

INVESTIGATION OF SHORELINE PATTERNS USING SATELLITE-BASED DETECTION: A CASE STUDY OF MY KHE BEACH, CENTRAL VIETNAM

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Abstract

This study investigates long-term shoreline changes at My Khe Beach in central Vietnam using satellite-derived data and the open-source toolkit CoastSat. By analysing shoreline positions from 1989 to 2025 across 26 transects, the research identifies patterns of erosion and accretion, with recent trends showing widespread shoreline retreat and localised beach growth near newly constructed coastal infrastructure. Monthly averaged shoreline data were used to reduce bias from uneven satellite coverage, and linear trend analysis was applied to assess shoreline movement over time. The findings highlight the spatial and temporal variability of shoreline dynamics and demonstrate the potential of remote sensing tools for coastal monitoring in data-scarce regions. This study provides valuable insights for coastal management and emphasises the need for further validation using ground-based survey data to improve accuracy and support sustainable planning across Vietnam's vulnerable shoreline zones.

Keywords: Satellite imagery, Coastsat, Shoreline, Erosion, Climate change.

1. Introduction

Vietnam has more than 3,200 kilometres of coastline [1], stretching from the northern provinces to the southern tip of the country. These coastal regions are home to more than half of the national population and serve as vital hubs for economic activity [2]. From fisheries and tourism to maritime trade and energy, the coastal zones play a crucial role in driving Vietnam's economic development. In addition to population growth and human activities, climate change is a major stressor on Vietnam's coastal regions, leading to a range

of negative impacts such as erosion, flooding, and ecosystem degradation posing risks to both livelihoods and infrastructure [3, 4].



Figure 1. Study area overview: (a) Regional context map, and (b) Location of 26 transects along My Khe Beach

Understanding changes in shoreline patterns is essential for a wide range of applications, including coastal engineering design, beach monitoring, hazard assessment, and long-term coastal management [4, 5, 6]. Traditionally, shoreline surveys have relied on ground-based methods, which, while accurate, are often limited in spatial and temporal coverage. The growing availability of satellite imagery and advancements in remote sensing techniques have

opened new opportunities for large-scale, long-term shoreline monitoring. Satellite-based shoreline detection offers high temporal resolution and broad spatial coverage, making it particularly valuable for assessing shoreline dynamics including remote beach areas [7, 8, 9, 10].

This study focuses on My Khe Beach (Figure 1) which is located about 10 kilometers northeast of downtown Quang Ngai City. The beach stretches approximately 7 kilometers in length. This beach area has recently undergone significant coastal changes [11]. By analysing shoreline patterns and trends over the past three decades using satellite-derived data, the research aims to provide insights into erosion and accretion dynamics along the beach. The findings are intended to support further studies to contribute to resilience strategies for Vietnam's vulnerable shoreline zones, where climate change and human activities continue to intensify environmental stress and shoreline vulnerability.

2. Methodology

In this study, shoreline changes along My Khe Beach were analysed using the open-source tool CoastSat [12]. It has been built with algorithms to automatically retrieve suitable satellite imagery such as Landsat and Sentinel via Google Earth Engine, applying cloud masking and pansharping to enhance image quality. It then uses spectral indices and supervised classification to identify the sand-water boundary, which is interpreted as the shoreline. CoastSat has emerged as a robust toolkit for extracting shoreline positions from publicly available satellite imagery, particularly in sandy beach environments. It has been evaluated by various research institutions and industry groups, demonstrating acceptable accuracy levels - typically within 10 meters of ground truth-making it suitable for long-term shoreline change assessments [4, 9, 10]. Its automation, transparency, and reproducibility further enhance its credibility as a reliable tool for coastal engineering and environmental research.

The shoreline positions were extracted from a rectangular polygon spanning from longitude 108.8822° to 108.9238° and latitude 15.1476° to 15.20663°, encompassing the shoreline zone where satellite-based shoreline extraction and analysis were conducted. This spatial extent was selected to capture the full range of shoreline dynamics across the beach while aligning with the resolution and coverage of available satellite imagery. Since shoreline position

can vary significantly depending on the tidal level at the time of image capture, tidal correction was applied using time-series data from the global tidal model FES2022 [15]. Particularly, FES2022 was used to match each image's timestamp with predicted tide levels, then adjusted shoreline positions horizontally based on tide height and beach slope to reflect mean sea level. For instance, a +0.5 m tide with a 5% slope results in a 10 m landward correction. For this study, the tidal time series were extracted at a reference location with a latitude of 15.17268° and a longitude of 108.895973°, at 15-minute intervals to ensure temporal precision. To investigate the shoreline trends, there are 26 transects used to extract the shorelines over time, enabling the analysis of shoreline change patterns such as erosion and accretion across the entire stretch of the beach.

