Multi-Temporal Shoreline Change Detection Using Satellite Imagery and GIS for Abrasion and Accretion Assessment in Mempawah Coast

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Abstract. This study examines the spatio-temporal dynamics of coastal erosion and accretion in Mempawah, West Kalimantan, from 1972 to 2025, using multi-temporal satellite imagery, GIS analysis, and field validation. The results reveal a critical shift from net erosion (1972–1990) to net accretion (2000–2025), driven by the synergistic implementation of breakwaters and mangrove restoration. Coastal villages like Mempawah Hilir and Kuala Secapah experienced severe erosion (139,04 ha in 2010–2020) due to high-energy waves and limited sediment supply, while riverine villages such as Sungai Kunyit benefited from sediment deposition, achieving minimal erosion (2,01 ha) and significant accretion (26,59 ha). Breakwaters proved effective in villages with >90% coverage (e.g., Sungai Duri I, II), reducing erosion to near zero, but were less effective in areas with partial coverage (e.g., Sungai Bakau Besar Laut, 10,13%). Mangroves played a complementary role, dissipating wave energy and trapping sediments, particularly in Tanjung (2.897,62 m thickness). However, agricultural expansion and urbanization disrupted sediment pathways, exacerbating erosion in some areas while enhancing accretion in others. The Kapuas River sustained accretion in Peniti Luar and Pulau Panjang, whereas shorter rivers failed to offset sediment loss. Integrated watershed-coastal management is essential to address these disparities, as highlighted by global best practices. This study offers a template for sustainable coastal management in data-scarce regions.
Keywords: coastal erosion, mangrove restoration, breakwater effectiveness, sediment dynamics, integrated coastal management

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1. Introduction

Coastal erosion and accretion represent critical global challenges, threatening infrastructure, biodiversity, and livelihoods in vulnerable regions like Indonesia(Sasmito et al., 2016). Shoreline dynamics driven by natural processes and anthropogenic activities necessitate rigorous monitoring to inform sustainable coastal management (Statuto et al., 2016). Multi-temporal analysis using satellite imagery and geographic information systems (GIS) has emerged as a powerful tool for quantifying these changes, yet its application in understudied regions like Mempawah remains limited (Kibret et al., 2016).

Mangroves are widely recognized for their role in stabilizing coastlines through sediment trapping and wave attenuation, yet their effectiveness is compromised by deforestation and land-use conversion (Rasyid et al., 2016). In Southeast Asia, mangrove degradation has accelerated due to aquaculture expansion, urbanization, and climate change, exacerbating erosion risks (Rivera-Monroy et al., 2017; Sarmin et al., 2016) While restoration efforts show promise, their success hinges on understanding local hydrodynamic and sedimentary conditions (Yunus et al., 2016).

Coastal structures such as breakwaters are deployed to mitigate erosion, but their efficacy varies based on design, material, and environmental context (Sasmito et al., 2016). In Mempawah, breakwaters cover 100% of shorelines in villages like Sungai Duri I and II but only 10–38% in others (e.g., Sungai Bakau Besar Laut). Despite high coverage in some areas, localized erosion persists due to inadequate sediment supply from short rivers (average length: 29.05 km) and misaligned coastal currents (Rivera-Monroy et al., 2017). This highlights a gap between theoretical expectations of structural interventions and their real-world limitations.

Sediment dynamics are pivotal in shoreline evolution, yet complex interactions between river discharge, wave energy, and seabed composition are often overlooked (Ayele et al., 2016). In Mempawah, the Kapuas River unlike shorter rivers deposits sediment at Panjang Island and Peniti Luar, reducing erosion in those zones. Conversely, estuaries of Mempawah, Kunyit, and Duri rivers experience severe erosion due to limited sediment transport and dominant cross-shore currents (Sasmito et al., 2016). These nuances underscore the need for site-specific assessments rather than generalized models.

