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MULTI-TEMPORAL SHORELINE DYNAMICS AND SPATIAL ECOTOURISM CARRYING CAPACITY IN MERU BETIRI, INDONESIA

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ABSTRACT: Coastal areas are dynamic environments that continuously experience shoreline changes due to the interaction of waves, tides, currents, and river discharge. These processes directly influence coastal stability, land availability, and the sustainability of tourism development, particularly in protected coastal zones. This study aims to analyse long-term shoreline dynamics and assess beach ecotourism suitability and spatially based carrying capacity in Meru Betiri National Park, East Java, Indonesia. Shoreline changes were quantified using multi-temporal high-resolution Google Earth imagery over a ten-year period (2012–2022) at four coastal locations: Muara Mbaduk, Rajekwesi, Teluk Ijo, and Sukamade. Manual shoreline digitisation was conducted to identify erosion and accretion patterns. Beach ecotourism suitability was evaluated using the Tourism Suitability Index (TSI), while the Regional Carrying Capacity (RCC) was calculated to estimate the maximum number of visitors that can be accommodated without causing environmental degradation. The results reveal spatial variability in shoreline dynamics, with net accretion of 1,535 m² at Muara Mbaduk, 36,340 m² at Rajekwesi, 2,687 m² at Teluk Ijo, and 30,497 m² at Sukamade. Muara Mbaduk is classified as suitable (TSI = 2.38), whereas Rajekwesi (TSI = 2.74), Teluk Ijo (TSI = 2.90), and Sukamade (TSI = 2.90) are classified as very suitable for beach ecotourism. The estimated carrying capacities are 493 persons/day at Muara Mbaduk, 327 persons/day at Rajekwesi, 66 persons/day at Teluk Ijo, and 90 persons/day at Sukamade. This integrated geomatics-based assessment provides spatially explicit information to support adaptive coastal management and sustainable tourism planning in dynamic and protected coastal environments.

Keywords: Shoreline dynamics, Google Earth imagery, Coastal geomatics, Ecotourism suitability

1. INTRODUCTION

Coastal zones are among the most dynamic geomorphological environments on Earth, continuously shaped by the interaction of various natural forces and processes. These zones are influenced by waves, tides, and currents [1], river discharge, and sediment transport [2], which collectively drive significant changes in coastal morphology [3]. In recent decades, shoreline dynamics have been further intensified by climate variability [4], sea-level rise [5], and increasing anthropogenic pressure [4], making long-term shoreline monitoring a critical component of sustainable coastal management and spatial planning.

Advances in geomatics and geospatial technologies have significantly improved the capability to monitor shoreline changes across various spatial and temporal scales. Remote sensing and Geographic Information Systems (GIS) are widely applied to detect shoreline position changes [6], support disaster mitigation [7], and provide spatial information for coastal management. In particular, high-resolution satellite imagery from Google Earth has been extensively used for shoreline analysis due to its wide spatial coverage [8], relatively high positional accuracy, and long temporal archive, making it suitable for multi-temporal shoreline change assessment in data-limited coastal environments.

Coastal areas within protected regions are increasingly utilised for tourism development. While tourism contributes to local economic growth, uncontrolled development can accelerate coastal degradation, habitat loss, and environmental pressure. Tourism activities cause environmental degradation through pollution, resource overuse, and the introduction of invasive species [9], including marine litter [10]. As a response, ecotourism has been promoted as a sustainable tourism approach that emphasises environmental conservation, responsible resource use, and community involvement [11]. However, tourism development in dynamic coastal environments must explicitly account for physical shoreline changes to ensure long-term sustainability and minimise ecological impacts.

The Tourism Suitability Index (TSI) approach and multi-criteria spatial analysis have been widely applied to evaluate coastal tourism potential using geomatics-based data. In parallel, carrying capacity assessment has become an important tool for estimating the maximum number of visitors that can be accommodated without causing ecological degradation or reducing visitor comfort [12]. However, many existing studies assess tourism suitability and carrying capacity independently, without explicitly considering long-term shoreline dynamics.

