in Sri Lanka and the broader South Asian region, highlighting the utility of remote sensing and DSAS based monitoring for evaluating coastal interventions. Long term monitoring is recommended to assess nourishment longevity and inform adaptive management strategies.

Keywords: Artificial Beach Nourishment, Shoreline Change, DSAS, MNDWI, Coastal Erosion

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I. INTRODUCTION

Coastal zones represent some of the world's most dynamic and socio economically valuable environments, supporting approximately 40% of the global population within 100 km of the shoreline (Small & Nicholls, 2003). Coastal regions provide critical ecosystem services, support economic activities such as tourism and fisheries, and serve as natural buffers against storm surges and sea level rise (Kumar et al., 2021). However, coastal erosion has become one of the most severe environmental challenges, threatening coastal communities, infrastructure, and ecosystems worldwide (Bird, 2008; Luijendijk et al., 2018).

Approximately 24% of sandy beaches worldwide are eroding at rates exceeding 0.5 m/yr, with some regions experiencing annual losses of several meters (Vousdoukas et al., 2020). The causes of coastal erosion are multifaceted,

encompassing natural processes such as wave action, tidal currents, and sediment transport dynamics, alongside anthropogenic pressures including sand mining, coastal development, dam construction that reduces sediment supply, and climate change induced sea level rise (Mentaschi et al., 2018; Ranasinghe, 2016). Knowledge about coastal processes, sediment behavior, and interchange within the coastal zone are majorly required for Coastal erosion management (CEM) (Gracia et al., 2018).

Sandy beaches serve as natural barriers against waves, support biodiverse ecosystems, and contribute to the tourism economy in many countries (Schlacher et al., 2007; Defeo et al., 2009). In the context of Sri Lanka, coastal tourism has become a major economic driver, with beach destinations accounting for a significant portion of tourist arrivals and foreign exchange earnings (SLTDA, 2023). The southwestern coastline, in particular, contributes the highest

share to the country's Gross Domestic Product (GDP), a trend expected to persist into the future (Amarasinghe, 2020). Preservation of these sandy beaches is essential from both environmental and economic perspectives.

As an island nation, Sri Lanka relies heavily on its coastline for economic activities. Among all the coastal regions, the western and southwestern coasts are the most valuable zones due to their strategic location, thriving tourism industry, and fishing communities that depend on healthy coastal ecosystems (Samarasekara et al., 2018). However, these regions face significant challenges due to climate change, coastal erosion, and human activities (Samadhini & Herath, 2024).

In Sri Lanka, records of coastal erosion date back to the 1920s (Swan, 1974; 1984) and have progressively continued over the years due to factors such as the loss of mangroves through encroachment, sourcing of firewood, and the clearing of coastal areas for construction (Mohan, 2020). Recent studies have highlighted the vulnerability of specific coastal segments. Weerasekara and Illeperuma (2024) identified Kalutara, Beruwala, Hikkaduwa, Kahawa, and Galle as areas experiencing significant erosion along the southwestern coastline, aligning with previous vulnerability assessments (Lin & Pussella, 2017; Kirishanthan, 2022). The southwestern coastal zone has been subjected to a series of natural and anthropogenic processes, including coastal erosion, accretion, sediment transport, environmental pollution, and coastal development, which cause changes over long and short term spans (Aedla et al., 2015).

Calido Beach, located in Kalutara on the western coast of Sri Lanka, is a unique coastal feature, a strip of beach that

runs between the Kalu Ganga (river) and the Indian Ocean (Sandamali & Abeykoon, 2020). This sand spit, also referred to as Kalutara North Beach, is known for its unique ecosystem where river and sea converge, creating a diverse environment that appears similar to a lagoon (Jayasinghe et al., 2020; Sandamali & Abeykoon, 2020). The beach is a favorite destination for both locals and tourists, contributing to the local economy and cultural identity.