2.1. Annual mean shoreline position

The annual mean shoreline position was calculated by averaging multiple shoreline profiles for each year. Given that the number of data points varied between individual profiles, a common set of x-values was first established, typically defined as a uniform interval spanning the full spatial extent of all shorelines. Each profile was then interpolated onto this shared line using linear interpolation. Once standardised, the mean shoreline position was computed by averaging the interpolated y-values at each grid point. This approach yields a single representative shoreline for each year, capturing the central tendency of shoreline positions across the dataset.

2.2. Monthly averaged shoreline position and trends

To reduce potential bias in estimating shoreline trends caused by uneven data distribution, long-term trends were calculated using monthly averaged time series instead of raw data. This averaging helps create a more balanced timeline and reduces the impact of data clustering, making the trend analysis more reliable over multiple decades.

The non-uniform temporal sampling of the shoreline time series - primarily results from increased satellite coverage and data availability in recent years. Particularly, there is a higher density of observations toward the latter part of the record. To illustrate the full coverage of satellite imagery available within the study area, Figure 2 provides a visual summary of data availability from 1988 to 2025, with each cell representing a month and colored to

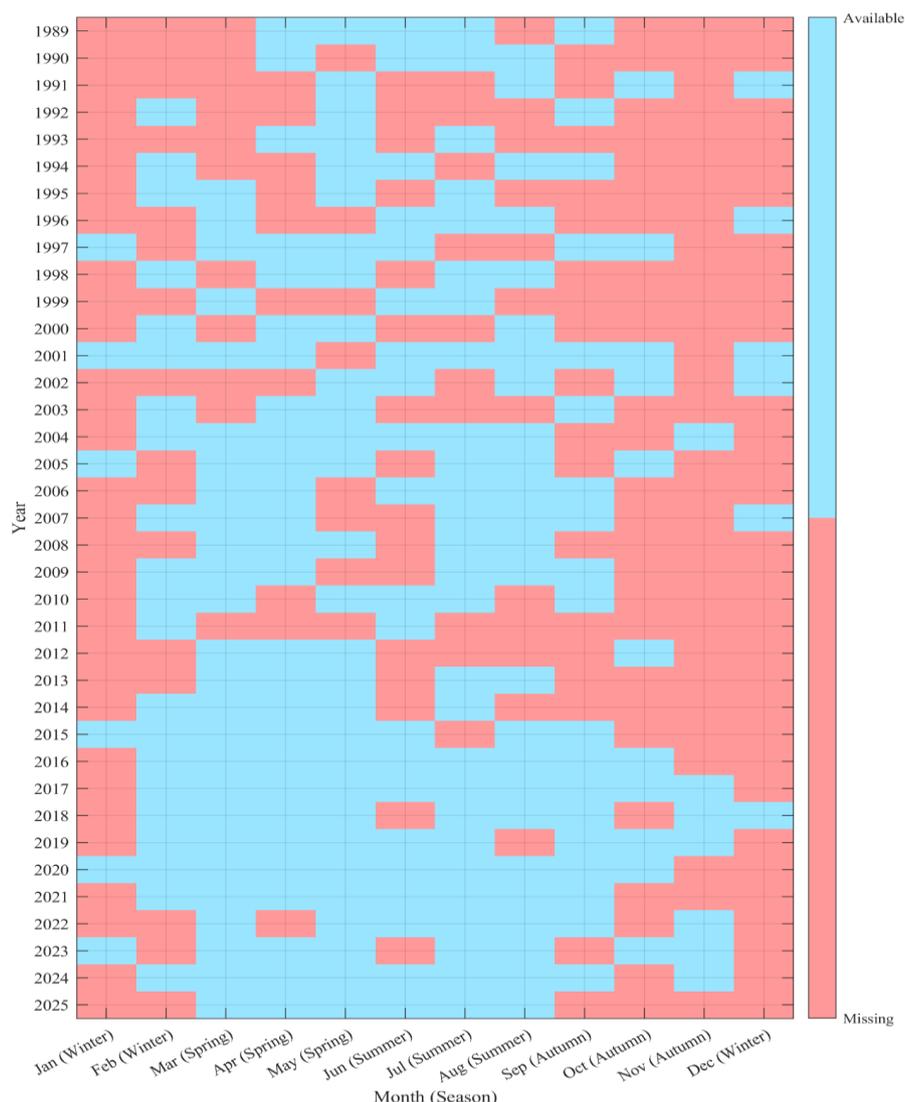


Figure 2. Visual representation of data availability by month and year (1989-2025)

indicate whether data is available (blue) or missing (red). It reveals significant variability in data coverage across years. Notably, years such as 2001, and the period from 2015 forwards show abundant data availability, with most months fully covered. In contrast, years like 1988, 1992, and several years in the mid-to-late 1990s and early 2000s, and 2011 exhibit substantial gaps, particularly at the beginning and end of each year.