This limitation is particularly significant in protected coastal areas, where conservation objectives must be balanced with the socio-economic benefits of tourism. National parks and marine protected areas require spatially explicit and scientifically robust information to support adaptive management strategies [13]. Meru Betiri National Park, located along the southern coast of East Java, Indonesia, is a protected coastal environment exposed to high-energy wave conditions from the Indian Ocean and influenced by riverine sediment input. The park contains several coastal ecotourism destinations—Muara Mbaduk, Rajekwesi, Teluk Ijo, and Sukamade—that exhibit diverse coastline characteristics and tourism activities [14].

Previous studies in Meru Betiri National Park have focused primarily on ecotourism development [14] and community-based management [15]. Most earlier research emphasised the socio-economic aspects of ecotourism, while no studies have addressed shoreline change analysis. Spatial-based studies of shoreline dynamics using Google Earth imagery have been shown to enhance monitoring and analysis significantly [16-18], whereas studies on coastal tourism suitability have generally been conducted independently [12, 19]. Existing research tends to treat shoreline change as a standalone geomorphological process, without explicitly integrating its spatio-temporal impacts into tourism carrying capacity assessment.

In contrast to previous studies, this research introduces an explicit spatial linkage between long-term shoreline dynamics and ecotourism carrying capacity by embedding quantified shoreline accretion–erosion trends into the delineation of usable tourism space and the calculation of carrying capacity parameters. The novelty of this study lies not only in integrating multi-temporal Google Earth shoreline analysis with the Tourism Suitability Index (TSI) and Regional Carrying Capacity (RCC), but also in demonstrating how shoreline change metrics directly influence spatial allocation, ecological constraints, and permissible visitor numbers in protected coastal environments. The originality of this study is further reflected in its combined evaluation of shoreline dynamics and tourism carrying capacity within a single spatial framework, enabling a more comprehensive understanding of how physical coastal changes affect the sustainability potential of ecotourism.

Compared to previous research, this study provides spatially explicit, site-specific insights that support adaptive coastal management and sustainable tourism planning in national parks. Section 2 then describes the study area and research methodology, including shoreline manual digitisation, tourism suitability analysis, and carrying capacity calculations. Section 3 presents and discusses the results of the shoreline dynamics, ecotourism suitability, and carrying capacity assessments. Finally, Section 4 summarises the main findings and outlines their implications for sustainable coastal management and ecotourism in protected coastal environments.

2. RESEARCH SIGNIFICANCE

This study uses an integrated remote sensing-based approach, combining long-term shoreline dynamics analysis with coastal ecotourism suitability and spatially based carrying capacity assessment in a protected coastal environment. The study explicitly links physical shoreline dynamics derived from multi-temporal Google Earth imagery with tourism sustainability indicators. The novelty of this study lies in its spatially explicit framework that simultaneously assesses coastal dynamics and tourism carrying capacity in Meru Betiri National Park, providing decision-support information for adaptive coastal management and ecotourism. The results of this study contribute to sustainable planning strategies in national parks and other dynamic coastal environments.

3. METHODOLOGY

The study was conducted at four coastal ecotourism destinations located within the management area of Meru Betiri National Park (TNMB), Sector I Sarongan, Banyuwangi, East Java, Indonesia, namely Sukamade, Teluk Ijo, Rajekwesi, and Muara Mbaduk (Fig.1). These locations were selected because they represent designated ecotourism areas whose management involves local buffer village communities, including community groups that previously engaged in environmentally destructive activities.

Shoreline change analysis was conducted to understand coastal dynamics, providing fundamental information for coastal management and spatial decision-making. Shoreline changes were identified using multi-temporal high-resolution satellite imagery from Google Earth Pro. Google Earth Pro provides multi-source satellite imagery, including high-resolution data (≤ 50 cm) from Maxar Technologies/DigitalGlobe (WorldView, GeoEye, QuickBird, and IKONOS), Airbus Defence and Space (Pleiades), and CNES/Airbus (SPOT), complemented by medium-resolution imagery from Landsat (NASA/USGS; 15–30 m) and Sentinel (Copernicus/ESA), as well as additional datasets from ImageSat International (EROS-B) [20].

