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Long-Term Shoreline Dynamics and Their Implications for Coastal Spatial Management

Dessy Mayasari[1], Ida Zubaidah[2], I Gede Wyana Lokantara[3], Robby Firmansyah[4]

[1]*Public Administration, Faculty of Law, Social and Political Sciences, Universitas Terbuka, Indonesia*
[2]*Sociology, Faculty of Law, Social and Political Sciences, Universitas Terbuka, Indonesia*
[3]*Department of Architecture, Faculty of Engineering, Universitas Negeri Medan, Indonesia*
[4]*Urban and Regional Planning, Faculty of Science and Technology, Universitas Terbuka, Indonesia*

**Corresponding Author: Dessy Mayasari*
E-mail: dessy@ecampus.ut.ac.id

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Abstract

Coastal development increasingly takes place in environments where dynamic shoreline processes undermine the permanence of spatial planning and infrastructure. This research investigates long-term shoreline change along the Tanjung Pandan coast, Indonesia, and assesses its implications for coastal management, with Tanjung Pendam serving as a strategic urban waterfront. A quantitative spatial-descriptive methodology, combined with planning interpretation, was employed using multi-temporal shoreline data from 2000, 2013, and 2025. Abrasion and accretion were spatially delineated and proportionally quantified, while the Integrated City Planning framework was used to analyze coastal-management conditions and planning trajectories. Results indicate that abrasion constitutes 91.86% of the total mapped shoreline-change area, whereas accretion accounts for only 8.14%, revealing a significant imbalance in coastal transformation. At Tanjung Pendam, shoreline dynamics coincide with tidal flooding and spatially variable coastal protection, underscoring a gap between coastal mobility and relatively static planning decisions. The findings do not directly attribute observed shoreline change to sea-level rise but highlight its significance as a future adaptation factor. This research demonstrates that historical shoreline data can serve as a practical foundation for adaptive coastal spatial management by enhancing the integration of shoreline monitoring, spatial planning, and differentiated coastal-management strategies.

Introduction

Coastal areas are dynamic spatial systems where the boundary between land and sea is continuously changing due to erosion, accretion, sediment movement, tidal processes, and human activities (Adebisi et al., 2021; Darwish, 2024; Nath et al., 2023). In urban coastal settings, these physical processes have significant spatial implications, as tourism facilities, public spaces, infrastructure, commercial activities, and settlements are often concentrated near the shoreline. Recent shoreline studies indicate that multi-temporal spatial analysis effectively reveals the magnitude and distribution of abrasion and accretion, providing an empirical foundation for coastal management. Research in Indonesian coastal regions has documented considerable spatial variation in shoreline retreat and advance, highlighting the need for ongoing shoreline monitoring to reduce physical and socioeconomic exposure (Kirby et al., 2021; Luthfiyani et al., 2026; Al-Marri et al., 2026). Therefore, shoreline dynamics should be regarded not only as geomorphological processes but also as spatial evidence critical to

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decisions regarding the future use and management of coastal land (Mishra et al., 2026; Vardopoulos et al., 2023; Wang et al., 2026).

This issue is particularly significant in coastal cities, where waterfront areas serve as both environmental interfaces and strategic development zones (Amado et al., 2026; Hegazy & Imam, 2026; Garau et al., 2026). Recent research demonstrates that shoreline dynamics influence tourism development, land availability, and the long-term stability of coastal functions. Consequently, coastal spatial planning requires greater integration of land–sea interactions, rather than treating terrestrial development and marine processes as separate systems. Evidence from coastal planning research indicates that such integration enhances spatial planning's capacity to identify conflicts and accommodate environmental change in development decisions. This relationship is especially pertinent in contexts where economic and tourism development intensifies along coastlines undergoing measurable physical transformation (Zhang & Wang, 2026; Li et al., 2025; Lin et al., 2026).

Tanjung Pandan, the urban centre of Belitung Regency, Indonesia, exemplifies this condition. The coastal area supports tourism, recreation, economic activities, public spaces, and urban infrastructure. In this context, Tanjung Pandan Beach holds strategic significance because of its proximity to the city center and its role as a destination for tourism and public use. The Integrated City Planning (ICP) framework designates approximately 14.42 hectares of Tanjung Pendam in Parit Village, Tanjung Pandan District, as a development area. This development aligns with broader priorities for urban growth, tourism enhancement, urban renewal, and coastal-based strategic tourism initiatives in Tanjung Pandan. However, this strategic development is occurring within a dynamic coastal environment. Multi-temporal spatial mapping for 2000, 2013, and 2025 identified 202,328.93 m^2 of abrasion and 17,923.99 m^2 of accretion, representing a total mapped shoreline-change area of 220,252.92 m^2. The ICP further documents ongoing coastal pressures at Tanjung Pendam, including tidal flooding, particularly between December and February, which can disrupt major events, and the deterioration of several coastal protection structures designed to mitigate abrasion risk (Baltranaite et al., 2020). These challenges are especially significant given the area's predominantly low topography, with an average elevation of five meters or less above sea level. Collectively, these observations indicate that strategic coastal development is proceeding within a spatial environment whose physical configuration is changing (Adebisi et al., 2021; Chalazas et al., 2026; Nugroho et al., 2025; Turki et al., 2025).

