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Shoreline Change Analysis Using Google Earth Engine (GEE) At Kura-Kura Beach, Bengkayang Regency

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Abstract

Kura-Kura Beach, Bengkayang Regency, is a coastal area experiencing dynamic shoreline changes. This study aims to analyze shoreline changes and their dynamics during the 2013–2025 period using Google Earth Engine (GEE), as well as to determine an appropriate mitigation concept. Landsat-8 satellite imagery was processed using the Normalized Difference Water Index (NDWI) to extract annual shorelines. The extracted shorelines were analyzed using spatial overlay in Quantum GIS (QGIS) to identify sediment loss and sediment addition, and the results were validated through field observations. The results showed that shoreline changes occurred dynamically, with sediment loss ranging from 0.18 to 1.70 ha and sediment addition ranging from 0 to 1.34 ha. The largest sediment loss occurred in 2022, while the largest sediment addition occurred in 2014. Overall, the average sediment loss and sediment addition were relatively balanced, at 0.633 ha and 0.625 ha, respectively. The 2013–2017 period tended to show greater sediment addition, while the 2018–2021 period showed no consistent dominance. The 2022–2025 period was characterized by the largest sediment loss in 2022. Comparison of shoreline changes before and after the jetty showed increased sediment addition around the jetty. Therefore, the jetty is recommended as a potential mitigation concept to support shoreline stability in segments experiencing sediment loss.

Keywords: Shoreline change, Kura-Kura Beach, Google Earth Engine (GEE), sediment loss, sediment addition

1. INTRODUCTION

The shoreline is a dynamic boundary between land and water that continuously changes over time. Changes in shoreline position may occur through the reduction and addition of sediment at different locations and periods. Consequently, shoreline changes do not always occur in a uniform direction along the entire coastal area. Some segments may experience a landward shift, while other segments may simultaneously experience a seaward shift. This condition reflects the dynamic nature of coastal morphology and the spatial variation of shoreline changes.

Kura-Kura Beach is one of the coastal areas in Bengkayang Regency that has experienced shoreline changes. The area is also utilized as a tourism destination, making shoreline stability important for the sustainability of tourism activities and the protection of facilities located near the coast. Changes in shoreline position can affect the condition of coastal land and infrastructure, particularly in segments experiencing significant changes. Therefore, the monitoring and analysis of shoreline changes are important for understanding the spatial and temporal dynamics of the coastal area.

Previous research has examined shoreline changes at Kura-Kura Beach using different methods. Sugiarto analyzed the morphometry of shoreline changes using time-series imagery and identified spatial variations in shoreline changes across different coastal segments [1]. Other research analyzed shoreline changes at Kura-Kura Beach using the CEDAS-NEMOS application and showed that sediment loss and sediment addition occurred simultaneously at different locations [2]. These studies demonstrate that shoreline changes at Kura-Kura Beach are spatially variable and do not occur uniformly along the entire coastal area.

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However, further analysis using a longer observation period and a different spatial analysis approach is required to provide a clearer description of shoreline changes at Kura-Kura Beach. The use of satellite imagery and cloud-based geospatial processing provides an opportunity to analyze shoreline changes efficiently over a relatively long period. Google Earth Engine (GEE) is a cloud-based geospatial analysis platform that enables the processing of large volumes of satellite imagery for environmental monitoring [3]. The Normalized Difference Water Index (NDWI) can be used to distinguish water and land areas, allowing the shoreline to be extracted from satellite imagery. The use of GEE is particularly relevant for long-term shoreline monitoring because it supports consistent processing of multi-temporal imagery within a cloud-based environment, reducing dependence on local computational resources and facilitating repeated analysis over extended observation periods.