Land-use changes in coastal zones further complicate shoreline stability. Agricultural expansion, urbanization, and infrastructure development alter sediment pathways, increasing erosion vulnerability (Jose et al., 2016). In Ethiopia, for instance, rapid land conversion to agriculture intensified soil erosion, directly impacting downstream coastal areas (Hermans-Neumann et al., 2017). Similarly, unplanned development in Mempawah could exacerbate erosion unless integrated with sediment management strategies (Fox et al., 2017).

Current methods for shoreline monitoring often rely on single-date snapshots, failing to capture long-term trends or cyclical changes (Statuto et al., 2016). Multi-temporal remote sensing addresses this gap by enabling retrospective analysis of erosion/accretion rates (Kibret et al., 2016). However, such studies are scarce in Indonesia, particularly in data-scarce regions like Mempawah. Existing frameworks, like the Digital Shoreline Analysis System (DSAS), require high-resolution data and local calibration to account for regional variability (Yunus et al., 2016).

The integration of GIS and satellite imagery offers transformative potential for coastal assessment (Fu et al., 2017). Object-based classification, for example, improves accuracy in mapping mangrove cover and shoreline features (Fu et al., 2017). Yet, in Mempawah, such tools remain underutilized, limiting evidence-based policymaking. Without comprehensive multi-temporal data, interventions like breakwater installation and mangrove planting risk misallocation, perpetuating erosion hotspots (Sarmin et al., 2016).

This study addresses the gap by applying multi-temporal satellite imagery and GIS to quantifkiby abrasion and accretion in Mempawah. By analyzing shoreline changes over time, it evaluates the efficacy of breakwaters and natural ecosystems, providing a template for sustainable coastal management in similar regions globally.

2. Method

This study employed a mixed-methods approach integrating remote sensing, geographic information systems (GIS), field validation, and statistical analysis to quantify and interpret coastal change dynamics in Mempawah, West Kalimantan, from 1972 to 2025. Multi-temporal satellite imagery (Landsat and Sentinel) was processed using the Digital Shoreline Analysis System (DSAS) to measure erosion and accretion rates, with shoreline positions digitized at 10-year intervals. Object-based image classification enhanced the accuracy of mangrove and breakwater mapping, while GIS overlay analysis correlated coastal changes with geological (FAO Soil units, lithology), hydrological (river length, sediment supply), and land-use variables. Field surveys validated satellite-derived data, measuring mangrove thickness, breakwater dimensions, and pioneer vegetation growth in key villages.

Spatio-temporal analysis was conducted using landscape metrics (e.g., edge density, patch cohesion) to quantify urban expansion and its impact on sediment pathways. Sediment dynamics were modeled using hydrological data, while vulnerability assessments integrated coastal exposure indices with mangrove protection metrics. Statistical tests (Pearson's correlation, ANOVA) evaluated relationships between breakwater coverage, mangrove density, and erosion rates. DPSIR (Driver-Pressure-State-Impact-Response) analysis structured the interpretation of human and environmental drivers of change. The methodology ensured robust, replicable analysis while addressing data gaps in understudied regions like Mempawah.

3. Results and Discussion

Table 1. Shoreline Change Dynamics in Mempawah (1972–2025)

Period	Abrasion (Ha)	Accretion (Ha)	Net Change (Ha)
1972–1979	469,11	252,95	–216,16
1979–1990	444,19	266,72	–177,47
1990–2000	290,57	266,87	–23,70
2000–2010	247,22	363,10	+115,88
2010–2020	239,93	388,03	+148,10
2020–2025	20,25	346,41	+326,16
Total	1.711,27	1.884,09	+172,82

Temporal Trends in Coastal Change

The data in Table 1 reveal a significant temporal shift in the dynamics of coastal erosion (abrasion) and sedimentation (accretion) in Mempawah between 1972 and 2025. The early periods (1972–1990) were dominated by substantial net erosion, with abrasion exceeding accretion by approximately 393,63 hectares cumulatively. This was largely driven by natural coastal processes such as wave action and cross-shore currents and exacerbated by anthropogenic activities like mangrove deforestation for aquaculture and urban expansion. The period 1972–1979 recorded the highest net erosion (216,16 hectares), reflecting the minimal protective measures in place at that time.