The imagery used in this study for the period 2012–2022 comprises high-resolution Google Earth data sourced from Maxar Technologies (WorldView satellite imagery) with a spatial resolution of ≤ 50 cm. Image selection was constrained by the availability of archived datasets, limiting temporal sampling. Seasonal variability, tidal stage differences, and extreme events (e.g., storms and cyclones) were not explicitly incorporated into the analysis; however, the multi-year temporal coverage and consistent manual digitisation approach allow the derived shoreline change trends to be interpreted as representative of long-term morphological tendencies rather than short-term episodic variability. These factors are therefore acknowledged as methodological limitations while maintaining the robustness of the long-term assessment of shoreline dynamics.

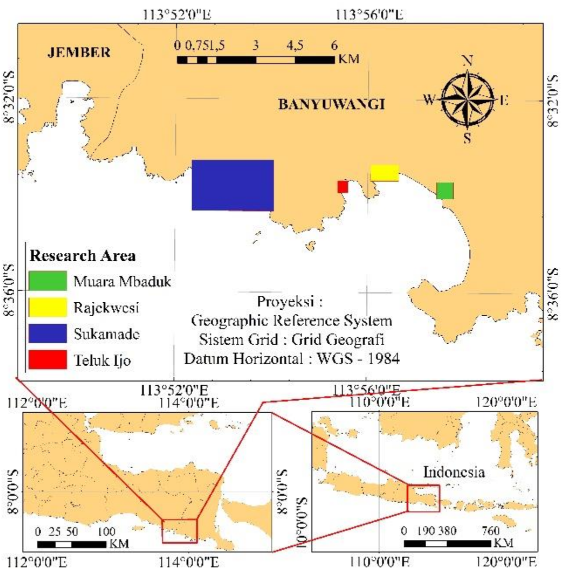

Fig.1 research Area

Google Earth imagery has been widely used to analyse shoreline changes at various spatial and temporal scales due to its high spatial resolution and accessibility [21, 18]. This analysis was also used to identify coastal erosion and accretion processes occurring along the shoreline [22].

Google Earth imagery was accessed using the cloud-based Google Earth Engine (GEE) platform and exported via Python for further analysis [20]. Shoreline manual digitisation was conducted manually following a consistent protocol, with shoreline positions delineated based on the wet–dry line, which represents the visible boundary between wet and dry beach surfaces and is commonly used as a proxy for the instantaneous shoreline in optical imagery. A single trained operator performed all manual digitisation to ensure consistency and minimise subjective interpretation bias. Positional uncertainty was estimated by accounting for image resolution and visual interpretation error; given the ≤50 cm spatial resolution, the horizontal shoreline uncertainty was conservatively estimated at ±1.0 m. This uncertainty was propagated into area change calculations using a buffer-based approach, and reported shoreline changes (m²/year) represent net trends within uncertainty bounds.

Coastal ecotourism suitability was evaluated using the Tourism Suitability Index (TSI) based on ten physical and environmental parameters with the following weights: beach type (0.20), beach width (0.20), seabed material (0.17), water depth (0.125), water clarity (0.125), current velocity (0.08), beach slope (0.08), land cover (0.01), presence of hazardous biota (0.05), and freshwater availability (0.005). Each parameter was assigned a weight and score according to predefined criteria, with scores ranging from 0 (lowest suitability) to 3 (highest suitability). The Tourism Suitability Index was calculated as the weighted sum of all parameters [12, 23, 24].

$$\mathbf{TSI} = \sum_{\mathbf{i=1}}^{\mathbf{n}}(\mathbf{BixSi}) \qquad (1)$$

Information: TSI = Tourism suitability index, n = Number of suitability parameters, Bi = Weight of the i-th parameter, Si = score of the i-th parameter. Tourism suitability was classified into four categories: very suitable (TSI ≥ 2.5), suitable (2 ≤ TSI < 2.5), not suitable (1 ≤ TSI < 2), and very unsuitable (TSI < 1) [12].

The Regional Carrying Capacity (RCC) of each location was calculated to determine the maximum number of visitors that can be accommodated without causing environmental degradation or reducing visitor comfort. The RCC concept considers ecological potential, available area or length, unit space requirements for specific activities, available time for tourism activities, and the average duration of visitor activities [12].

$$\mathrm{RCC} = \mathrm{Kx\ Lp/Lt\ x\ Wt/Wp} \tag{2}$$

The RCC (persons/day) was calculated using parameters including ecological potential per unit area (K), usable area or length (Lp), unit area requirement (Lt), available tourism time per day (Wt), and time spent by visitors for each activity (Wp) [25, 12].