Kura-Kura Beach is an important study area because it is a coastal tourism area that is subject to continuous shoreline dynamics. Changes in shoreline position may influence coastal land availability, tourism facilities, and the stability of coastal areas. The availability of multi-temporal satellite imagery provides an opportunity to examine these changes over a relatively long period and to identify spatial differences in shoreline dynamics. In this study, Landsat-8 satellite imagery was processed using Google Earth Engine to extract annual shorelines at Kura-Kura Beach during the 2013–2025 period. The extracted shorelines were subsequently analyzed using Quantum GIS through a spatial overlay approach to identify areas of sediment loss and sediment addition. The analysis was also supported by field observations to validate the results of the satellite-based shoreline extraction. In addition, shoreline changes before and after the presence of the jetty near the research area were compared to provide a basis for recommending a mitigation concept.

Therefore, this study aims to analyze shoreline changes at Kura-Kura Beach, Bengkayang Regency, during the 2013–2025 period, analyze the dynamics of shoreline changes across different observation periods, and determine an appropriate mitigation concept based on the observed shoreline changes. The contribution of this study is the application of a cloud-based, multi-temporal shoreline extraction workflow using GEE combined with spatial overlay analysis to support long-term shoreline monitoring at Kura-Kura Beach.

2. METHODS

2.1. Study Area and Data

The research was conducted at Kura-Kura Beach, Sungai Raya Kepulauan District, Bengkayang Regency, West Kalimantan, Indonesia. The study focused on shoreline changes during the 2013–2025 period. The primary data consisted of Landsat-8 satellite imagery available on the Google Earth Engine platform. The study area was defined using a research boundary polygon covering the coastal area of Kura-Kura Beach.

The research also utilized shoreline extraction results, spatial data processed using Quantum GIS, and field observation data for validation. The main research tools consisted of Google Earth Engine for satellite image processing and shoreline extraction, Quantum GIS for spatial analysis and map preparation, and field observation equipment for validation.

2.2. Satellite Image Processing and Shoreline Extraction

Satellite image processing and shoreline extraction were conducted using Google Earth Engine. Landsat-8 imagery was selected for the study period and clipped according to the research boundary. Image preprocessing was performed to reduce the influence of cloud cover before the calculation of the water index.

The Normalized Difference Water Index was calculated to distinguish water and land areas using the following equation:

$$NDWI = \frac{Green - NIR}{Green + NIR} \quad (1)$$

where Green represents the green spectral band and NIR represents the near-infrared spectral band. The NDWI result was used to identify the boundary between land and water. The extracted shoreline for each observation year was subsequently converted into vector data and exported for further spatial analysis.

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2.3. Shoreline Change Analysis

The extracted shorelines from each observation year were analyzed using a spatial overlay technique in Quantum GIS. The overlay analysis was used to compare the position of shorelines between different years and identify areas experiencing sediment loss and sediment addition.

Sediment loss was identified from areas where the shoreline shifted landward, resulting in a reduction in land area. Sediment addition was identified from areas where the shoreline shifted seaward, resulting in an increase in land area. The area of sediment loss and sediment addition was calculated in hectares.

To analyze the dynamics more clearly, the observation period was divided into three intervals: 2013–2017, 2018–2021, and 2022–2025. The division was used to identify differences in shoreline change patterns across the three observation periods.

2.4. Analysis of Shoreline Changes Before and After the Jetty

The potential use of a jetty as a mitigation concept was analyzed by comparing shoreline changes before and after the presence of the jetty near the research area. The period 2013–2019 was used to represent shoreline conditions before the presence of the jetty, while the period 2020–2025 was used to represent conditions after the presence of the jetty.

The analysis focused on the spatial distribution of sediment loss and sediment addition around the jetty. The comparison was used as an initial basis for assessing the potential of the jetty to support shoreline stability. However, the analysis did not directly establish a causal relationship between the jetty and shoreline changes because hydrodynamic and sediment transport analyses were not included in this study.