Despite increasing research on shoreline change, a significant analytical gap persists. Many studies quantify shoreline displacement, abrasion, accretion, or erosion rates, while others assess implications for land-use change or coastal vulnerability (Darmiati & Atmadipoera, 2020). Recent research has begun to link shoreline dynamics with spatial planning, such as identifying erosion hotspots that intersect with planned land uses. However, translating straightforward long-term shoreline evidence into practical guidance for strategic urban coastal development remains a challenge, particularly in contexts where detailed vulnerability modeling or complex indices are unavailable or unnecessary (Anfuso et al., 2021). This situation highlights an evidence-to-planning gap between measurable coastal transformation and its practical interpretation within ongoing development initiatives. This study addresses this gap using a deliberately transparent methodology. Instead of developing a new vulnerability index or assigning scores to planning policies, it calculates the proportional contribution of abrasion and accretion to the total area identified as experiencing shoreline change. The resulting spatial patterns are interpreted and examined in relation to the strategic development context defined by the ICP. The objective is not to evaluate the ICP's performance, but to identify planning implications that arise when strategic coastal

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development is considered alongside empirical evidence of long-term shoreline transformation (Arjasakusuma et al., 2021).

Such integration is increasingly vital for sustainable coastal management. Urban coastal development must balance economic and tourism objectives with environmental change, public safety, spatial resilience, and the long-term protection of coastal resources. Failing to incorporate evolving coastal conditions into spatial decisions may hinder efforts to build resilient settlements, strengthen environmental adaptation, protect coastal ecosystems, and sustain productive coastal economies (Awad & El-Sayed, 2021). This study's novelty lies in translating a straightforward, measurable pattern of shoreline transformation into policy-relevant spatial evidence. Accordingly, this study quantifies the magnitude and proportional dominance of abrasion and accretion along the Tanjung Pandan coast from 2000 to 2025 and examines their implications for the strategic development and sustainable management of Tanjung Pendam Beach.

Methods

Research Approach

A quantitative spatial-descriptive approach, combined with planning interpretation, was employed to examine long-term shoreline dynamics and their implications for strategic coastal development in Tanjung Pandan, Belitung Regency, Indonesia. The analysis was structured at two interconnected spatial levels. At the meso scale, shoreline changes along the Tanjung Pandan coastal area were assessed over 25 years, from 2000 to 2025. At the strategic-area scale, the findings were interpreted in relation to Tanjung Pendam Beach, a key tourism and public-space development area within the broader Tanjung Pandan coastal system (Gopinath et al., 2023). The research design clearly distinguished between measuring physical coastal change and interpreting development planning. Shoreline change was the primary empirical component and was measured quantitatively through the spatial extent of abrasion and accretion. In contrast, the Integrated City Planning (ICP) document established Tanjung Pendam's formal development context but was not scored, weighted, or evaluated as a policy-performance variable. This approach ensured that physical findings were derived exclusively from measurable spatial data, while the planning analysis focused on interpreting how those findings relate to the strategic functions and development directions identified in the ICP (De Paula et al., 2021).

The study first established the magnitude and spatial pattern of shoreline change, then examined its relevance to strategic coastal development. This approach was chosen because the study does not aim to develop a new vulnerability index or determine the causal mechanisms of shoreline change. Instead, it provides a transparent connection between measurable long-term coastal transformation and the planning considerations relevant to development in a dynamic coastal environment.

Data Collection

Two main datasets were utilized: multi-temporal shoreline data and coastal development planning data. The spatial dataset comprised shoreline positions for 2000, 2013, and 2025, representing a 25-year observation period. Landsat imagery was used to identify the land–water boundary, with the Modified Normalized Difference Water Index (MNDWI) supporting shoreline extraction. Shoreline-change processing was conducted using the Digital Shoreline Analysis System (DSAS), consistent with procedures established in the original research dataset. The primary spatial data consisted of shoreline positions for the three observation years and the resulting polygons classified as abrasion and accretion areas. These data were processed within a Geographic Information System (GIS) environment to calculate the area of

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each change category in square meters and to represent their spatial distribution along the Tanjung Pandan coastline. The three observation years were selected to characterize long-term shoreline transformation rather than short-term seasonal variations.