Tourism activities considered in the carrying capacity analysis included swimming, sunbathing, beach recreation, beach sports, fishing, camping, and relaxing activities, as well as surfing. The parameters in Table 1 are used to calculate the total capacity for each study location.

Usable coastal area and shoreline length (Lp) were derived from the digitised shoreline using a GIS-based spatial allocation approach. The wet–dry line served as the baseline for generating an inland buffer representing potential tourism-use zones. In contrast, unsuitable areas such as dunes, protected zones, dense vegetation, and conservation-restricted areas were excluded through spatial masking based on land cover data and field observations. In the Sukamade area, designated as a sea turtle nesting site, nesting zones and adjacent ecological buffers were excluded to minimise disturbance, resulting in a reduced effective Lp that reflects ecologically permissible tourism use under conservation constraints.

Table 1. Ecological potential per unit area (K), usable area or length (Lp), unit area requirement (Lt), available tourism time per day (Wt), and time spent by visitors for each activity (Wp) [24]

Activity	K	Lt	Wt	Wp
Swimming / Snorkelling (20 m spacing)	2 persons	500 m²	6 hours	3 hours
Beach recreation / Leisure sitting / Sports / Sunbathing	1 persons	25 m	6 hours	3 hours
Fishing	1 persons	25 m	6 hours	3 jam
Camping	4 persons	400 m²	24 hours	24 hours
Surfing	1 persons	50 m	6 hours	2 hours

4. RESULTS AND DISCUSSION

4.1 Shoreline Change Analysis

Shoreline dynamics at the study sites exhibit spatial and temporal variability, reflecting the interaction between hydrodynamic processes and local coastal characteristics. Shoreline changes at Muara Mbaduk, Rajekwesi, Teluk Ijo, and Sukamade occur through erosion (abrasion) and accretion. This pattern is consistent with previous studies, which show that shoreline evolution in coastal environments is generally characterised by alternating erosion and sedimentation driven by waves, tides, and sediment transport mechanisms [26].

Table 2. Changes in the beach area in Muara Mbaduk

GE image date	Area (m²)		Area Difference (m²/year)	Information
	Abrasion (m²)	Accretion (m²)		
Muara Mbaduk				
2012/12 - 2016/01	998	22,566	6,995	Increase
2016/01 - 2019/11	1,748	8,230	1,691	Increase
2019/11 - 2022/12	30,843	4,545	-6,714	Reduce
2012/12 - 2022/12	15,106	16,641	154	Increase

Fiure.2 Shoreline change map in Muara Mbaduk obtained from multi-temporal Google Earth imagery (2012–2022), depicting areas of erosion and accretion identified through polygon overlay analysis. At Muara Mbaduk, shoreline changes during the period 2012–2022 show alternating phases of accretion and erosion (Table 2).

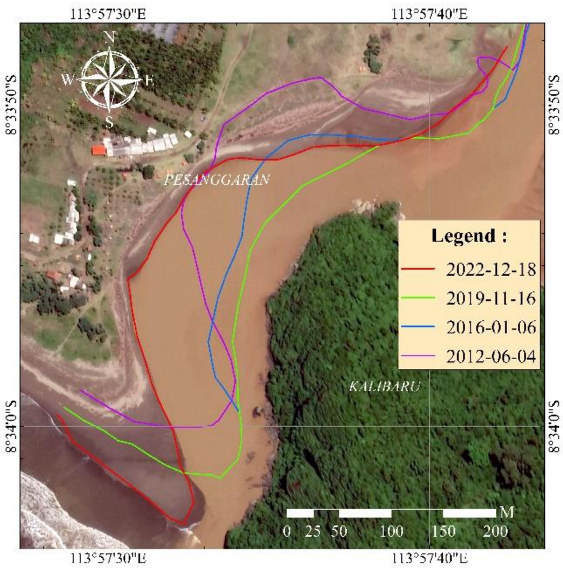

Fig.2 Map of shoreline changes in Muara Mbaduk

From 2012 to 2016, accretion dominated with an average increase of 6,995 m²/year, while from 2016 to 2019, accretion continued at a lower rate of 1,691 m²/year. In contrast, the period 2019–2022 was characterized by significant erosion, resulting in a net loss of 6,714 m²/year. Over the past 10 years, Muara Mbaduk has experienced a net increase in land area of 1,535 m². The high variability observed at this location is primarily influenced by the presence of a river mouth, which facilitates sediment redistribution and periodic shoreline adjustment [26].