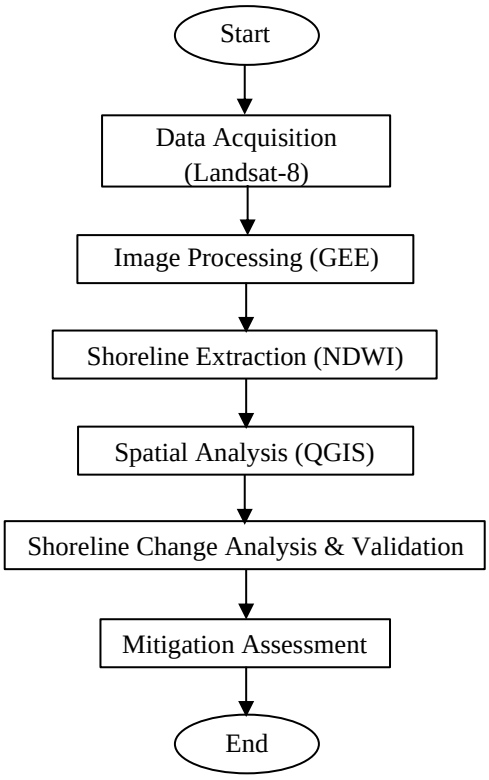


Figure 1. Research workflow

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3. RESULTS AND DISCUSSION

3.1. Shoreline Extraction Results

Based on the shoreline extraction process using Google Earth Engine, annual shoreline change data were obtained for Kura-Kura Beach during the 2013–2025 observation period. The extracted results are presented as the area of sediment loss and sediment addition for each observation year, as shown in Table 1.

Table 1. Annual Sediment Loss and Sediment Addition at Kura-Kura Beach

No	Year	Sediment Loss (ha)	Sediment Addition (ha)
1	2014	0.54	1.34
2	2015	0.54	0.27
3	2016	0.36	0.45
4	2017	0.18	0.54
5	2018	0.63	0
6	2019	0.29	1.15
7	2020	1.16	0.18
8	2021	0.18	0.72
9	2022	1.70	0.45
10	2023	0.18	0.45
11	2024	0.63	0.89
12	2025	1.22	1.07

The analysis used satellite imagery covering the 2013–2025 period. However, the results of shoreline change analysis begin in 2014 because the calculation compares the shoreline position in a given year with the shoreline position in the previous year. Therefore, 2013 serves as the baseline year for calculating shoreline changes in 2014.

The largest sediment loss occurred in 2022, covering 1.70 ha, while the largest sediment addition occurred in 2014, covering 1.34 ha. The average sediment loss during the observation period was 0.633 ha, while the average sediment addition was 0.625 ha. The relatively similar average values indicate that the overall shoreline changes tended to be relatively balanced between sediment loss and sediment addition.

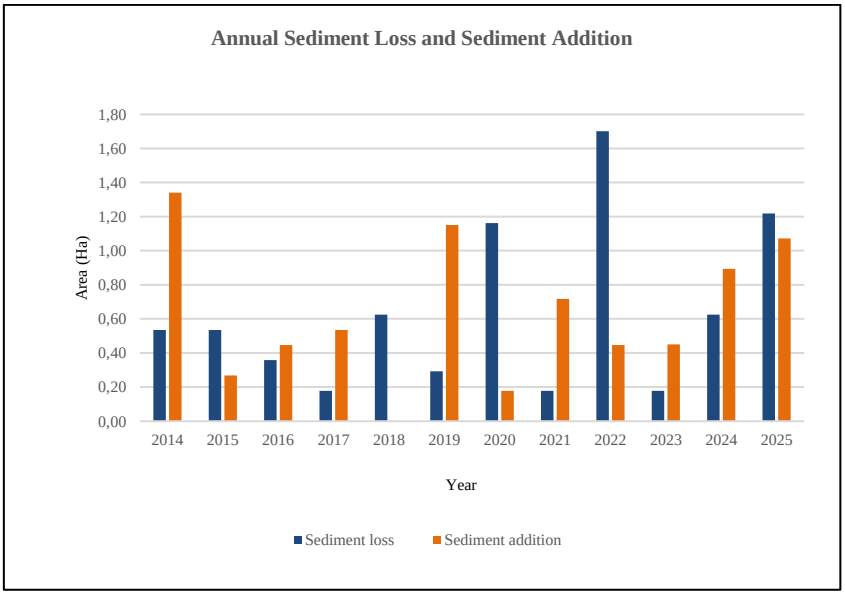


Figure 2. Annual graph sediment loss and sediment addition at Kura-Kura Beach

Figure 2 shows that shoreline changes varied considerably between years. Sediment loss reached its highest value in 2022 at 1.70 ha, while sediment addition reached its highest value in 2014 at 1.34 ha. The annual variation indicates that shoreline dynamics were not characterized by a consistent trend throughout the observation period, with the dominant process changing between years.