Planning data were sourced from the Integrated City Planning of Belitung Regency, with particular emphasis on the Major Project for Tanjung Pendam Beach. The ICP identifies an approximately 14.42-hectare development area in Parit Village, Tanjung Pandan District. The document also outlines the area's strategic functions and development directions, including tourism development, urban restructuring, *urban renewal*, and coastal-based tourism development. Information on existing coastal conditions reported in the ICP was collected as supporting evidence for the planning interpretation. This included documented tidal flooding, seasonal limitations on major events, and deterioration of coastal protection structures at several locations. These observations were not included as quantitative variables in the shoreline calculation but were used solely to provide contextual evidence when interpreting the relevance of shoreline dynamics to the development and management of Tanjung Pendam.

Data Analysis and Indicators

The analysis examined three directly observable spatial indicators: shoreline change, abrasion area, and accretion area. These indicators were chosen because they can be derived from the multi-temporal shoreline dataset without additional weighting or assumptions.

Table 1. Shoreline Change Indicators and Analytical Parameters

Indicator	Measurement	Unit	Analytical purpose
Shoreline change	Differences among shoreline positions in 2000, 2013, and 2025	Spatial	Identifying the spatial pattern of coastal change
Abrasion	Area classified as land loss	m²	Measuring the extent of abrasion
Accretion	Area classified as land formation	m²	Measuring the extent of accretion

The magnitude of abrasion and accretion from the mapped polygons. The relative contribution of each to the total area identified as shoreline change was subsequently calculated using a proportional measure:

$$P_i = \frac{A_i}{A_{abr} + A_{acc}} \times 100$$

where P_i is the proportion of shoreline-change category iii (%), A_i is the area of either abrasion or accretion (m²), A_{abr} is the total mapped abrasion area (m²), and AA_{acc} is the total mapped accretion area (m²). This calculation quantifies each category's contribution to the total mapped shoreline change area. Because this is a descriptive proportional measure rather than a newly developed index, we applied no weighting, scoring, or classification threshold. The category with the higher percentage was interpreted as the dominant form of shoreline transformation during the observation period.

The resulting percentages do not indicate the proportion of the entire Tanjung Pandan coastal territory affected by abrasion or accretion. Instead, they reflect only the composition of the area identified through spatial analysis as experiencing shoreline change. This definition prevents overinterpretation of the proportional results and ensures consistency between the calculation and the mapped spatial data. The analysis was limited to describing the magnitude, proportion, and spatial pattern of observed shoreline change. It did not attribute the observed abrasion or

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accretion to sea-level rise, climate change, tidal processes, sediment dynamics, or anthropogenic intervention (Manno et al., 2022). Establishing such causal relationships would require additional hydrodynamic, oceanographic, sedimentological, and long-term sea-level observations, which were beyond this study's scope.

Spatial Analysis and Planning Interpretation

Spatial analysis connected the quantitative shoreline results to their geographical and planning context. The primary spatial output was a multi-temporal shoreline map depicting shoreline positions in 2000, 2013, and 2025, along with mapped abrasion and accretion areas. The authors interpreted this map alongside proportional calculations to identify the spatial distribution and dominant forms of coastal transformation. The map provided geographical evidence of shoreline changes, while the quantitative analysis determined the relative magnitude of abrasion and accretion (Meziane et al., 2024). Together, these elements formed the empirical foundation for the initial results. The second stage assessed the planning significance of these findings using the ICP map of the Tanjung Pendam development area. The ICP map was not analyzed through quantitative overlay scoring or policy evaluation. Instead, it established Tanjung Pendam's spatial and functional position within the broader coastal environment considered in the shoreline analysis. This approach enabled interpretation of coastal dynamics at the Tanjung Pandan meso scale in relation to a strategic area characterized by concentrated tourism, public space, and urban development functions.

The planning interpretation addressed three aspects documented in the ICP: the spatial extent of the development area, its strategic development functions, and existing coastal constraints. Development directions were evaluated alongside empirical shoreline findings to assess their relevance for future coastal development and management. Information on tidal flooding and existing coastal protection served as contextual evidence supporting this interpretation, rather than as evidence of a causal relationship with the mapped shoreline changes. These two stages of analysis were complementary. The first stage identified the physical changes along the coastline and determined the dominant type of change. The second stage analyzed the relevance of these changes for the development of Tanjung Pendam as a strategic coastal area. No assumptions were made regarding a direct causal relationship between shoreline change and deficiencies in the ICP, nor was the ICP evaluated for effectiveness. The analysis focused on identifying planning considerations that arise when strategic development occurs within a coastline exhibiting measurable long-term change.

The methodological innovation is the direct translation of empirical shoreline evidence into planning-relevant spatial interpretation. Instead of employing a complex composite index or policy-scoring mechanism, this approach maintains a straightforward and verifiable measure of coastal transformation within a real strategic development context. This distinction between measured coastal change, documented development direction, and the planning implications of their spatial relationship provides a practical foundation for discussing adaptive and sustainable management of strategic urban coastal areas.