Prior to 2017, Calido Beach served two critical natural functions: the flow of freshwater from the Kalu River into the sea was regulated while sand was deposited in the estuary, and sand dunes controlled wave energy, thereby reducing erosion (Mohan, 2020). However, in May 2017, severe flooding associated with the southwest monsoon brought heavy rainfall to the southwestern parts of Sri Lanka, causing widespread damage and loss of life (Sandamali & Abeykoon, 2020; DMC, 2017). In an emergency response to control flooding and discharge excess water to the sea, authorities and local residents excavated a channel across the Calido sand dune (Mohan, 2020; Sandamali & Abeykoon, 2020).

This intervention had profound and unintended consequences. The sand dune separated from the mainland and moved inland, with subsequent analysis revealing approximately 690 m of movement of the sand dune center in a southeast direction, accompanied by a 47% enlargement of the dune area due to deformation and loss of vegetation cover (Sandamali & Abeykoon, 2020). Additionally, the removal of the sand bar led to saltwater intrusion into the Kalu River, making freshwater undrinkable for local communities, particularly during drought periods (Mohan, 2020; Thennakoon et al., 2024).

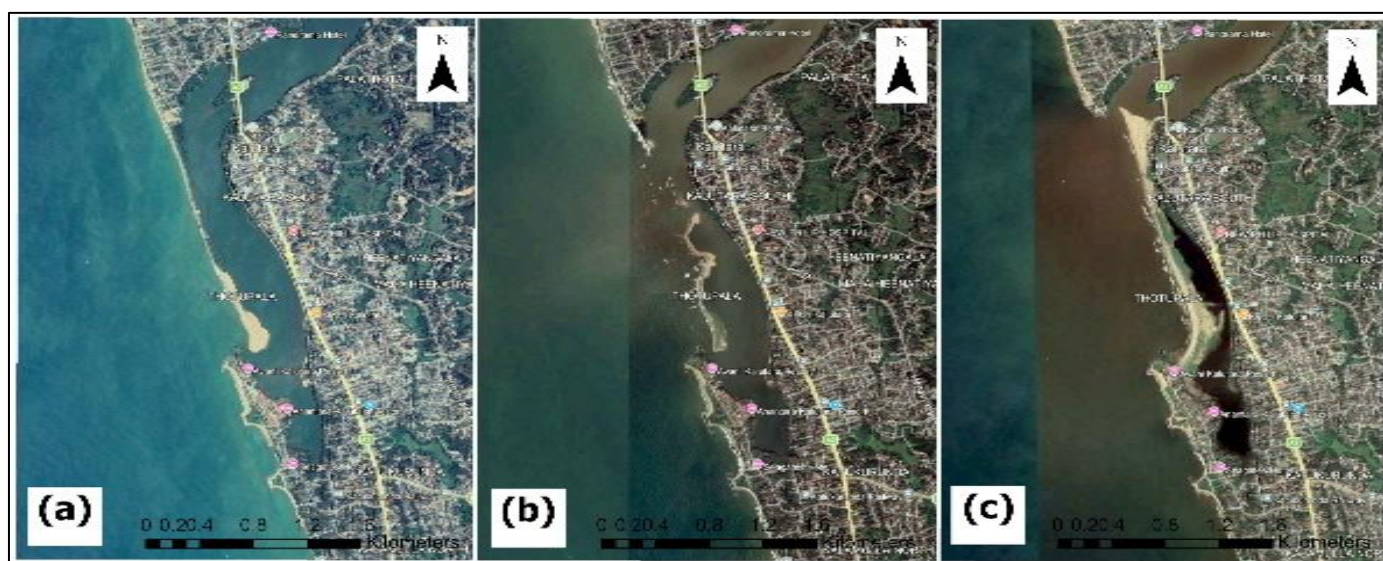


Fig 1 Satellite images: before the critical damage (a), damaged (b) and after the nourishment (c)

Recognizing the severe coastal degradation resulting from the sand bar removal, the Coast Conservation Department (CCD) initiated a large scale beach nourishment project in 2017 to restore Calido Beach. The project involved the placement of approximately 300,000 m³ of dredged sand along a 2 km stretch of shoreline, with the objective of

restoring the recreational beach and providing enhanced coastal protection (Mohan, 2020; Chandrakeerithi, 2020). The total cost of the nourishment project across three locations (Calido Beach, Ratmalana-Angulana, and Mount Lavinia) was Rs. 890 million (Mohan, 2020).