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3.2. Shoreline Change During 2013-2017

During the 2013–2017 period, shoreline changes occurred spatially across different coastal segments. The 2014 shoreline showed the most prominent change compared with the other observation years. The sediment addition area in 2014 reached 1.34 ha, which was the largest value during the entire observation period.



Figure 3. Shoreline Change Map of Kura-Kura Beach, 2013–2017

The overlay results for the 2013–2017 period show that shoreline changes at Kura-Kura Beach did not occur uniformly throughout the study area. Some coastal segments experienced a seaward shift, while other segments experienced a landward shift. The shoreline position in 2014 appeared to be the most prominent compared with the other observation years, particularly in several coastal segments. This condition is consistent with the annual extraction results, which showed that sediment addition in 2014 reached 1.341 ha, the highest value during the observation period. In the following years, the shoreline positions were relatively closer to one another, indicating smaller changes compared with the change observed between 2013 and 2014.

The spatial variation observed in this period is consistent with the findings of Sugiarto [1], who identified differences in shoreline changes between coastal segments at Kura-Kura Beach based on time-series imagery. The results also support the findings of Galdi et al. [2], who reported that sediment loss and sediment addition occurred simultaneously at different locations along Kura-Kura Beach. Therefore, the 2013–2017 period indicates that shoreline changes were spatially variable and did not occur uniformly along the entire coastline.

3.3. Shoreline Change During 2018-2021

The 2018–2021 period showed a different pattern compared with the previous period. Sediment loss and sediment addition occurred alternately at different coastal segments without a consistent dominant tendency.



Figure 4. Shoreline Change Map of Kura-Kura Beach, 2018-2021

The spatial distribution of the changes indicates that the shoreline did not experience a uniform shift throughout the entire study area. Some locations experienced sediment loss, while other locations experienced sediment addition. This pattern is consistent with previous research conducted at Kura-Kura Beach, which

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identified the simultaneous occurrence of sediment loss and sediment addition at different locations [2]. The results indicate that shoreline changes during this period were spatially variable, with the magnitude and dominant process differing between coastal segments.

The results demonstrate that shoreline changes during this period remained dynamic. The absence of consistent dominance between sediment loss and sediment addition indicates that the overall shoreline condition continued to reflect a relatively balanced coastal dynamic. Thus, although certain coastal segments experienced more prominent changes, the overall shoreline did not shift uniformly in a single direction.

3.4. Shoreline Change During 2022-2025

The 2022–2025 period showed continued shoreline changes, although the magnitude of change varied between years. The 2022 shoreline showed the most landward position and had the largest sediment loss area during the study period, covering 1.70 ha.



Figure 5. Shoreline Change Map of Kura-Kura Beach, 2022-2025

The overlay results for the 2022–2025 period show that shoreline changes continued to occur at different locations within the study area. The 2022 shoreline appeared to be the most landward in several segments compared with the shorelines from 2023, 2024, and 2025. This condition is consistent with the annual extraction results, which showed that the sediment loss area in 2022 reached 1.701 ha, the highest value during the 2013–2025 observation period. However, sediment addition also continued to occur in the following years, particularly in 2023 and 2024.

The spatially variable pattern observed in this period is consistent with the findings of Sugiarto [1] and Galdi et al. [2], who reported that shoreline changes at Kura-Kura Beach varied between coastal segments and that sediment loss and sediment addition could occur simultaneously. Therefore, although significant sediment loss occurred in several segments, particularly in 2022, the overall shoreline change during 2022–2025 should not be interpreted as a uniform landward shift of the entire coastline. Instead, the results indicate that the shoreline continued to undergo dynamic changes, with the dominant process varying between locations and observation years.