Results and Discussion

Long-Term Shoreline Dynamics of the Tanjung Pandan Coast, 2000-2025

Multi-temporal analysis reveals a significant transformation of the coastal boundary along the Tanjung Pandan urban coast from 2000 to 2025. Shoreline positions recorded in 2000, 2013, and 2025 offer a 25-year perspective that enables observation of the persistence and direction of spatial change. This temporal dimension is especially relevant in urban coastal environments, where the shoreline serves not only as a physical boundary between land and sea but also as the interface with tourism activities, public spaces, infrastructure, and other

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urban functions, which typically have more permanent spatial locations than the coastal boundary itself (Satiroğlu, 2024). Comparison of the three observation years indicates that the coastline did not remain stable during the study period. Both abrasion and accretion are evident, demonstrating that coastal transformation involved concurrent processes of land loss and land formation. However, these processes differed significantly in spatial extent. The intermediate shoreline in 2013 further illustrates that a configuration observed at a single point in time does not necessarily persist through to 2025. This temporal variation underscores that a seaward shoreline position or newly formed coastal land at an intermediate date should not be interpreted as evidence of permanent coastal stability.

The shoreline dataset comprised three observation years (2000, 2013, and 2025), defining two observation intervals: 2000-2013 and 2013-2025. The mapped shoreline changes across these intervals to distinguish temporal patterns of abrasion and accretion. However, the current results do not report interval-specific abrasion and accretion areas separately. Therefore, the total mapped areas reported below refer to the overall 2000-2025 observation period. Figure 1 depicts the multi-temporal shoreline configuration. The 2000 shoreline serves as the initial spatial reference, while the 2013 and 2025 shorelines illustrate subsequent changes in the position and geometry of the coastal edge. The final spatial representation differentiates areas classified as abrasion and accretion throughout the observation period. The abrasion polygon occupies a substantially larger area than the accretion polygon, indicating an asymmetric pattern of coastal transformation. The spatial pattern in Figure 1 yields two key observations. First, coastal change is not characterized by a uniform shoreline displacement in a single direction. Variations in shoreline geometry across the three observation years reveal a more complex spatial adjustment of the coastal boundary. Second, while accretion occurred during the observation period, particularly in the intermediate configuration, the final mapped change pattern is dominated by a much larger area of abrasion. The coexistence of these processes confirms the spatial dynamism of the Tanjung Pandan coast, and their contrasting extents indicate a significant imbalance between land loss and land formation.

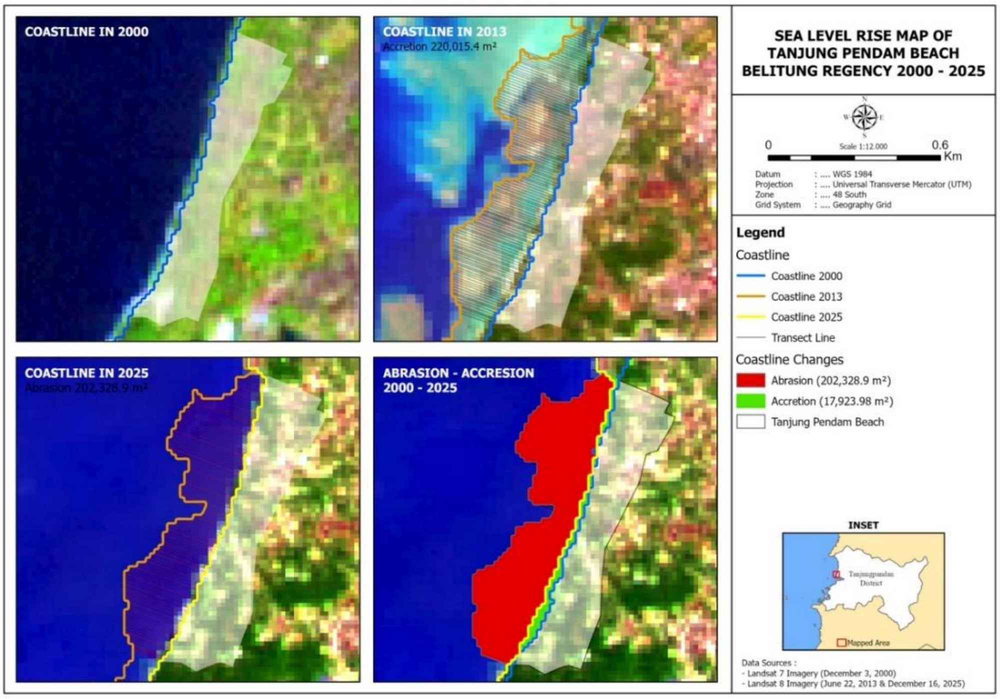

Figure 1.Multi-temporal shoreline change and spatial distribution of abrasion and accretion along the Tanjung Pandan coast, 2000–2025.