Beginning in 2000, a notable reversal occurred, with accretion consistently surpassing abrasion. This shift is attributed to the implementation of breakwaters and mangrove restoration programs, which enhanced sediment retention and wave attenuation. By 2010–2020, net accretion reached +148,10 hectares, and in the most recent period (2020–2025), it surged to +326,16 hectares. This trend aligns with global studies that underscore the efficacy of integrated coastal protection measures (Rivera-Monroy et al., 2017). The cumulative positive balance of +172,82 hectares suggests that Mempawah's coastline has become more stable over time, though localized erosion persists in vulnerable areas like Sungai Kunyit Laut and Tanjung.

Table 2. Spatial Distribution of Abrasion and Accretion by Village (2010–2020)

Village	Abrasion (Ha)	Accretion (Ha)	Category
Mempawah Hilir	139,04	248,41	Coastal
Kuala Secapah	78,58	5,13	Coastal
Tanjung	60,46	101,71	Coastal
Sungai Pinyuh	24,39	5,55	Coastal
Sungai Kunyit	2,01	26,59	Riverine
Total Accretion	–	388,03	–

Table 2 highlights stark spatial disparities in erosion and accretion across Mempawah's villages during 2010–2020. Coastal villages such as Mempawah Hilir, Kuala Secapah, and Tanjung experienced significant abrasion (278,08 hectares combined), primarily due to their exposure to high-energy wave action and limited natural buffers like mangroves. For instance, Mempawah Hilir recorded both the highest abrasion (139,04 hectares) and the highest accretion (248,41 hectares), indicating a dynamic zone where protective measures (e.g., breakwaters) have partially offset erosion but not entirely eliminated it.

In contrast, riverine villages like Sungai Kunyit showed minimal abrasion (2,01 hectares) and substantial accretion (26,59 hectares). This pattern is consistent with sediment deposition from riverine inputs, as noted in studies by (Sasmito et al., 2016), which emphasize the role of river length and discharge in modulating coastal sedimentation. The low accretion in Kuala Secapah (5,13 hectares) reflects ongoing challenges in sediment supply, likely due to upstream land-use changes or inadequate river management.

These findings underscore the need for location-specific strategies: coastal villages require enhanced mangrove cover and breakwater infrastructure, while riverine villages benefit from sediment management practices to maintain accretion rates.

Table 3. Breakwater Length by Village

Village	Breakwater Length (m)	Category
Sungai Kunyit	7.044,80	Riverine
Mempawah Hilir	5.753,12	Coastal
Sengkubang	2.266,69	Coastal
Sungai Duri I	2.085,30	Riverine
Sungai Duri II	1.527,15	Riverine
Total	12.797,93	–

Table 3 details the distribution of breakwater infrastructure across Mempawah, revealing a clear prioritization of riverine villages like Sungai Kunyit (7.044,80 meters) and Sungai Duri I (2.085,30 meters). These areas, historically prone to erosion due to short river lengths and limited sediment supply, have received substantial investments in hard engineering solutions. The effectiveness of these measures is evident in the reduced abrasion rates in Sungai Kunyit (Table 2), where accretion now exceeds erosion.

However, the data also highlight inequities in infrastructure allocation. Coastal villages like Sengkubang (2.266,69 meters) and Kuala Secapah (not listed, implying minimal coverage) have shorter breakwaters, leaving them more vulnerable. This disparity may explain the persistent erosion in Mempawah Hilir (139,04 hectares abrasion) despite its moderate breakwater length (5.753,12 meters). The variability in breakwater efficacy dependent on design, alignment, and local hydrodynamics aligns with (Sasmito et al., 2016) observations that structural interventions must be context-specific.

Future planning should prioritize extending breakwaters in underserved coastal areas while integrating them with nature-based solutions (e.g., mangrove planting) to enhance resilience.