Beach nourishment is recognized globally as a soft engineering solution for coastal protection, offering advantages over hard structures such as seawalls and groynes (Hanson et al., 2002; Dean & Houston, 2016). When properly designed, nourished beaches can provide storm protection, enhance recreational value, and maintain natural coastal processes (Dean, 2002). However, nourishment is not a permanent solution and typically requires periodic renourishment every 3 - 10 years depending on sediment loss rates (Miller, 2018; Staudt et al., 2022). The effectiveness of nourishment depends on various factors including sediment characteristics, wave climate, and project design (Lakshitha et al., 2025).

Recent research has advanced understanding of how artificial sandbars influence wave transformation and coastal protection. Kuang et al. (2024) demonstrated that artificial sandbars can reduce wave setup by up to 22% and cause considerable changes in wave skewness, wave asymmetry, and flow velocity under normal wave conditions. Under storm wave conditions, the wave dissipation coefficient of an artificial sandbar increases first and then decreases with increasing incident wave height, indicating that the protective effect strengthens initially but may weaken under extreme conditions (Kuang et al., 2024).

These findings have direct relevance to the Calido Beach nourishment project, where the placement of dredged sand effectively functions as an artificial sandbar intended to attenuate wave energy and reduce shoreline erosion. Understanding the wave dynamics associated with such structures is essential for evaluating project effectiveness and designing future interventions.

Despite the significance of the Calido Beach nourishment project and its substantial financial investment, no comprehensive scientific assessment of its effectiveness has been published. While several studies have examined various aspects of the Kalutara coastal area including rare earth element potential (Jayasinghe et al., 2020), coastal land area changes using NDWI (Thennakoon et al., 2024), and morphodynamics following the 2017 flood (Sandamali & Abeykoon, 2020) none have quantitatively assessed the post nourishment shoreline dynamics using DSAS or compared pre and post nourishment erosion rates.

This gap is significant for several reasons. First, it limits the ability of coastal managers to make evidence based decisions regarding future nourishment interventions. Second, it hinders understanding of how nourished beaches respond to Sri Lanka's specific wave climate and sediment transport regimes. Third, it constrains the development of best practices for coastal management in the region.

This study aims to evaluate the effectiveness of the 2017 - 2020 carried artificial beach nourishment project at Calido Beach, Kalutara, in mitigating shoreline erosion. By employing multi temporal remote sensing and shoreline change analysis, this research provides the first empirical assessment of post nourishment shoreline dynamics at this location.

II. METHODOLOGY

The methodological framework of this study was designed to quantitatively assess the effectiveness of the artificial beach nourishment project conducted between 2017 and 2020 at Calido Beach, Kalutara, in mitigating shoreline erosion. A multi-stage approach was employed, integrating remote sensing (RS), Geographic Information Systems (GIS), and statistical shoreline change analysis.

➤ Study Area

Calido Beach, also known locally as Kalutara North Beach, is situated along the western coast of Sri Lanka within the Kalutara District. The study area lies approximately 40 km south of Colombo, the commercial capital of Sri Lanka, between latitudes 6°33'N and 6°36'N and longitudes 79°57'E and 79°58'E (Figure 1).