Shoreline dynamics may be influenced by several environmental factors, including wave conditions, longshore sediment transport, currents, sediment availability, tidal variation, and seasonal changes. These processes can redistribute sediment between coastal segments, resulting in sediment loss in some locations and sediment addition in others. The present study does not quantify the individual contribution of these factors because hydrodynamic and sediment transport modelling were not included in the analysis. Therefore, the annual variations identified in this study should be interpreted as observed shoreline change patterns rather than as direct evidence of the influence of a specific environmental factor [4][5].

Another limitation is the spatial resolution of Landsat-8 imagery, which may affect the precision of shoreline extraction, particularly in narrow coastal segments and areas with complex shoreline features. Variations in tidal conditions and image acquisition conditions may also influence the detected land–water boundary. Consequently, the extracted shoreline should be interpreted within the spatial and temporal limitations of the satellite data. Future studies should incorporate higher-resolution imagery, more detailed field measurements, and hydrodynamic or sediment transport modelling to improve the understanding of shoreline dynamics.

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3.5. Shoreline Changes Before and After the Jetty

The comparison of shoreline changes before and after the presence of the jetty was conducted using the 2013–2019 period as the pre-jetty condition and the 2020–2025 period as the post-jetty condition.



Figure 6. Comparison of Shoreline Changes Before and After the Jetty: (a) 2013–2019 and (b) 2020–2025.

Before the jetty period, sediment loss was distributed across several coastal segments, particularly in the central to eastern parts of the study area. Sediment addition was also identified around the jetty area, although the distribution was relatively limited.

After the jetty period, sediment addition around the jetty appeared to become more developed, and the shoreline position in the surrounding area shifted seaward. This pattern indicates that the area around the jetty experienced a tendency toward increased sediment accumulation after the structure was present.

The observed pattern provides a basis for recommending the jetty as a potential mitigation concept for supporting shoreline stability in segments experiencing sediment loss. However, the result should be interpreted as a spatial association rather than direct proof of causation. Further analysis involving hydrodynamic conditions and sediment transport is required to determine the direct influence of the jetty on shoreline changes.

From a practical perspective, the workflow developed in this study can support routine shoreline monitoring by providing an efficient method for identifying coastal segments experiencing sediment loss and sediment addition. Repeated monitoring using multi-temporal satellite imagery can provide information for identifying shoreline segments that require further investigation or management intervention. Structural measures such as jetties may be considered where persistent sediment loss and coastal protection needs are demonstrated. However, structural measures should be evaluated together with ecosystem-based approaches, such as mangrove rehabilitation or other suitable coastal vegetation measures, where environmental conditions allow. A combination of structural and ecosystem-based approaches may provide a more integrated basis for long-term coastal management.

4. CONCLUSION

Kura-Kura Beach, Bengkayang Regency, experienced dynamic shoreline changes during the 2013–2025 period, characterized by variations in sediment loss and sediment addition across different years and coastal segments. The largest sediment loss occurred in 2022, covering 1.70 ha, while the largest sediment addition occurred in 2014, covering 1.34 ha. The average sediment loss and sediment addition were relatively similar, at 0.633 ha and 0.625 ha, respectively, indicating that the overall shoreline changes tended to reflect a relatively balanced coastal condition. The 2013–2017 period tended to show greater sediment addition, the 2018–2021 period showed alternating sediment loss and sediment addition without consistent dominance, and the 2022–2025 period was characterized by the largest sediment loss in 2022. The comparison of shoreline changes before and after the presence of the jetty showed that sediment addition around the jetty tended to increase and the shoreline shifted seaward in the surrounding area. These results support the use of the GEE-based workflow as a practical approach for routine shoreline monitoring, while the observed jetty association should not be interpreted as direct evidence of causation. Future monitoring should combine higher-resolution imagery, field

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observations, and hydrodynamic or sediment transport modelling. For coastal management, structural measures and ecosystem-based approaches may be considered in combination according to local coastal conditions.

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