Table 3. Changes in the beach area in Rajekwesi

GE image date	Area (m²)		Area Difference (m²/year)	Infor-mation
	Abrasion (m²)	Accretion (m²)		
Rajekwesi 2012/06 - 2016/03		13,791	3,678	Increase
2016/03 - 2018/10	10,73	1,911	324	Increase
2018/10 - 2022/12	586	22,146	5,174	Increase
2012/06 - 2022/12	294	36,634	3,461	Increase

Fig.3 Shoreline change map in Rajekwesi obtained from multi-temporal Google Earth imagery (2012–2022), depicting areas of erosion and accretion identified through polygon overlay analysis. Rajekwesi Beach exhibited a predominantly accretional trend throughout the study period (Table 3). From 2012 to 2016, accretion occurred at a rate of 3,678 m²/year, with no significant erosion. Subsequent periods (2016–2018 and 2018–2022) also showed net accretion, resulting in a cumulative increase in land area of 36,340 m² over 10 years. The relatively stable accretional pattern at Rajekwesi is influenced by river input, wave action, and tidal processes that promote sediment deposition along the shoreline [27].

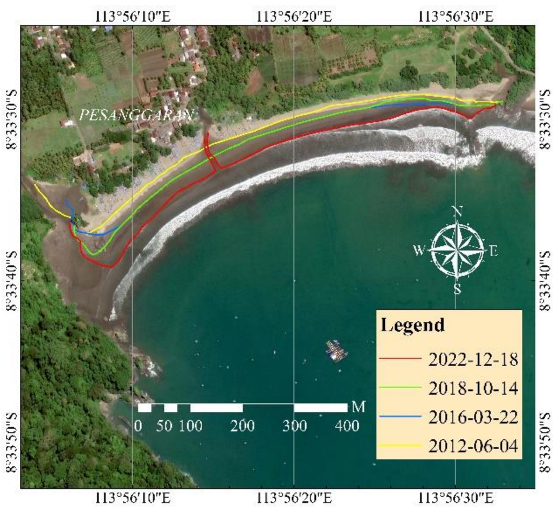

Fig.3 Map of shoreline changes in Rajekwesi

Figure 4 Shoreline change map in Teluk Ijo obtained from multi-temporal Google Earth imagery (2012–2022), depicting areas of erosion and accretion identified through polygon overlay analysis. Teluk Ijo displayed comparatively minor shoreline changes compared to the other sites (Table 4). Accretion was observed during 2012–2016, with an average increase of 841 m²/year, whereas no significant changes occurred between 2016 and 2018. From 2018 to 2022, slight erosion dominated, resulting in a reduction of 78 m²/year. Overall, Teluk Ijo experienced a modest net increase of 2,687 m² in the inland area over 10 years. The relatively stable shoreline at Teluk Ijo can be attributed to its bay morphology and the dominance of wave-driven processes acting on a sandy beach system [26]

Table 4. Changes in the beach area in Teluk Ijo

GE image date	Area (m²)		Area Difference (m²/year)	Information
	Abrasion (m²)	Accretion (m²)		
Teluk Ijo 2012/06-2016/01		3,013	841	Increase
2016/01-2018/10			0	-
2018/10-2022/12	434	111	-78	Reduce
2012/6 - 2022/12		2,687	256	Increase

Figure 5 Shoreline change map in Sukamade obtained from multi-temporal Google Earth imagery (2012–2022), depicting areas of erosion and accretion identified through polygon overlay analysis. Sukamade Beach exhibited complex shoreline dynamics influenced by both river discharge and high-energy wave conditions (Table 5).