Monthly averages of shoreline positions were calculated using a custom function that grouped time-series data by calendar month across multiple years. This allowed for the identification of consistent seasonal patterns in shoreline movement. Prior to averaging, the data were cleaned using an outlier rejection function that filtered out invalid or data

points such as unrealistic shoreline shifts (e.g., >40 m between consecutive points) and poor image classification quality, ensuring only reliable data contributes to the monthly average. This step also included removing NaN values and unrealistic shoreline shifts using a despiking algorithm. Together, these steps ensured that the monthly averages were based on reliable shoreline positions.

In this study, a linear trend analysis was applied to all transects using a method that fits a straight line through the data over a specified period. Based on a review of shoreline variations, which commonly exhibited multi-phase patterns such as up-down-up or down-up-down, each transect was divided into three segments to better capture these temporal trends. Each fitted line provides a slope and an intercept, where the slope shows how fast

and in which direction the shoreline is changing. A positive slope means the shoreline is moving seaward, indicating accretion or beach growth. A negative slope means the shoreline is retreating landward, which suggests erosion and loss of beach area.

3. Results

3.1. Annual mean shoreline patterns

To provide an overview of shoreline patterns, Figure 3 plots a satellite view of a coastal region, overlaid with shoreline variations in the form of the median annual shoreline positions from 1988 and 2025 and the location of selected transects for linear shoreline trend extractions.

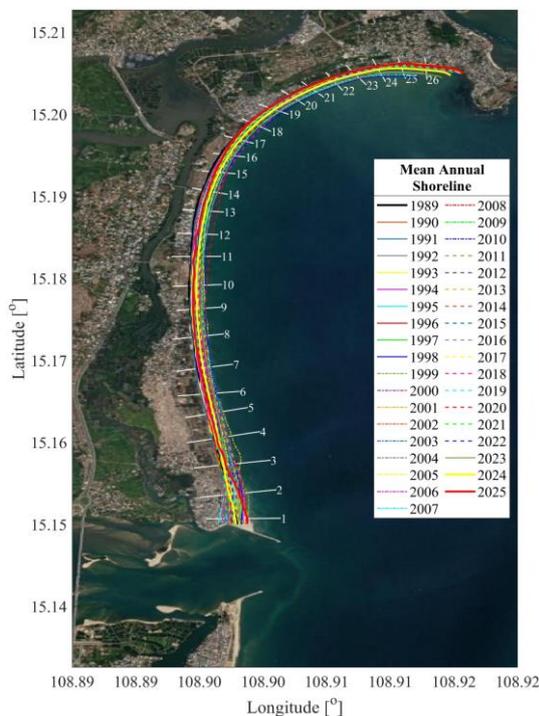


Figure 3. Annual mean shoreline portions from 1989-2025 and location of transects

The first year (1989) and the two most recent years (2024 and 2025) were highlighted using thick lines in black, yellow, and red respectively to emphasise key points in the shoreline trend analysis." As shown, in 2024 and 2025, the shorelines were moved closer to the shore than other years indicating that the erosion trend in the most recent years has been well captured in the shoreline data extracted from satellite imagery. It can also be seen from the mean annual shoreline patterns that, in recent years, the shorelines near Transect 1 and Transect 2 have shifted further offshore, indicating accretion or beach growth in this area. This change is likely due to the construction of a new

breakwater near Transect 1, which has influenced sediment deposition and shoreline stability.

3.2. Monthly shoreline trends across all transects

To provide further insight into the shoreline patterns along the beach, Figure 3 presents a detailed visualisation of shoreline changes across 26 transects from 1990 to 2025. Each transect is represented by a horizontal bar segmented by time, with color-coded sections indicating the nature of change: green for accretion (beach growth) and red for erosion (shoreline retreat). The x-axis spans the years, while the y-axis lists the transects from Transect 01 to Transect 26. Numerical values within each segment quantify the magnitude of change in meters. A positive value means the shoreline has moved seaward, suggesting beach growth, while a negative value indicates landward retreat, reflecting erosion or loss of beach area.