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This distinction is critical for interpreting the 2013 shoreline. Accretion indicates that certain segments of the coastal edge experienced seaward development during the study period. However, the 2025 configuration demonstrates that an intermediate shoreline condition should not serve as a permanent reference for spatial development. In practical terms, coastal land that appears stable or newly formed during one observation period may still be part of an evolving coastal system. Consequently, long-term spatial decisions should incorporate the shoreline's historical configuration rather than relying solely on its position at a single date. The magnitude of this imbalance using the proportional calculation defined in Equation (1). Over the 2000-2025 observation period, the total mapped shoreline-change area was 220,252.92 m², comprising 202,328.93 m² of abrasion (91.86%) and 17,923.99 m² of accretion (8.14%). These percentages represent the relative contributions of abrasion and accretion to the total mapped shoreline-change area, rather than the proportions of the entire Tanjung Pandan coastal territory. The mapped results indicate that abrasion accounted for the larger share of the identified shoreline change in table 2.

Table 2. Magnitude and Proportion of Mapped Shoreline Change, 2000-2025

No	Shoreline change	Area (m²)	Proportion (%)
1	Abrasion	202,328.93	91.86
2	Accretion	17,923.99	8.14
3	Total	220,252.92	100.00

The quantitative results reinforce the spatial evidence presented by the map. Abrasion constitutes more than ninety percent of the area identified as shoreline change, demonstrating a pronounced dominance of land loss within the mapped transformation. Although accretion is present, it accounts for less than ten percent of the total. This difference is substantial, indicating that the two processes represent markedly different proportions of the observed coastal transformation. The proportional values must nevertheless be interpreted according to their analytical definition. The 91.86% abrasion proportion does not indicate that 91.86% of the entire Tanjung Pandan coastal area has been eroded. It indicates that abrasion constitutes 91.86% of the area specifically identified as having experienced shoreline change. This distinction prevents generalizing the proportional result beyond the mapped change area and ensures consistency with the methodology's calculation. More importantly, combining the map and proportional analysis reveals a spatial issue relevant to coastal management. The physical coastline is temporally mobile, whereas urban development is generally implemented within relatively fixed spatial boundaries. Tourism facilities, public spaces, roads, utilities, and other permanent investments are expected to occupy defined locations for extended periods. A coastline dominated by abrasion within its mapped change area therefore creates a planning condition in which the temporal behaviour of the physical boundary should be considered alongside the permanence of development decisions.

This finding does not imply that all coastal development should be restricted. Rather, it indicates that the historical mobility of the shoreline should become part of the spatial evidence used to determine how coastal space is managed. Development intensity, the location of permanent facilities, waterfront infrastructure, coastal protection, and the maintenance of transitional space between urban functions and the sea require particular attention where historical shoreline transformation is evident. The results also suggest that relying solely on the most recent shoreline position may overlook the longer-term spatial behaviour of the coastal edge. The findings should also be distinguished from causal interpretation of sea-level rise. Although the map was developed within a broader sea-level-rise research context, the spatial evidence analyzed here directly demonstrates shoreline change, abrasion, and accretion. It does

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not independently demonstrate that sea-level rise caused the observed 2000–2025 transformation. Establishing such attribution would require additional observations of long-term sea-level trends, tides, waves, sediment transport, and hydrodynamic processes. The present findings are therefore interpreted as empirical evidence of coastal dynamics that is relevant to adaptation and spatial management, rather than as a direct measurement of the effect of sea-level rise.

The spatial implications are particularly significant in the context of Tanjung Pendam, where strategic tourism and public-space functions are concentrated within the broader Tanjung Pandan coastal system. The ICP identifies Tanjung Pendam as a focal point for tourism enhancement, urban restructuring, and *urban renewal*. Concurrently, the area experiences seasonal tidal flooding and deterioration of coastal protection structures at several locations. While these conditions cannot be directly attributed to the calculated abrasion proportion, their coexistence with long-term shoreline transformation underscores the importance of considering coastal dynamics in future development decisions. The principal concern is not solely the numerical dominance of abrasion, but the potential disconnect between a changing physical coastline and spatial development based on relatively fixed land boundaries. For a strategic waterfront such as Tanjung Pendam, the evidence indicates that tourism development, public-space improvement, infrastructure investment, and coastal protection should be planned with consideration of the long-term trajectory of shoreline change. The observed dominance of abrasion provides a measurable physical basis for this approach (Šimac et al., 2021). In this context, sustainable coastal management requires not only the enhancement of waterfront functions but also the alignment of development decisions with the spatial dynamics of the coastal environment.

Challenges and Policy Implications for Coastal Management in Tanjung Pandan

Long-term shoreline dynamics along the Tanjung Pandan coast demonstrate that coastal management must address a physical boundary subject to temporal change. This challenge is amplified in urban coastal environments, where tourism, public spaces, infrastructure, and economic activities rely on stable spatial arrangements. At the local scale, Tanjung Pendam exemplifies this issue, as intensive public use and strategic urban functions intersect with shoreline variability and existing coastal protection infrastructure. Consequently, the management challenge extends beyond physical shoreline change to encompass maintaining diverse coastal functions within a dynamic environmental system.