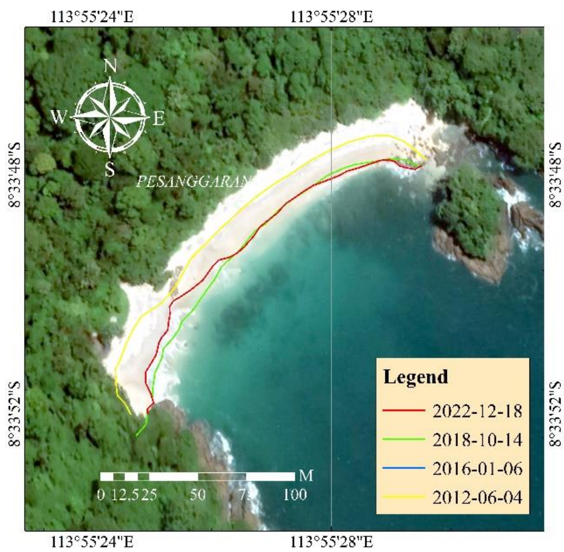

Fig.4 Map of shoreline changes in Teluk Ijo

Table 5. Changes in the beach area in Sukamade

GE image date	Area (m^2) Abrasion (m^2)	Accretion (m^2)	Area Difference (m^2/year)	Information
Sukamade				
2012/06 - 2016/01	17,256	105,695	24,681	Increase
2016/01 - 2018/10	50,497	47,801	-980	Reduce
2018/10 - 2022/12	75,560	9,607	-15,829	Reduce
2012/06-2022/12	75,467	105,964	2,904	Increase

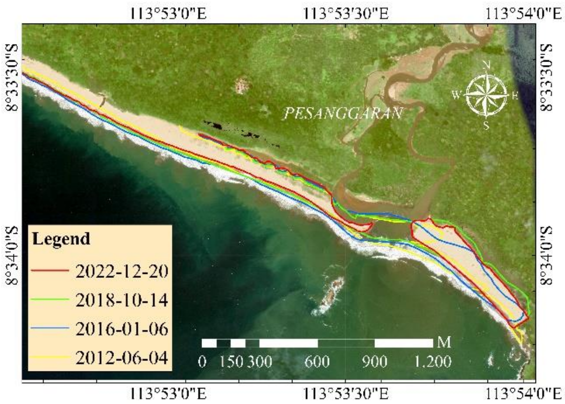

Fig.5 Map of shoreline changes in Sukamade

During the period 2012–2016, strong accretion dominated, resulting in an average increase of 24,681 m²/year. However, subsequent periods showed erosion-dominated phases, with net losses of 980 m²/year (2016–2018) and 15,829 m²/year (2018–2022). Despite these fluctuations, Sukamade experienced a net increase of 30,497 m² in the inland area over the ten years. River mouths are dynamic environments where sediment transport processes shape shoreline morphology [28].

Field observations indicate that Muara Mbaduk is characterised by an average water colour of 8 Pt-Co, low water clarity (<3 m), high turbidity (68 NTU), and elevated total suspended solids (TSS; 60 mg/L), with the presence of marine debris. This site represents a dynamic estuary influenced by strong south–southwest wave forcing and the seasonal discharge of the Buyuk River, resulting in an open estuary during the rainy season and sand-bar closure during the dry season. Rajegwesi Beach shows average water colour below 3 Pt-Co, moderate clarity (3–6 m), turbidity of 15 NTU, and TSS of 18 mg/L, with marine debris observed. The beach is exposed to high wave energy from the south–southwest, particularly during the eastern monsoon. At the same time, while increased river discharge in the rainy season delivers fine sediments to the estuary and influences coastal morphological dynamics. Teluk Ijo Beach is characterised by average water colour below 3 Pt-Co, water clarity of 3–6 m, turbidity of 16 NTU, and TSS of 12 mg/L, with no observed debris. The site is dominated by south–southwest waves from the Indian Ocean; although its embayed morphology provides relative shelter, wave energy and currents remain strong, especially during the eastern monsoon. Sukamade Beach exhibits very clear waters with average colour below 1 Pt-Co, high clarity (>6 m), low turbidity (3 NTU), and low TSS (4 mg/L), with no observed debris. The beach is exposed to large south–southwest waves and highly seasonal river discharge, posing flood risks during the rainy season but safer conditions during the dry season, and it functions as an active sandy beach that serves as an important sea turtle nesting habitat.

