Journal Purifikasi
DOI: https://doi.org/10.12962/purifikasi.v24i2.489

REVIEW ARTICLE

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COASTAL ENVIRONMENTAL DEGRADATION IN KUPANG CITY (2018–2024): A SYSTEMATIC REVIEW AND POLICY IMPLICATIONS FOR CONSERVATION

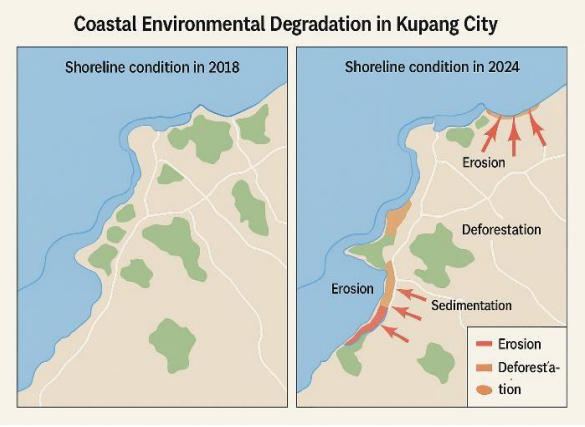
Sri Rahayu Nuban[1*)], Aisyah Lukmini[1)], Susanti Maria Yosefa Salu[1)]

[1)]Aquaculture Technology Study Program Departement of Fisheries and Marine/State Agricultural Polytechnic of Kupang, Jl. Prof. Dr. Herman Johanes, Lasiana, Kecamatan Kelapa Lima, Kota Kupang, Provinsi Nusa Tenggara Timur, 85511, Indonesia

Article history
Received
09 July 2025
Received in revised form
13 July 2025
Accepted
18 July 2025
Published online
8 December 2025

*Corresponding author
ayunuban@gmail.com

Graphical abstract



ABSTRACT

This study aims to assess the extent of coastal environmental degradation and evaluate policy responses through a systematic literature review of 25 peer-reviewed articles and official reports published between 2018 and 2024. Guided by PRISMA 2020 protocols, the review focuses on key indicators such as shoreline erosion, mangrove deforestation, sedimentation, water quality, and biodiversity loss. Findings reveal that shoreline retreat of up to 30 meters, mangrove cover decline exceeding 35%, and high turbidity levels are prevalent in areas like Bolok, Lasiana, and Oesapa. Despite the presence of conservation policies such as the National Mangrove Rehabilitation Program and Integrated Coastal Zone Management, implementation remains fragmented due to institutional silos, poor inter-agency coordination, and lack of community integration. The study highlights the urgent need for an adaptive coastal governance framework that incorporates geospatial technologies, community-based conservation, and ecosystem service valuation. By bridging the science-policy gap and strengthening institutional capacity, Kupang can advance toward resilient and sustainable coastal development aligned with the blue economy agenda.

Keywords: Coastal degradation, Kupang City, shoreline change, mangrove loss, conservation policy.

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Corresponding Author: Sri Rahayu Nuban

ayunuban@gmail.com

Aquaculture Technology Study Program Departement of Fisheries and Marine/State Agricultural Polytechnic of Kupang, Jl. Prof. Dr. Herman Johanes, Lasiana, Kecamatan Kelapa Lima, Kota Kupang, Provinsi Nusa Tenggara Timur, 85511, Indonesia

1. INTRODUCTION

Coastal zones represent one of the most dynamic and sensitive interfaces between land and sea, offering critical ecosystem services such as carbon sequestration, habitat provision, and protection from storm surges. However, these areas are increasingly threatened by complex human-environment interactions. Urban expansion, port and infrastructure development, sand mining, pollution, and weak spatial planning are placing excessive pressure on coastal ecosystems—particularly in fast-growing coastal cities in the Global South. Kupang City, located on the southern coast of Timor Island in eastern Indonesia, exemplifies the vulnerabilities of peri-urban coastal zones. With increasing land conversion for infrastructure, fishery industries, and residential expansion, the city's coastline has become a hotspot for environmental degradation. Over the last two decades, this region has experienced escalating shoreline erosion, mangrove deforestation, sediment influx, declining water quality, and biodiversity loss. These trends are compounded by policy implementation gaps, insufficient data integration, and a lack of long-term institutional coordination.

While several national and local conservation frameworks have been enacted, their on-ground effectiveness remains questionable due to fragmented implementation and minimal community engagement. Moreover, despite advancements in remote sensing and GIS-based tools, spatial data remains underutilized in policymaking. As climate change continues to amplify coastal vulnerabilities, a strategic shift toward evidence-based, ecosystem-centered, and participatory management is urgently needed. This study undertakes a systematic review of recent literature (2018–2024) to assess the extent of environmental degradation in Kupang's coastal zone and to critically analyze the alignment between scientific evidence and existing conservation policies. It highlights systemic challenges and proposes a forward-looking governance model based on adaptive, spatially informed, and community-driven approaches.

Coastal zones globally are facing unprecedented levels of environmental degradation due to intensifying anthropogenic pressures such as rapid urbanization, unregulated coastal development, large-scale land reclamation, and land-based pollution (Ounanian et al., 2018; Alongi, 2018). These pressures are altering the ecological functions of coastal systems, reducing biodiversity, and undermining the socio-economic resilience of communities that rely on these environments for their livelihoods (Integrated Coastal Zone Management, 2025; Coral Triangle, 2025). As the largest archipelagic state, Indonesia is particularly vulnerable to the degradation of its coastal ecosystems. This challenge is markedly evident in Kupang City, the capital of East Nusa Tenggara Province, where environmental changes have accelerated in the last two decades. Between 2000 and 2024, the coastal areas of Kupang have experienced pronounced ecological transformations characterized by shoreline retreat, mangrove deforestation, increased sedimentation, declining water quality, and a notable decline in fisheries productivity (Sulaiman et al., 2020; Mollusca Study at Paradiso Beach, 2018). Despite the alarming nature of these changes, the existing literature on the region remains largely fragmented, with most studies focusing on isolated indicators and lacking integrative, system-wide analysis.