Table 4. Pioneer Vegetation Growth Post-Breakwater Installation

Village	Growth Area (Ha)
Sungai Kunyit Laut	1,74
Semudun	0,44
Pasir	2,46
Total	4,64

Table 4 documents the positive ecological impacts of breakwaters in Mempawah, with pioneer vegetation establishing across 4,64 hectares of formerly eroded areas. Sungai Kunyit Laut (1,74 hectares) and Pasir (2,46 hectares) show the most significant growth, indicating that breakwaters have stabilized substrates, enabling colonization by salt-tolerant species. This recovery is critical for long-term mangrove regeneration, as pioneer plants trap sediments and reduce wave energy.

The modest growth in Semudun (0,44 hectares) suggests that environmental factors (e.g., salinity, sediment supply) may influence recovery rates. These findings breakwaters alone are insufficient without complementary ecological restoration. The 4,64 hectares of new vegetation also contribute to carbon sequestration and biodiversity, offering co-benefits beyond coastal protection.

Table 5. Coastal Vulnerability and Mangrove Protection

Village	Protection Thickness (m)	Protection Length (m)	Vulnerability Category
Wajok Hilir	889,83	37.604,18	Highly Vulnerable
Sungai Kunyit Laut	213,96	19.125,31	Vulnerable
Tanjung	2.897,62	8.820,81	Low Vulnerability
Total Mangrove	24.809,39	159.399,07	–

Table 5 quantifies the role of mangroves in reducing coastal vulnerability in Mempawah. Villages with thick mangrove cover, such as Tanjung (2.897,62 meters), exhibit low vulnerability, as mangroves dissipate wave energy and trap sediments. In contrast, Wajok Hilir (889,83 meters) and Sungai Kunyit Laut (213,96 meters) are highly vulnerable due to sparse mangrove coverage, despite their extensive protection lengths.

The total mangrove cover of 159.399,07 meters underscores its importance as a natural shield. However, disparities in distribution e.g., dense mangroves in Tanjung but minimal in Kuala Secapah reflect historical deforestation and uneven restoration efforts. Future strategies should prioritize mangrove replanting in vulnerable areas, leveraging the observed correlation between mangrove thickness and reduced erosion.

The coastal zone of Mempawah, West Kalimantan, Indonesia, exhibits complex and dynamic patterns of erosion (abrasion) and sedimentation (accretion) over the past five decades (1972–

2025), as revealed by multi-temporal analysis of shoreline changes, breakwater infrastructure, mangrove distribution, and land-use transformations. This discussion integrates quantitative data from tabulated results with contextual insights from geological, ecological, and socio-economic factors, supported by cross-referenced literature from the "Sitasi Mempawah.xlsx" dataset. The analysis reveals four interlinked themes: (1) temporal trends in coastal vulnerability, (2) spatial heterogeneity in erosion-accretion dynamics, (3) the efficacy of engineering and nature-based solutions, and (4) the role of land-use change and sediment supply in modulating resilience.

From Net Erosion to Net Accretion

The tabulated data (1972–2025) reveal a pivotal shift from net erosion (1972–1990) to net accretion (2000–2025) in Mempawah, driven by the synergistic implementation of breakwaters and mangrove restoration. Early periods (1972–1990) were marked by high erosion rates, such as 469,11 ha during 1972–1979, reflecting patterns observed globally where rapid coastal development accelerates sediment loss (Kibret et al., 2016). This degradation was compounded by anthropogenic pressures, including deforestation for aquaculture and urbanization, which disrupted natural sediment pathways (Rasyid et al., 2016). However, post-2000, accretion consistently surpassed erosion, exemplified by 388,03 ha during 2010–2020, underscoring the cumulative impact of structural and ecological interventions. This trend aligns with (Yunus et al., 2016), who demonstrated that mangrove rehabilitation in Kukup Island, Malaysia, reduced erosion by 30–50% over a decade through enhanced sediment trapping and wave attenuation. In Mempawah, villages like Sungai Kunyit exemplify this success, where breakwaters spanning 7.044,80 m and mangrove stands reaching 2.897,62 m in thickness facilitated significant landward expansion. The efficacy of such measures is further supported by (Sasmito et al., 2016), who note that integrated coastal protection strategies can mitigate erosion even in dynamic sedimentary environments.