The reported net shoreline area changes (m²) and annual change rates were assessed in relation to positional uncertainty associated with manual digitization and image geolocation errors (±1.0 m). An uncertainty envelope was applied to establish a minimum detection threshold, with only changes exceeding it considered robust. The dominant accretion and erosion trends identified in this study surpass the estimated detection threshold, confirming their reliability for long-term shoreline change assessment.

Overall, the results demonstrate that coastal areas within Meru Betiri National Park are highly dynamic and vulnerable to shoreline changes. Natural factors such as waves, tides [29], and river discharge play a fundamental role in controlling shoreline evolution. Understanding site-specific shoreline dynamics is therefore essential for supporting coastal management and spatial planning decisions [27]. Previous studies have emphasised that erosion and accretion processes often occur through sediment migration from one location to another along the coast, highlighting the importance of sediment supply and transport pathways in coastal systems.

The application of multi-temporal Google Earth imagery provides an effective approach for detecting and quantifying shoreline changes in data-limited coastal environments [30]. High-resolution Google Earth imagery allows detailed visual interpretation of shoreline positions and has been shown to provide acceptable positional accuracy for coastal change analysis. This study confirms that multi-temporal Google Earth imagery provides a practical, robust, and scalable approach for long-term shoreline monitoring and coastal dynamics assessment, particularly in data-limited coastal environments [31].

4.2 Regional Carrying Capacity (RCC) for Sustainable Coastal Ecotourism Management

Beach ecotourism suitability is an important component in assessing the capacity of coastal areas to support sustainable tourism development. The Tourism Suitability Index (TSI) has been widely applied to evaluate the appropriateness of coastal areas for tourism activities based on physical and environmental characteristics [23]. In this study, beach ecotourism suitability was assessed for four coastal destinations in Meru Betiri National Park, namely Muara Mbaduk, Rajekwesi, Teluk Ijo, and Sukamade, using ten suitability parameters (Table 6). These parameters include beach type, beach width, water base Material, water depth, water clarity, current speed, beach slope, land cover, presence of dangerous biota, and freshwater availability, following established approaches for coastal ecotourism assessment.

The results indicate that all four locations feature white-sand beaches, which are highly favourable for beach-based ecotourism. Beach width measurements at Muara Mbaduk (25–69 m), Rajekwesi (22–117 m), Teluk Ijo (13–21 m), and Sukamade (77–122 m) yielded high suitability scores, indicating sufficient space to accommodate tourism activities. Differences among locations were observed in water-based Material, water clarity, and current speed. Muara Mbaduk, located at a river estuary, is characterised by sandy–muddy bottom sediments and low water clarity (20–50%), resulting in lower suitability scores for these parameters. In contrast, Rajekwesi, Teluk Ijo, and Sukamade exhibit sandy bottom waters and higher water clarity, particularly at Teluk Ijo and Sukamade, where water clarity exceeds 80%, indicating favourable conditions for recreational activities.

Current speed represents a limiting factor at locations directly facing the open sea. Muara Mbaduk shows relatively low current velocities (12–17 cm/s), resulting in higher suitability scores, whereas Rajekwesi, Teluk Ijo, and Sukamade experience stronger currents (>51 cm/s), which reduce their suitability for certain water-based activities. The beach slope at all locations is gentle (<10°), and no dangerous biota were observed during field observations. Freshwater availability within 0.5 km further enhances the suitability of all sites for tourism development.

Based on the calculated TSI values, Muara Mbaduk is classified as suitable (TSI = 2.38), while Rajekwesi (TSI = 2.74), Teluk Ijo (TSI = 2.90), and Sukamade (TSI = 2.90) are classified as very suitable for beach ecotourism. These results indicate that, despite local physical constraints, the overall environmental conditions of the study sites support sustainable beach-based ecotourism activities.

Table 6. Suitability of beach tourism categories in the Merubetiri area for Muara Mabduk, Rajekwesi, Teluk Ijo, and Sukamade.