Notably, in the most recent years, 22 out of 26 transects are experiencing erosion, indicated by red bars with negative values. The erosion rates vary, with some transects showing mild retreat (e.g., -0.77 at Transect 13) and others showing more significant shoreline loss (e.g., -8.21 at Transect 20). This widespread erosion trend suggests a regional pattern of shoreline retreat in recent years, potentially driven by natural coastal processes, sea level rises.

In the early transects (Transect 01 to Transect 07), we observe a mix of erosion and accretion phases. For example, Transect 01 experienced significant erosion between 1990 and 2005, with shoreline retreat values of -5.64 and -3.50 meters, followed by a strong accretion phase of +32.65 meters leading up to 2025. Transect 02 shows relatively minor but consistent accretion throughout the period. Transects 03 to 07 display alternating trends, with early accretion followed by erosion. Transects 08 through 12 continue this pattern of alternating shoreline behaviour. These transects show moderate accretion in the early years, such as +4.32 to +5.07 meters, followed by erosion phases ranging from -3.35 to -6.48 meters. Moving further down the transect list, Transects 13 to 16 exhibit similar alternating trends but with slightly reduced magnitudes. Accretion values range from +2.79 to +4.35 meters, while erosion values are generally between -1.06 and -3.58 meters. These patterns suggest that while some areas are relatively stable, others are more dynamic and sensitive to environmental changes.