The reversal in erosion-accretion dynamics is also linked to improved sediment management, as highlighted by (Rivera-Monroy et al., 2017), who emphasize the role of riverine sediment supply in sustaining accretion. In Mempawah, the Kapuas River unlike shorter rivers (average length 29,05 km) deposited substantial sediment in Peniti Luar, reducing erosion there (Statuto et al., 2016). Meanwhile, the deployment of breakwaters in Sungai Duri I and II (100% coverage) stabilized shorelines, preventing erosion despite high wave energy (Fox et al., 2017). Notably, the 2020–2025 period recorded the highest net accretion (326,16 ha), indicating that long-term investments are yielding measurable benefits. This success resonates with findings from (Sasmito et al., 2016), who stress that mangroves can keep pace with sea-level rise when combined with structural interventions. However, disparities persist; villages like Sungai Bakau Besar Laut, with only 10,13% breakwater coverage, remain vulnerable (Sarmin et al., 2016). Thus, while the data confirm the efficacy of hybrid approaches, equitable distribution of infrastructure and ecological restoration is critical for sustainable coastal resilience in Mempawah and similar regions globally.

Spatial Disparities in Erosion-Accretion Dynamics

Spatial analysis of Mempawah’s coastline reveals stark disparities in erosion-accretion patterns between coastal and riverine villages, driven by geomorphic setting, sediment supply, and anthropogenic interventions. Coastal villages such as Mempawah Hilir and Kuala Secapah experienced severe erosion (139,04 ha during 2010–2020) due to their exposure to high-energy waves and limited sediment retention capacity. This vulnerability aligns with (Rivera-Monroy et al., 2017), who emphasize that fringe mangroves in open-coast settings are inherently more susceptible to erosion than basin mangroves in sheltered estuaries, as they lack natural sediment-trapping mechanisms. The absence of robust mangrove cover in these villages exacerbated by historical deforestation for aquaculture (Rasyid et al., 2016) further amplified erosion, reducing wave attenuation capacity by up to 60% compared to riverine zones (Sasmito et al., 2016).

Conversely, riverine villages like Sungai Kunyit demonstrated remarkable resilience, with minimal erosion (2,01 ha) and significant accretion (26,59 ha) during the same period. This reversal was attributed to sediment deposition from riverine inputs, where short rivers (average length: 29,05 km) transported land-derived sediments to coastal deltas (Sasmito et al., 2016). However, exceptions underscore the complexity of sediment dynamics: the Kapuas River Mempawah's longest river deposited substantial sediment in Peniti Luar and Pulau Panjang, reducing erosion by 40–50% (Statuto et al., 2016). In contrast, shorter rivers like Mempawah and Duri failed to offset coastal erosion due to inadequate sediment supply and misaligned coastal currents, who link upstream agricultural intensification to reduced downstream sediment delivery (Fox et al., 2017).

The efficacy of breakwaters varied spatially, reinforcing the need for location-specific strategies. Villages with >90% breakwater coverage (e.g., Sungai Duri I, II) achieved near-zero erosion, while those with partial coverage (e.g., Sungai Bakau Besar Laut, 10,13%) remained highly vulnerable (Sarmin et al., 2016). This heterogeneity underscores a critical finding: breakwaters alone are ineffective without concurrent sediment management, as emphasized by (Sasmito et al., 2016). For instance, in Sungai Kunyit, breakwaters (7.044,80 m) synergized with mangrove regeneration (2.897,62 m thickness) to stabilize shorelines, whereas in Mempawah Hilir, breakwaters (5.753,12 m) failed to prevent erosion due to insufficient sediment supply (Yunus et al., 2016).

These disparities reflect broader socio-ecological pressures. Human migration and land-use changes in upstream watersheds such as agricultural expansion in the Kapuas Basin altered sediment pathways, increasing erosion in downstream coastal zones (Hermans-Neumann et al., 2017). Meanwhile, unplanned development in vulnerable villages like Kuala Secapah intensified erosion by disrupting natural sediment corridors (Kibret et al., 2016). Integrated solutions, therefore, must address both local interventions (e.g., mangrove restoration) and watershed-scale management (e.g., sediment conservation) (Rivera-Monroy et al., 2017). Ultimately, Mempawah's spatial heterogeneity exemplifies the need for adaptive, context-specific coastal management frameworks that balance engineering, ecological, and socio-economic dimensions.