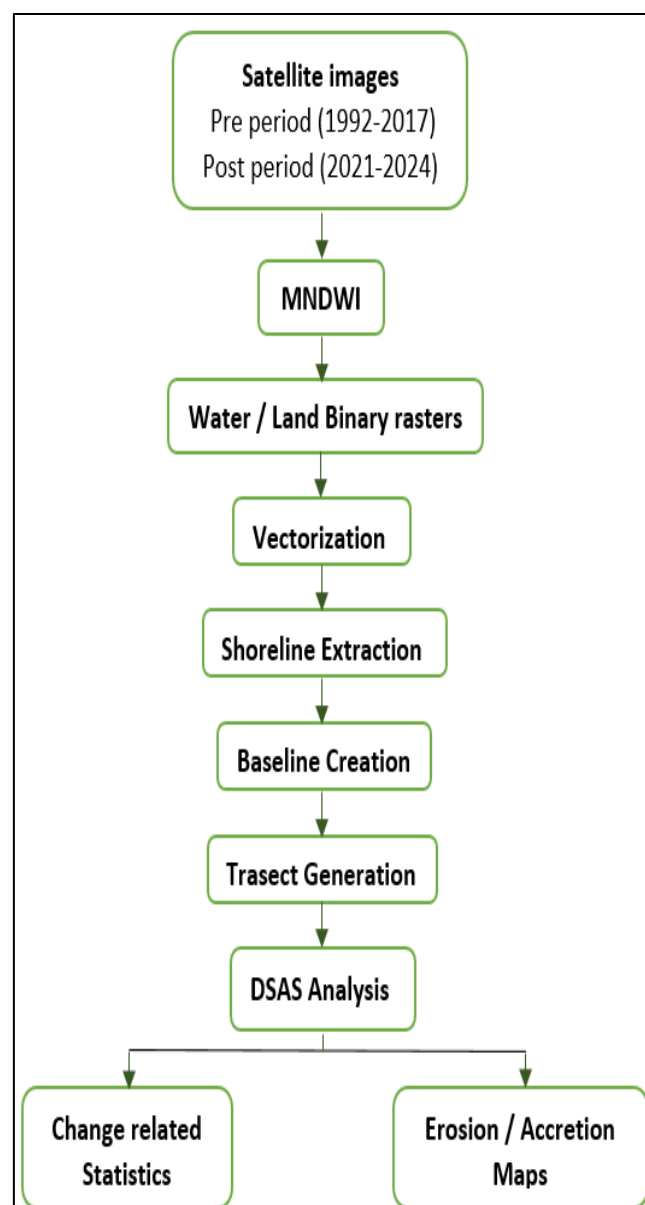


Fig 2 Conceptual Methodology



Fig 3 Calido Beach, Kaluthara (Study area)

➤ Satellite Data

This study utilized satellite imagery from two complementary sources: the Landsat series (NASA/USGS) and Sentinel 2 (European Space Agency). Landsat provides the longest continuous archive of medium resolution Earth observation data (1972 - present), while Sentinel 2 offers higher spatial resolution for recent years. Satellite data for the study period were processed using the Google Earth Engine (GEE) platform to generate annual median composites. The selected years were categorized into two distinct periods:

- Pre nourishment period: 1992, 1996, 2000, 2004, 2008, 2012, 2016, and 2017 (prior to the breach).
- Post-nourishment period: 2021, 2022, 2023, and 2024.

All pre-nourishment period images were acquired from Landsat datasets (Landsat 5, 7, and 8), while post nourishment images were retrieved from the Sentinel 2 collection.

➤ MNDWI Calculation.

The Modified Normalized Difference Water Index (MNDWI) was proposed by Xu (2006) as an improvement over the original Normalized Difference Water Index (NDWI) (McFeeters, 1996).

- Formula:

$$\text{MNDWI} = (\text{Green} + \text{SWIR1}) / (\text{Green} - \text{SWIR1})$$

Where:

Green = Surface reflectance in the green band

SWIR1 = Surface reflectance in shortwave infrared band

Binary thresholding was applied to the MNDWI rasters to delineate the water and terrestrial (land) interface. The optimal threshold value for each scene was determined through iterative validation against corresponding high resolution true color composites, ensuring accurate shoreline extraction across different conditions.