No	Paremeters	Weight X Score			
		Muara Mbaduk	Raje-kwesi	Teluk Ijo	Suka-made
1	Beach type	0.60	0.60	0.60	0.60
2	Beach Width (m)	0.60	0.60	0.60	0.60
3	Water-base Material	0.00	0.51	0.51	0.51
4	Depth(m)	0.38	0.38	0.38	0.38
5	Brightness (%)	0.13	0.25	0.38	0.38
6	Current Speed (cm/s)	0.24	0.00	0.00	0.00
7	Beach Slope (degrees)	0.24	0.24	0.24	0.24
8	Land Cover	0.03	0.00	0.03	0.03
9	Dangerous biota	0.15	0.15	0.15	0.15
10	Freshwater (km)	0.02	0.02	0.02	0.02
	Travel Suitability Index (TSI)	2.38 Suitable	2.74 Very suitable	2.90 Very suitable	2.90 Very suitable

To complement the suitability assessment, the Regional Carrying Capacity (RCC) was calculated to determine the maximum number of visitors that can be accommodated without degrading environmental quality or visitor experience. RCC estimation considers ecological potential [32], available area or length [33], duration of tourism activities, and time spent by visitors [25]. At Muara Mbaduk, dominant tourism activities include swimming, beach recreation, relaxing, and camping. The combined RCC for these activities reaches 493 persons/day, with camping accounting for the largest proportion due to the availability of extensive land. At Rajekwesi, tourism activities include swimming, beach recreation, relaxing, and fishing, resulting in a total carrying capacity of 327 persons/day. Teluk Ijo has a lower carrying capacity of 66 persons/day due to its smaller beach area and the inclusion of activities such as surfing, fishing, and camping. Sukamade differs from other sites, as tourism activities are primarily focused on turtle nesting observation and hatchling release. Due to ecological sensitivity and spatial limitations, the carrying capacity at Sukamade is restricted to 90 persons/day.

In this study, the Regional Carrying Capacity (RCC) was calculated as a static daily value based on spatial and activity-based parameters. However, actual visitor capacity may vary temporally due to seasonal visitation patterns, sea turtle nesting seasons, and episodic shoreline changes driven by extreme wave events or sediment redistribution. During peak tourism seasons, effective visitor numbers may approach or exceed the estimated RCC. In contrast, during nesting periods or following erosion events, the usable area and shoreline length may be temporarily reduced, resulting in a lower effective RCC. Therefore, the reported RCC should be interpreted as a baseline reference, and adaptive management measures, including seasonal access control and temporal zoning, are recommended.

From a management perspective, these findings highlight the importance of integrating suitability assessment with carrying capacity analysis to support sustainable ecotourism planning. Marine and coastal ecotourism offers significant economic benefits but also poses risks to fragile coastal ecosystems if not properly managed [34]. By applying suitability and carrying capacity approaches [35], tourism development in national parks can be aligned with conservation objectives, environmental education [36], and local community empowerment [37], and the preservation of local knowledge [38].

5. CONCLUSION

This study demonstrates that coastal areas within Meru Betiri National Park experienced dynamic shoreline changes over ten years (2012–2022), characterised by varying rates of accretion and erosion influenced by waves, tides, and river discharge. Muara Mbaduk showed a net increase of 1,535 m²; Rajekwesi recorded the highest accretion, with an additional 36,340 m²; Teluk Ijo recorded a modest increase of 2,687 m²; and Sukamade gained 30,497 m². These findings confirm the spatial variability of coastal dynamics within the study area. The beach ecotourism suitability assessment indicates that Muara Mbaduk is classified as suitable (TSI = 2.38). In contrast, Rajekwesi (TSI = 2.74), Teluk Ijo (TSI = 2.90), and Sukamade (TSI = 2.90) are classified as very suitable for beach ecotourism. Carrying capacity analysis further shows that Muara Mbaduk can accommodate up to 493 persons/day, Rajekwesi 327 persons/day, Teluk Ijo 66 persons/day, and Sukamade 90 persons/day. By explicitly linking shoreline change trends to tourism suitability and Regional Carrying Capacity, this study provides a spatially explicit and management-relevant framework that supports adaptive coastal management and sustainable ecotourism planning in dynamic and protected coastal environments.

6. ACKNOWLEDGMENTS

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