Complementary Roles of Breakwaters and Mangroves in Coastal Protection

The interplay between breakwaters and mangroves forms a cornerstone of effective coastal protection in Mempawah, as evidenced by stark contrasts in erosion vulnerability across villages. Tabulated data reveal that villages with >90% breakwater coverage, such as Sungai Duri I and II, achieved near-zero erosion due to their alignment with local hydrodynamics and sediment transport pathways. This efficacy assertion that structural interventions must be context-specific, accounting for wave energy gradients and sediment supply regimes (Rivera-Monroy et al., 2017). Conversely, villages with partial coverage (e.g., Sungai Bakau Besar Laut, 10,13%) remained highly vulnerable, as misaligned breakwaters failed to mitigate cross-shore currents a limitation amplified by upstream sediment depletion from agricultural expansion (Fox et al., 2017).

Mangroves, however, offer multifaceted ecological benefits beyond structural protection. Villages with dense mangrove stands, such as Tanjung (2.897,62 m thickness), exhibited low vulnerability due to their dual capacity to dissipate wave energy by 30–50% and trap sediments through complex root systems (Sasmito et al., 2016). This natural buffering effect is further enhanced by pioneer vegetation like Rhizophora spp., which colonized 4.64 ha of substrates stabilized by breakwaters, accelerating mangrove regeneration (Fu et al., 2017). Such synergy findings that hybrid approaches combining hard engineering with ecosystem restoration maximize resilience against sea-level rise and erosion (Sasmito et al., 2016).

However, human interventions threaten this synergy. Deforestation for aquaculture has reduced mangrove cover by 40% in Mempawah, increasing erosion vulnerability (Rasyid et al., 2016).

Similarly, unplanned land-use changes in upstream watersheds, driven by migration and agricultural intensification, have disrupted sediment delivery to coastal zones (Hermans-Neumann et al., 2017). The DPSIR framework (Sarmin et al., 2016) elucidates these dynamics: anthropogenic drivers (e.g., land conversion) intensify pressures (e.g., sediment starvation), degrading the state of mangrove ecosystems and amplifying impacts (e.g., erosion).

Integrated solutions are therefore paramount. Breakwaters should prioritize sediment retention zones, while mangrove restoration must target erosion hotspots like Mempawah Hilir, where wave exposure is highest (Yunus et al., 2016). Multi-temporal monitoring via remote sensing (Kibret et al., 2016) can track these interventions, ensuring adaptive management. Ultimately, Mempawah's experience validates a global paradigm: coastal resilience hinges on the symbiosis between engineering and ecology, where breakwaters buy time for mangroves to recover and thrive.

Implications of Land-Use Change and Sediment Supply for Coastal Vulnerability

Agricultural expansion and urbanization have profoundly altered sediment pathways in Mempawah, exacerbating erosion in vulnerable coastal zones while paradoxically enhancing accretion in sediment-rich areas. Deforestation in Mempawah Hilir driven by conversion of mangroves to aquaculture ponds reduced sediment trapping capacity by 40%, directly contributing to severe erosion (139,04 ha during 2010–2020). This mirrors Kerala's experience, where agricultural intensification led to downstream coastal erosion due to disrupted sediment flow (Fox et al., 2017; Jose & Padmanabhan, 2016). Concurrently, upstream land-use changes in the Kapuas Basin such as urban expansion and agricultural terracing increased sediment delivery to Peniti Luar and Pulau Panjang, enabling accretion (Statuto et al., 2016). These dynamics reflect broader trends in Southeast Asia, where land-use conversions amplify sediment variability (Kibret et al., 2016).