➤ Shoreline Extraction & Baseline Creation

Binary MNDWI rasters were converted into vector polygon features using the Raster to Polygon tool in ArcGIS. From these features, the land water interface was extracted using the Polygon to Line tool to generate discrete shoreline polylines. To ensure data integrity, each shoreline underwent systematic quality control to remove topological artifacts. The lines were then processed with the Smooth Line tool to reduce high frequency noise while preserving the essential geometric characteristics of the coast.

For the statistical analysis, shorelines were categorized into two temporal groups: pre-nourishment and post-nourishment. Two distinct offshore baselines were established to serve as the starting point for transect generation:

➤ *The Digital Shoreline Analysis System (DSAS) analysis*

The Digital Shoreline Analysis System (DSAS) is a high performance software developed by the United States Geological Survey (USGS) that operates within the ArcGIS environment. It is the global standard for calculating, editing, and interpreting statistical shoreline change from different data sources, such as satellite imagery and historical maps. The Digital Shoreline Analysis System (DSAS) was utilized to quantify the spatio temporal dynamics of the Calido Beach sandbar. The analytical workflow was executed in two primary phases: transect generation and statistical calculation.

To establish a consistent measurement framework, transects were cast perpendicular to the respective offshore baselines using the DSAS Transect Builder tool. To ensure high resolution spatial coverage of the study area, a smooth transect spacing was maintained, providing a dense grid of measurement points. A specific search distance was defined for each baseline to encompass the maximum landward and seaward extents of the shoreline positions observed between 1992 and 2024. This systematic approach ensured that all pre nourishment and post nourishment shorelines were intersected, allowing for the calculation of standardized change statistics at discrete, repeatable intervals along the coast.

Using the generated transects, four primary statistical indices were extracted to evaluate the effectiveness of the nourishment project.

➤ *Net Shoreline Movement (NSM)*

• *Formula:*

$$NSM = D_{\text{recent}} - D_{\text{past}}$$

Where:

D_{recent} = Distance from baseline to the most recent shoreline

D_{past} = Distance from baseline to the earliest shoreline

• *Interpretation:*

$NSM > 0$ = Accretion (shoreline moved seaward)

$NSM < 0$ = Erosion (shoreline moved landward)

• Units: m (meters)

➤ *Shoreline Change Envelope (SCE)*

SCE is the total distance between the most landward and most seaward shorelines along a transect, regardless of chronology.

• *Formula:*

$$SCE = D_{\text{max}} - D_{\text{min}}$$

Where:

D_{max} = Maximum distance from baseline

D_{min} = Minimum distance from baseline

• Units: m (meters)

SCE represents the total range of shoreline movement over the study period, providing a measure of shoreline mobility regardless of net change.

➤ *End Point Rate (EPR)*

EPR is the rate of change calculated using only the first and last shoreline positions.

• *Formula:*

$$EPR = NSM / Y_{\text{resent}} - Y_{\text{past}}$$

Where:

Y_{recent} = Year of most recent shoreline

Y_{past} = Year of earliest shoreline

• *Interpretation:*

$EPR > 0$ = Accretion rate (m/yr)

$EPR < 0$ = Erosion rate (m/yr)

• Units: meters per year (m/yr)

This metric provides a standardized annual rate of change (m/yr), allowing for a direct comparison between the historical erosion trends and the recent trends.

➤ *Linear Regression Rate (LRR)*

LRR is the rate of change calculated using linear regression through all shoreline positions along a transect.

• *Formula:*

$$LRR = \text{slope of } D = a + bY$$

Where:

D = Distance from baseline

Y = Year

b = Linear regression rate (LRR)

• Units: meters per year (m/yr)

Same as EPR, but uses all available shorelines.

➤ *Erosion / Accretion Mapping*

Thematic erosion / accretion maps were generated to visualize the spatial distribution of shoreline change along Calido Beach.

III. RESULTS

➤ *Before Shoreline Change Dynamics before Nourishment (1992-- 2017)*



Fig 4 Pre Nourishment shoreline variation (1992 -2017)



Fig 5 Pre Nourishment Erosion / Accretion Map (1992 -2017)

The pre nourishment analysis was conducted using 8 shoreline positions derived from Landsat imagery (1992 - 2016) across 974 transects spaced at 5 m intervals. Shoreline change rates were calculated using End Point Rate (EPR), and Linear Regression Rate (LRR) with a 95% confidence interval.