Current conditions at Tanjung Pendam indicate that coastal protection measures are already integrated into management strategies. The ICP identifies seawalls as key structures designed to mitigate abrasion and tidal flooding. However, the condition of these seawalls varies across different sections; some are well-maintained, while others are damaged or lack continuous protection. Field documentation highlights further variation in waterfront conditions, including areas where protection structures interface directly with public spaces and sections with alternative forms of physical protection. These observations suggest that coastal protection in Tanjung Pendam functions as a spatially heterogeneous system.

The spatial variation illustrated in Figure 2 gains significance when analyzed alongside historical shoreline data. This evidence does not establish a causal relationship between damaged or absent seawalls and observed abrasion, nor does it suffice to evaluate the engineering performance of specific structures. Instead, the simultaneous occurrence of shoreline transformation and varied protection conditions highlights a broader management issue: coastal change, protection infrastructure, and urban functions are spatially interconnected and should not be managed in isolation. Coastal protection must therefore be

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addressed within the context of the overall coastal system, rather than as isolated responses to individual damaged sites.

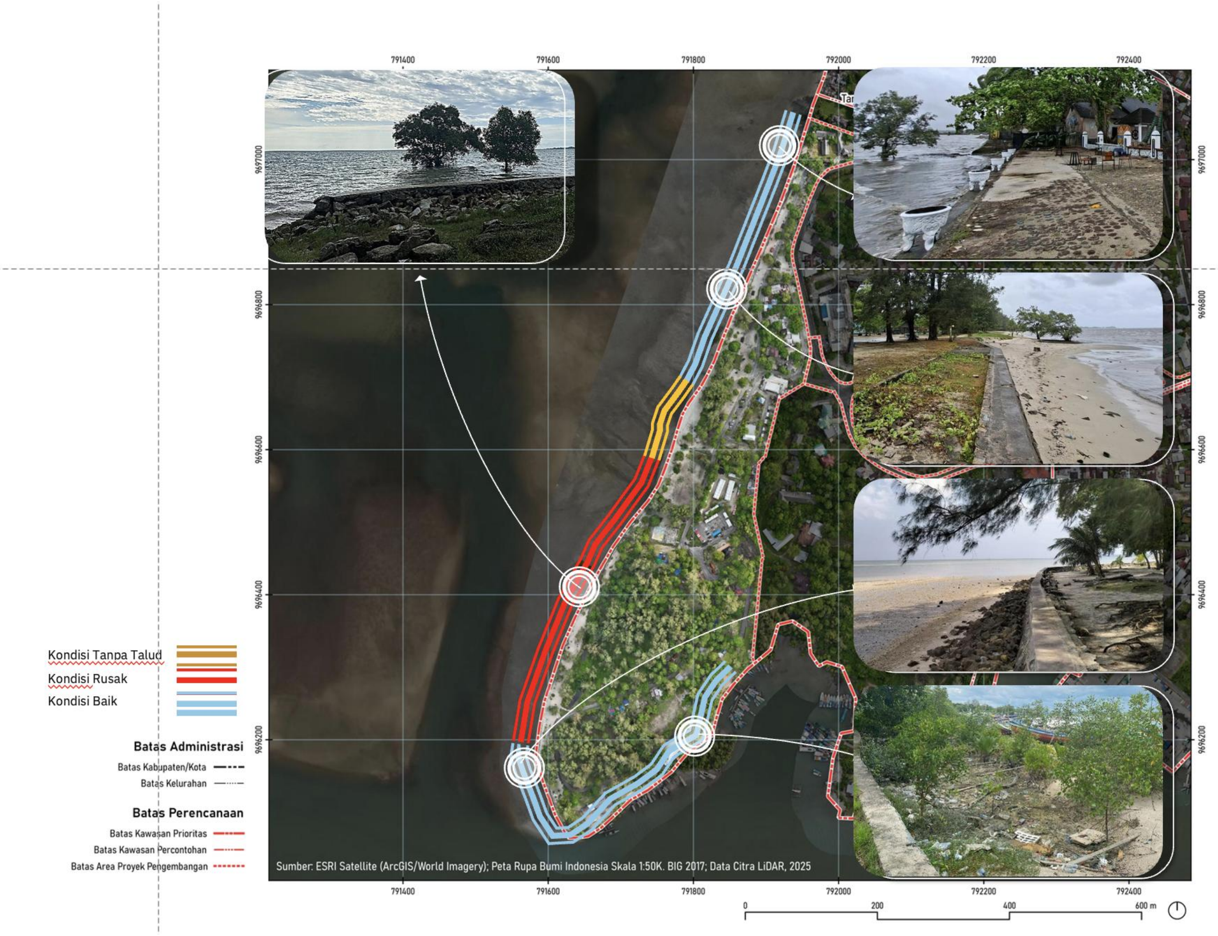

Figure 2. Spatial distribution and documented conditions of coastal protection structures along the Tanjung Pendam coastline.