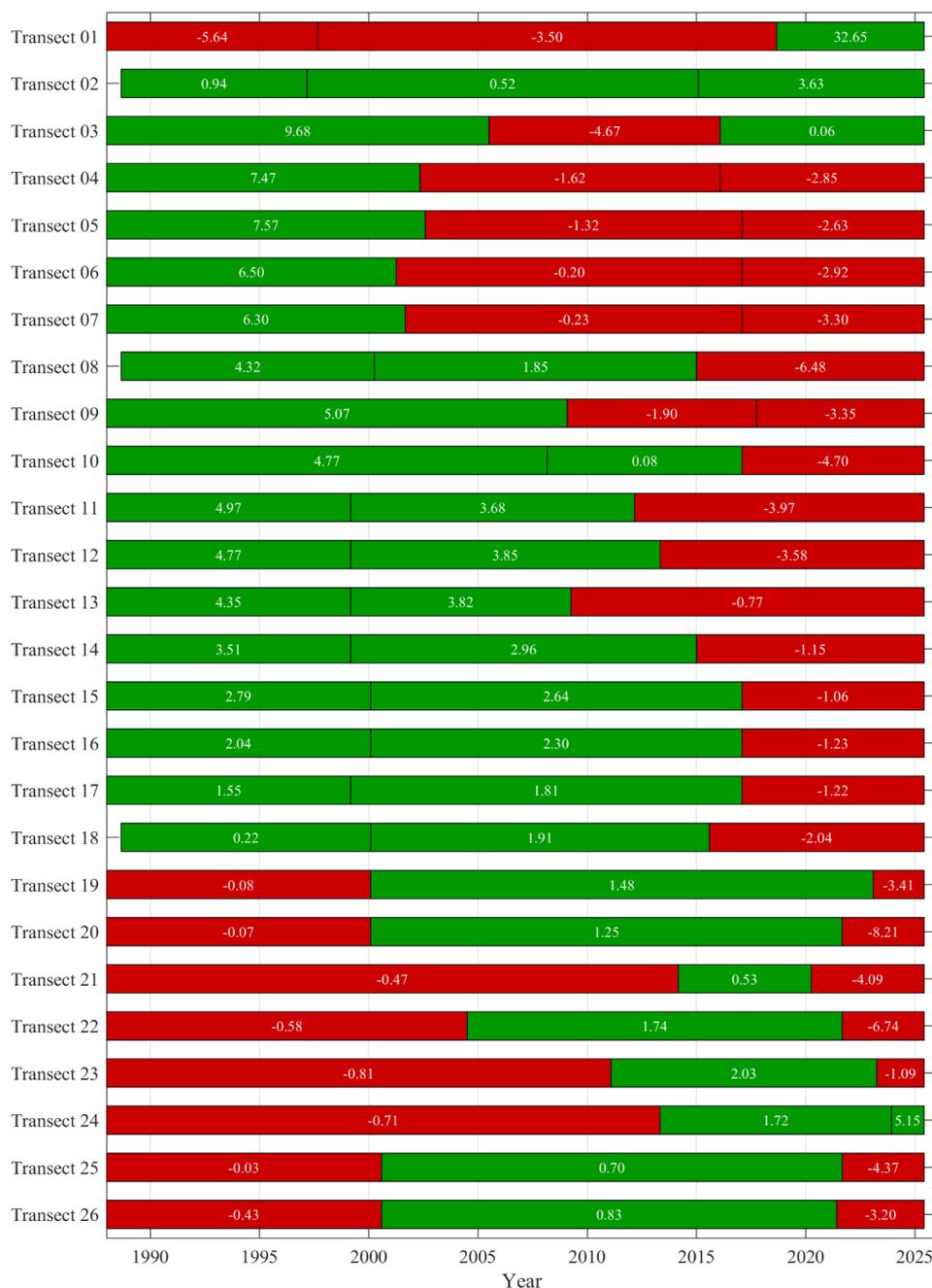


Figure 4. Shoreline change rates (m/year) for 26 transects from 1989 to 2025, divided into three-time segments. Green indicates accretion (positive change), red indicates erosion (negative change)

The final group of transects (Transect 17 to Transect 26) shows more complex and varied shoreline behaviour. Some transects exhibit strong accretion followed by sharp erosion, while others maintain a relatively balanced profile. For instance, Transect 20 shows a significant erosion event of -8.21 meters, indicating a possible hotspot of shoreline retreat. These later transects may be influenced by more recent coastal developments, sea-level rise, or

changes in wave energy distribution.

Overall, information presented in Figure 4 highlights the spatial and temporal variability of shoreline changes across the study area. It underscores the importance of site-specific analysis when assessing coastal dynamics and reinforces the need for continuous monitoring to inform sustainable coastal management strategies.

4. Discussion and conclusion

This study applies a shoreline detection technique using the open-source toolkit Coastsat to examine shoreline changes over multiple decades, focusing on a case study at My Khe Beach in central Vietnam. While this method is applied to a specific location, it is adaptable to other similar beach environments, especially where historical shoreline survey data is unavailable. By using satellite imagery and automated processing, Coastsat enables consistent and repeatable shoreline extraction, offering valuable insights into long-term shoreline changes.

However, it is noted that CoastSat is primarily designed for detecting shorelines on sandy beaches using satellite imagery from Landsat and Sentinel-2. While it performs well in these environments, its accuracy can be compromised in areas with rocky coasts, vegetation, tidal flats, or human-made structures, where the sand-water boundary is less distinct. Furthermore, the toolkit relies on optical satellite imagery, which is affected by cloud cover, shadows, and water turbidity, potentially leading to gaps or errors in shoreline detection [12, 16, 17].

Another limitation is the spatial resolution of the satellite imagery. For instance, the old Landsat imagery is usually coarse, which may not be sufficient for detecting fine-scale shoreline changes or narrow beach features. Furthermore, the toolkit does not inherently account for vertical changes (e.g., dune erosion), focusing only on the horizontal shoreline position. This limits the ability to assess volumetric changes or sediment budgets, which are important for understanding coastal vulnerability and resilience [9, 12, 13].

It is important to note that a key limitation of this study is the absence of surveyed beach profile data to validate the shoreline time series detected by Coastkit. As a result, the accuracy of the satellite-derived shorelines cannot be quantified at this stage. This limitation is particularly significant for coastal engineering and management decisions, where even small positional errors in shoreline data can lead to misinterpretation of erosion or accretion trends.

Additionally, it is important to quantify the uncertainty associated with the shoreline positions extracted using CoastSat. Published validation studies indicate that CoastSat-derived shorelines typically have a horizontal positional uncertainty of approximately ± 10 metres compared to ground-truth survey data [12, 15]. As a result, the shoreline changed

rates reported in this study should be interpreted with this uncertainty in mind, and confidence in the results is limited by this positional accuracy.

To overcome these limitations, future work should focus on validating CoastSat outputs using survey data such as from similar beach areas in Vietnam [9]. Such data can be collected through various methods, including LiDAR or newer drone-based surveying techniques [18, 19]. Additionally, it may be beneficial to use locally measured sea level data to generate the tidal time series required by CoastSat, rather than relying on global tidal databases. Combining CoastSat-derived shorelines with numerical models or machine learning techniques [20] could further enhance predictive capabilities and support scenario-based coastal planning, both for the study area and across Vietnam more broadly.

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