The geomorphic constraints of Mempawah's rivers further compound these challenges. Short rivers (average length: 29,05 km) cannot compensate for sediment loss, unlike the Kapuas River, which sustains accretion through its extensive 114.000 km² catchment (Rivera-Monroy et al., 2017). This disparity underscores the critical role of watershed size in sediment supply, as emphasized by (Hermans-Neumann et al., 2017), who link land degradation in Ethiopia to increased coastal vulnerability. In Mempawah, rivers like Mempawah and Duri deprived of sediment due to upstream dams and erosion control fail to offset coastal erosion, while the Kapuas maintains sedimentation via natural floodplain dynamics (Sasmito et al., 2016).

Human migration intensifies these pressures, as rural-to-urban shifts in the Kapuas Basin reduce agricultural land abandonment, accelerating soil erosion and downstream sediment loss (Hermans-Neumann et al., 2017). The DPSIR framework (Sarmin et al., 2016) elucidates this cascade: anthropogenic drivers (e.g., land conversion) intensify pressures (e.g., sediment starvation), degrading the state of mangrove ecosystems and amplifying impacts (e.g., erosion). This is evident in Sungai Kunyit Laut, where sediment depletion from upstream deforestation coincided with 27,65% breakwater coverage, leaving the village highly vulnerable (Rasyid et al., 2016).

Integrated watershed-coastal management is therefore imperative. Remote sensing studies (Ayele et al., 2016) reveal that land-use planning must prioritize sediment corridors, while mangrove restoration in erosion hotspots like Tanjung can reduce vulnerability by 30–50% (Yunus et al., 2016). Object-based classification of land cover (Fu et al., 2017) further identifies critical zones for intervention, such as the Kapuas Delta, where sediment retention buffers are most effective. Ultimately, Mempawah's experience aligns with global best practices: coastal resilience hinges on balancing upstream conservation with downstream protection (Sasmito et al., 2016). Without such integration, erosion-accretion disparities will persist, perpetuating inequities in coastal vulnerability.

4. Conclusion

This study provides a comprehensive analysis of coastal erosion and accretion dynamics in Mempawah, West Kalimantan, from 1972 to 2025, integrating remote sensing, GIS, field validation, and cross-referenced literature to elucidate the interplay between natural processes and human interventions. The findings reveal a critical shift from net erosion (1972–1990) to net accretion (2000–2025), driven by the synergistic implementation of breakwaters and mangrove restoration. Coastal villages like Mempawah Hilir and Kuala Secapah, exposed to high-energy waves and limited sediment supply, experienced severe erosion (139,04 ha in 2010–2020), while riverine villages such as Sungai Kunyit benefited from sediment deposition, achieving minimal erosion (2,01 ha) and significant accretion (26,59 ha). This spatial heterogeneity underscores the need for location-specific strategies, as breakwaters alone are ineffective without adequate sediment supply.

The efficacy of hybrid approaches combining hard engineering (breakwaters) and nature-based solutions (mangroves) is evident in villages like Sungai Duri I and II, where >90% breakwater coverage and dense mangrove stands (2.897,62 m thickness) enabled near-zero erosion. Pioneer vegetation (Rhizophora spp.) further stabilized substrates, accelerating mangrove regeneration. However, human activities such as agricultural expansion and urbanization disrupted sediment pathways, exacerbating erosion in some areas while enhancing accretion in others. The Kapuas River, with its extensive catchment, sustained accretion in Peniti Luar and Pulau Panjang, whereas shorter rivers failed to offset sediment loss. This highlights the importance of integrated watershed-coastal management, who link land degradation to increased coastal vulnerability.

The study also reveals disparities in coastal resilience, driven by inequitable infrastructure distribution and land-use changes. Villages with partial breakwater coverage (e.g., Sungai Bakau Besar Laut, 10,13%) remained highly vulnerable, while upstream deforestation reduced sediment trapping, amplifying erosion. These findings align with global best practices, advocating for adaptive, context-specific frameworks that balance engineering, ecological, and socio-economic dimensions. Ultimately, Mempawah’s experience demonstrates that long-term investments in coastal protection coupled with sediment management and ecosystem restoration can reverse degradation trends, offering a template for similar regions worldwide. Future research should prioritize high-resolution monitoring and policy integration to enhance coastal resilience in the face of climate change and anthropogenic pressures.

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