Sources: Integrated Spatial Planning (ICP), BPIW, 2025

This issue is also evident in current planning documents. The ICP records tidal flooding, especially from December to February, which restricts major activities at Tanjung Pendam and contributes to the deterioration of coastal protection structures in several areas. At the same time, broader planning initiatives promote tourism development, urban restructuring, and *renewal*, while regional spatial plans integrate tourism and other urban functions within the coastal zone. Thus, the primary challenge is not merely shoreline protection, but sustaining these functions as coastal conditions evolve over the lifespan of urban investments. At the policy level, Indonesia's coastal and spatial planning framework establishes a foundation for integrated management, while national and regional instruments guide urban development, tourism, infrastructure, and environmental management. Evidence from Tanjung Pandan does not indicate contradictions or failures within these policies. Instead, it highlights an implementation challenge: translating broad coastal management principles into spatial decisions that explicitly account for historical shoreline mobility. This distinction matters because administrative land-use boundaries remain relatively fixed, while the physical coastal boundary continues to change (Sui et al., 2020). Incorporating a stronger temporal dimension into coastal spatial management is essential. Historical shoreline data can enhance existing planning tools by informing development control, infrastructure maintenance, waterfront management, and the siting of long-term facilities. For Tanjung Pendam, this does not imply

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the need for continuous hard coastal protection along the entire waterfront. Instead, the observed variation in conditions supports a differentiated management strategy, tailoring interventions to the specific characteristics and functions of individual coastal segments. Critical infrastructure, high-use public areas, flexible recreational spaces, and environmentally sensitive zones may each require distinct management approaches.

Sea-level rise should similarly be incorporated as a forward-looking adaptation consideration rather than interpreted as a proven cause of the mapped abrasion. The present analysis does not quantify its contribution to shoreline transformation. A precautionary planning approach would therefore integrate historical shoreline monitoring with elevation, tidal, sea-level, and hydrodynamic information as additional evidence for future site-specific interventions. This would allow observed historical change and future environmental scenarios to inform planning without treating them as equivalent evidence. The Tanjung Pandan case underscores the need to shift from reactive coastal protection to adaptive spatial management (Scott & Townend 2020). Sustainable management requires addressing shoreline monitoring, protection infrastructure, land-use planning, public space functions, tourism, and environmental adaptation as interconnected elements of a unified coastal system. Tanjung Pendam illustrates that the central challenge is not simply whether to protect or develop the waterfront, but how to sustain its social and economic functions amid long-term environmental change (Surbakti et al., 2025). Incorporating historical shoreline evidence into spatial decision-making can strengthen coastal policy by shifting from static land allocation to a more precautionary, spatially responsive, and adaptive approach to urban coastal management.

The findings indicate that the Tanjung Pandan coast should not be regarded as a fixed physical boundary. Spatial evidence reveals a long-term transformation, with abrasion consistently prevailing over accretion within the mapped shoreline-change area. Furthermore, the multi-temporal analysis demonstrates that shoreline positions identified during intermediate periods did not necessarily persist in subsequent conditions. This temporal variability is essential for interpreting coastal space, as it suggests that the contemporary shoreline represents only a single stage within an ongoing land–sea interface transformation. For urban coastal management, this implies that spatial decisions based solely on current shoreline conditions may fail to account for the historical mobility of the coastal boundary.

This interpretation aligns with the broader concept of shoreline dynamics, which recognizes erosion and accretion as spatial manifestations of interacting coastal processes rather than isolated occurrences. The present findings advance this perspective by highlighting the planning relevance of historical shoreline evidence. While conventional shoreline studies often focus on the magnitude, rate, and spatial distribution of coastal change, in Tanjung Pandan, the significance of such evidence is also influenced by the permanence of functions situated adjacent to the coastline. Tourism facilities, public spaces, infrastructure, and other urban investments typically occupy fixed spatial allocations, even as the physical boundary continues to shift. The central issue, therefore, is the temporal mismatch between shoreline mobility and the relative permanence of spatial development decisions.

The conditions documented at Tanjung Pendam further support this interpretation. Although coastal protection infrastructure exists, its condition and spatial continuity differ along the waterfront. Some segments remain functional, while others are damaged or lack continuous structural protection (Theocharidis et al., 2024). The ICP also acknowledges tidal flooding and the deterioration of coastal protection as current constraints. These conditions should not be regarded as direct causes or effects of the mapped shoreline transformation. Rather, shoreline dynamics may result from the interaction of oceanographic, geomorphological, sedimentary, climatic, and anthropogenic processes. The key finding is their spatial coexistence: historical

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shoreline change, varied coastal protection, and intensive urban functions are present within the same coastal system.