The Shoreline Change Envelope (SCE) revealed substantial shoreline variability prior to nourishment, with an average total movement of 60.10 m across all transects. The maximum SCE reached 199.30 m while the minimum was 0.37 m, indicating highly heterogeneous shoreline behavior along the study area. Net Shoreline Movement (NSM) averaged 22.99 m, with 63.35% of transects showing net accretion and 36.65% showing net erosion. The maximum net

accretion was 199.30 m , while the maximum net erosion was -70.19 m.

The End Point Rate (EPR) analysis revealed an overall average shoreline change rate of 0.96 ± 0.07 m/yr across the pre-nourishment period. Accretion dominated the shoreline behavior, with 63.35% of transects (n = 617) exhibiting positive rates averaging 2.21 m/yr, while 36.65% of transects (n = 357) showed erosion with an average rate of -1.18 m/yr. Statistically significant accretion ($p < 0.05$) was observed in 49.18% of transects, whereas significant erosion was detected in 27.00% of transects. The maximum accretion rate recorded was 9.82 m/yr, while the maximum erosion rate was -4.39 m/yr.

The Linear Regression Rate (LRR) analysis, which incorporates all shoreline positions rather than only endpoints,

yielded an overall average rate of 1.18 ± 0.69 m/yr. Accretional transects accounted for 59.86% (n = 583) with an average rate of 2.42 m/yr, while erosional transects represented 40.14% (n = 391) with an average rate of -0.67 m/yr. Notably, while 22.79% of transects exhibited statistically significant accretion ($p < 0.05$), no transects showed statistically significant erosion at the 95% confidence level, indicating that erosional trends were not consistently sustained throughout the 25-year period. Consistent with the EPR results, the maximum accretion rate was observed as 9.43 m/yr, and the maximum erosion rate as -2.97 m/yr.

➤ *Shoreline Change Dynamics After Nourishment (2021 - 2024)*



Fig 6 Post Nourishment shoreline variation (2021 -2024)

The post-nourishment analysis was conducted using 4 shoreline positions (2021 - 2024) across 1,054 transects. A 95% confidence interval was applied, reflecting the shorter temporal span and higher resolution of Sentinel-2 imagery.

The Shoreline Change Envelope (SCE) for the post nourishment period averaged 20.87 m, considerably lower than the pre nourishment average of 60.10 m. Maximum SCE was 68.64 m , while minimum was 0.26 m. Net Shoreline Movement (NSM) averaged 18.00 m, with a striking 90.23%

of transects (n = 951) showing net accretion and only 9.77% (n = 103) showing net erosion. Maximum net accretion reached 68.64 m, while maximum net erosion was -26.94 m.

The End Point Rate (EPR) analysis for the post-nourishment period revealed a substantial increase in shoreline change rates, with an overall average rate of 6.00 ± 2.83 m/yr. Accretion became overwhelmingly dominant, with

90.23% of transects (n = 951) exhibiting positive rates averaging 6.74 m/yr, while only 9.77% of transects (n = 103) showed erosion with an average rate of -0.89 m/yr. Statistically significant accretion ($p < 0.05$) was observed in 55.69% of transects, whereas significant erosion was detected in only 0.28% of transects. The maximum accretion rate recorded was 22.86 m/yr, while the maximum erosion rate was -8.97 m/yr.

Table 1 Summary of Pre and Post Nourishment DSAS Analysis Statistics

Parameter	Pre Nourishment (1992–2017)	Post Nourishment (2021–2024)
Time span	25 years	4 years
Number of transects	954	1054
Average SCE	60.10 m	20.87 m
Average NSM	22.99 m	18.00 m
% Accretional transects (EPR)	63.35%	90.23%
% Erosional transects (EPR)	36.65%	9.77%
Average EPR (overall)	0.96 ± 0.07 m/yr	6.00 ± 2.83 m/yr
Average accretion rate (EPR)	2.21 m/yr	6.74 m/yr
Average erosion rate (EPR)	-1.18 m/yr	-0.89 m/yr
Maximum accretion rate (EPR)	9.82 m/yr	22.86 m/yr
Maximum erosion rate (EPR)	-4.39 m/yr	-8.97 m/yr

The Linear Regression Rate (LRR) analysis, which incorporates all shoreline positions rather than only endpoints, yielded comparable results with an overall average rate of 5.98 ± 1.76 m/yr. Accretional transects accounted for 90.70% (n = 956) with an average rate of 6.68 m/yr, while erosional transects represented only 9.30% (n = 98) with an average rate of -0.84 m/yr. Statistically significant accretion was observed in 38.43% of transects, while significant erosion was detected in just 0.19% of transects. Consistent with the EPR results, the maximum accretion rate was observed as 22.32 m/yr, and the maximum erosion rate as -8.23 m/yr. The strong agreement between EPR and LRR estimates indicates that the post nourishment accretion trend is robust and not merely an artifact of endpoint selection. The dramatic reduction in erosional transects from 36.65% pre nourishment to 9.77% post nourishment, coupled with the substantial increase in average accretion rates from 2.21 m/yr to 6.74 m/yr, demonstrates the profound impact of the 2017 nourishment intervention on shoreline dynamics at Calido Beach.

IV. DISCUSSION

➤ Effectiveness of the 2017 Artificial Beach Nourishment

The results demonstrate a substantial and statistically significant shift in shoreline dynamics following the 2017 nourishment intervention at Calido Beach. The effectiveness of the intervention is evident across multiple indicators. The percentage of erosional transects decreased dramatically from 36.65% pre-nourishment to just 9.77% post-nourishment, representing a 73% reduction in the proportion of the shoreline experiencing erosion. Concurrently, accretion became overwhelmingly dominant, with over 90% of transects exhibiting net accretion post-nourishment compared to 63% pre-nourishment, indicating that the added sediment has not only been retained but has contributed to active beach building. The overall average End Point Rate (EPR) increased

from 0.96 m/yr to 6.00 m/yr, reflecting the rapid morphological adjustment following sediment placement—a pattern consistent with global observations that nourished beaches often exhibit higher initial change rates as the system equilibrates. Notably, despite these higher annual rates, the average Shoreline Change Envelope (SCE) decreased from 60.10 m to 20.87 m, suggesting that the post-nourishment shoreline operates within a narrower envelope of movement, indicating enhanced stability. While erosion was significantly reduced overall, persistent erosion was observed at localized hotspots, which were historically erosional. These localized zones may represent areas of sediment loss due to alongshore transport gradients or localized hydrodynamic conditions that warrant targeted management attention.

➤ Comparison with Global Beach Nourishment Studies

The findings of this study align closely with documented nourishment projects worldwide, reinforcing the validity of the observed trends. Dean and Houston (2016) reported that well-designed nourishment projects typically yield accretion rates of 3–8 m/yr in the initial years post-placement, a range consistent with the 6.74 m/yr average accretion rate observed at Calido Beach. Furthermore, Hanson et al. (2002) noted that nourished beaches often require periodic renourishment every 3–10 years depending on sediment loss rates; the sustained accretion observed four years after the Calido Beach intervention suggests that this project has exceeded typical short-term expectations. The high percentage of statistically significant accretion (55.69% by EPR) compares favorably with successful projects in Florida and the Netherlands, where 40–60% of nourished shorelines show significant positive change within the first decade (Cooke et al., 2020). This alignment with international case studies provides confidence that the Calido Beach nourishment project has achieved outcomes comparable to those documented in regions with more extensive coastal management histories.