This distinction is particularly important in the context of sea-level rise. Although rising sea levels pose a significant long-term concern for coastal settlements, the current spatial evidence does not allow for isolating their specific contribution to observed shoreline transformation. Directly attributing shoreline retreat to sea-level rise would require supplementary tidal, wave, sediment, elevation, hydrodynamic, and long-term sea-level data. Consequently, the findings support a precautionary rather than a causal interpretation. Historical shoreline change demonstrates existing coastal mobility, while sea-level rise should be considered as an additional future factor in adaptation strategies. Distinguishing between observed changes and projected environmental pressures prevents overstatement and maintains the relevance of climate adaptation for long-term coastal management, when these physical conditions are considered within the existing policy framework. Indonesian coastal-management principles emphasize integration between terrestrial and marine processes, while spatial and development planning establishes functions for settlements, infrastructure, tourism, environmental protection, and economic development. Similarly, regional planning directions reflected in the ICP acknowledge both strategic urban functions and existing coastal constraints. The evidence from Tanjung Pandan therefore does not indicate that the principal problem is the absence of policy recognition (Wang et al., 2024). Rather, the gap is primarily operational and spatial: broad principles of integrated and sustainable coastal management must be translated into site-specific decisions capable of responding to a shoreline that changes over time.

This finding contributes a significant dimension to adaptive coastal-management theory. Adaptation extends beyond constructing more robust protection infrastructure in response to visible physical impacts. Adaptive management prioritizes learning from environmental change, monitoring evolving conditions, and adjusting interventions as new evidence emerges. In the context of Tanjung Pandan, historical shoreline information can serve as a continuous planning input rather than solely as a record of past coastal processes. Regular shoreline monitoring could inform infrastructure maintenance, development control, waterfront management, and decisions regarding the spatial relationship between permanent facilities and the coastal edge. The varied conditions at Tanjung Pendam indicate that a uniform response is not appropriate (Kirby et al., 2021). While hard protection may be necessary for certain functions, structural interventions are not universally suitable for all coastal segments. Critical infrastructure, intensive public spaces, recreational areas, and environmentally sensitive sections each possess distinct levels of permanence, exposure, and capacity to accommodate change. Adaptive spatial management therefore necessitates differentiated interventions that address both the physical coastal conditions and the specific functions present along the waterfront. This approach shifts the management focus from stabilizing the entire shoreline to determining where protection, accommodation, monitoring, or spatial flexibility are most appropriate. This approach also reinforces the connection between coastal adaptation and sustainable development (Darmiati & Atmadipoera, 2021).

Sustainable coastal management cannot be limited to either environmental protection or the maximization of economic use of waterfront land. In urban coastal contexts, sustainability relies on balancing productive tourism and public functions with the preservation of environmental adaptability and long-term spatial safety (Nguyen et al., 2022). Achieving this balance requires development decisions that acknowledge uncertainty, rather than presuming that current physical conditions will persist throughout the lifespan of infrastructure and urban investments. The primary contribution of this study is not the introduction of another composite vulnerability index, but rather the demonstration of an alternative application of

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straightforward shoreline-change evidence (De Paula el al., 2021). Historical coastal transformation can serve as an operational indicator for spatial planning, linking measurable physical change with decisions related to coastal protection, land use, infrastructure, and adaptation. The Tanjung Pandan case thus suggests a broader conceptual principle: sustainable coastal planning requires improved alignment between the temporal dynamics of the shoreline and the temporal permanence of development decisions. This alignment offers a practical basis for transitioning from reactive coastal protection to spatially differentiated, evidence-based, and adaptive management of urban coastal environments.

Conclusion

The findings indicate that the Tanjung Pandan coast functions as a dynamic spatial system, where long-term shoreline change significantly influences coastal management and spatial planning. Multi-temporal analysis establishes abrasion as the primary transformation process within the mapped shoreline-change area, whereas accretion constitutes a much smaller proportion. Furthermore, variations in historical shoreline positions suggest that the coastal boundary should not be regarded as a permanently stable spatial reference for long-term land use, infrastructure, or waterfront management decisions. At Tanjung Pendam, these findings are especially pertinent when evaluated alongside documented coastal-management conditions in the ICP, such as tidal flooding and spatial variability in coastal protection structures. While their coexistence does not imply causality, it illustrates that strategic urban and tourism functions are situated within a coastal environment already subject to physical change and management limitations. Although current planning frameworks offer a general foundation for integrated coastal management, the primary challenge is translating these principles into implementation responsive to both spatial and temporal dynamics. The observed shoreline transformation is not directly attributed to sea-level rise in this study. Rather, sea-level rise should be considered as a prospective adaptation factor and incorporated alongside historical shoreline monitoring, elevation data, tidal records, and hydrodynamic information in future site-specific planning. The principal contribution of this research is to demonstrate that relatively straightforward historical shoreline evidence can serve as an operational foundation for adaptive coastal spatial management without necessitating the development of a complex vulnerability index. Sustainable management of Tanjung Pandan thus requires closer alignment between shoreline temporal dynamics and the permanence of spatial decisions, enabling coastal functions to remain productive while adopting more precautionary, flexible, and responsive approaches to long-term environmental change.

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