➤ *Factors Contributing to Nourishment Success*

Several factors may explain the apparent success of the Calido Beach nourishment intervention. First, the project appears to have provided adequate sediment volume to overcome historical erosion gradients, with approximately 300,000 m³ of sand placed along a 2 km stretch of shoreline. This volume was likely sufficient to create a stable beach profile capable of absorbing wave energy and resisting erosion. Second, Kalutara's relatively moderate wave climate may have promoted sediment retention rather than rapid offshore transport, allowing the placed sand to remain within the active beach system. The median significant wave height of 0.98 m and wave periods of approximately 5.3 seconds (Lakshitha et al., 2025) represent conditions conducive to sediment retention rather than rapid dispersion. Third, unlike many nourished beaches constrained by hard engineering structures such as groynes or jetties, Calido Beach benefits from natural alongshore sediment transport patterns that distribute nourishment material effectively along the shoreline. Finally, the timing of this analysis—capturing the initial 4-year post-nourishment period—coincides with the phase when accretion rates are typically highest following sediment placement, which may explain the pronounced positive change observed.

➤ *Limitations*

Several methodological limitations should be acknowledged when interpreting the findings of this study. The temporal asymmetry between the pre-nourishment period (25 years) and the post-nourishment period (4 years) may bias comparisons toward long-term trends versus short-term adjustment, potentially overstating the contrast between periods. Additionally, the spatial resolution of the satellite imagery differs between periods: Landsat imagery (30 m) was used for pre-nourishment analysis, while Sentinel-2 imagery (10 m) was employed post-nourishment, potentially affecting shoreline delineation accuracy and the detectability of small-scale changes. Uncertainty parameters also differed between periods, with the pre-nourishment analysis using a 12 m default uncertainty and 95% confidence interval, while post-nourishment used a 6 m uncertainty and 95% confidence interval, limiting direct statistical comparability of significance levels. The absence of field validation—including ground-based GPS measurements and sediment sampling—means that remote sensing-derived shoreline positions could not be verified against on-the-ground conditions. Furthermore, hydrodynamic context, including wave climate, tidal range, and storm event data, was not incorporated into the analysis, which could help explain interannual variability and the persistence of localized erosion hotspots. Future research should address these limitations through integrated field monitoring programs and extended temporal analysis.

➤ *Implications for Coastal Management in Sri Lanka*

The findings of this study offer several actionable insights for coastal managers in Sri Lanka. First, artificial beach nourishment can be highly effective in mitigating erosion along Sri Lankan sandy coasts when properly designed and implemented, as demonstrated by the dramatic reduction in erosional transects and the dominance of

accretion at Calido Beach. This provides empirical evidence to support the continued use of nourishment as a viable coastal protection strategy in the country. Second, long-term monitoring using remote sensing, as employed in this study, provides a cost-effective means of evaluating project performance and identifying erosion hotspots requiring intervention. Such monitoring should be institutionalized as a standard component of future nourishment projects to enable adaptive management. Third, renourishment planning should consider the persistent erosion observed at Transect 384 and other localized hotspots, which may require targeted sediment placement or supplementary structures such as submerged breakwaters to enhance sediment retention in these vulnerable zones. Finally, integration with nature-based solutions—including dune restoration, mangrove planting, and conservation of existing coastal vegetation—could enhance long-term resilience by leveraging natural processes to complement engineered interventions. This hybrid approach aligns with international best practices and may improve the sustainability of coastal protection efforts in Sri Lanka.

V. CONCLUSION

This study assessed the effectiveness of the 2017 artificial beach nourishment at Calido Beach, Kalutara, using multi-temporal satellite imagery and DSAS shoreline change analysis. The results demonstrate that the nourishment intervention has been highly effective in mitigating shoreline erosion:

- Erosional transects decreased from 36.65% to 9.77%
- Accretional transects increased to over 90%
- Overall shoreline change rates increased significantly, reflecting active beach building
- Total shoreline mobility (SCE) was reduced by 65%

These findings support the continued use of beach nourishment as a viable coastal protection strategy in Sri Lanka, while emphasizing the importance of sustained monitoring and adaptive management to address localized erosion hotspots.

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