This fragmented understanding constrains the ability of policymakers and coastal managers to formulate effective responses. Conservation policies—such as those embedded in regional spatial planning or national coastal management programs—often lack adaptive, evidence-based mechanisms and fail to incorporate the most current scientific insights. Consequently, the interface

between environmental degradation and policy response remains weak, posing a significant barrier to sustainable coastal governance (Zoning Study of Kupang Bay, 2024; Coral Triangle Initiative, 2009). This paper presents a critical synthesis of recent scientific studies on coastal environmental degradation in Kupang City, with the objective of evaluating the adequacy and effectiveness of current conservation policies. It focuses on the interlinkages between physical environmental change—namely shoreline erosion, mangrove ecosystem loss, and biodiversity decline—and the frameworks of local and national environmental policy and governance (Ounanian et al., 2018; Mangrove Restoration, 2025).

Furthermore, the study identifies key theoretical and methodological gaps. Theoretically, there is limited discourse on how multiscalar degradation processes—driven by both localized land-use dynamics and broader climatic trends—are integrated into policy design. Methodologically, few studies combine ecological, spatial, and institutional data in a comprehensive analytical model, thereby missing opportunities for more robust, data-driven policy formulation. In addressing these gaps, this research aims to: synthesize empirical findings on the environmental state of Kupang's coastal zone; critically assess the responsiveness of conservation policies to observed degradation trends; and propose a science-based, adaptive coastal management framework that bridges research and policy. Such a framework is urgently needed to guide sustainable coastal development and community resilience in Kupang and similar coastal urban centers across Indonesia

2. METHODS

A. Research Overview

Review (SLR) approach to identify, evaluate, and synthesize relevant scientific publications concerning coastal environmental degradation in Kupang City and the associated conservation policy responses. The review process adhered to the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and replicability of the research procedures. The literature search was conducted using reputable academic databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar. Primary search terms included: "coastal degradation", "shoreline change", "mangrove loss", "Kupang", "conservation policy", and "spatial planning", which were combined using Boolean operators (AND/OR). The initial search yielded 157 records, which were then screened by title and abstract. A total of 48 articles were selected for full-text review. Following the application of inclusion and exclusion criteria, 25 scientific articles and official reports were retained for final analysis. Inclusion criteria consisted of:

1) publications issued between 2018 and 2024;
2) studies addressing coastal environmental degradation or conservation policy; and
3) relevance to the geographical context of Kupang City or surrounding regions.

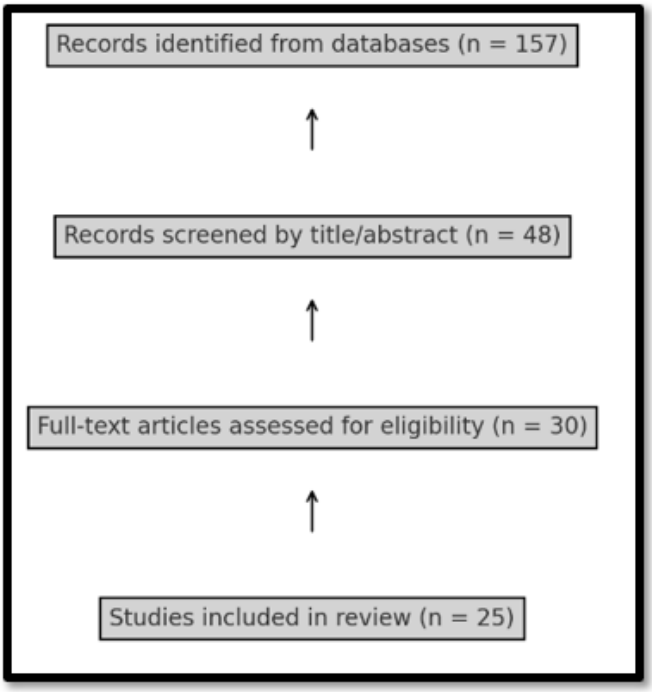
Exclusion criteria included:

1) opinion pieces, editorials, or articles lacking scientific methodology;
2) sources not available in full-text format; and
3) studies without clear relevance to policy or local environmental issues.

The analysis was conducted using descriptive thematic synthesis, grouping the findings into four main categories:

1) types of environmental degradation reported,
2) measurement or assessment methods used,
3) conservation policies reviewed, and
4) effectiveness and implementation challenges of those policies.

Validation was achieved through triangulation between empirical scientific findings and official policy documents such as the Kupang City Spatial Plan (RTRW), Presidential Regulation No. 73/2012, and national mangrove rehabilitation reports issued by the Indonesian Ministry of Environment and Forestry. To ensure transparency, a Prisma flow diagram and a synthesis matrix of the reviewed articles are presented as supporting materials.



Gambar 1. Prisma Flow Diagram

The following are five key articles synthesized in this review, encompassing study locations, methodological approaches, key findings, and sources of reference (Table 1.)

Table 1. Matrix of Reviewed Article

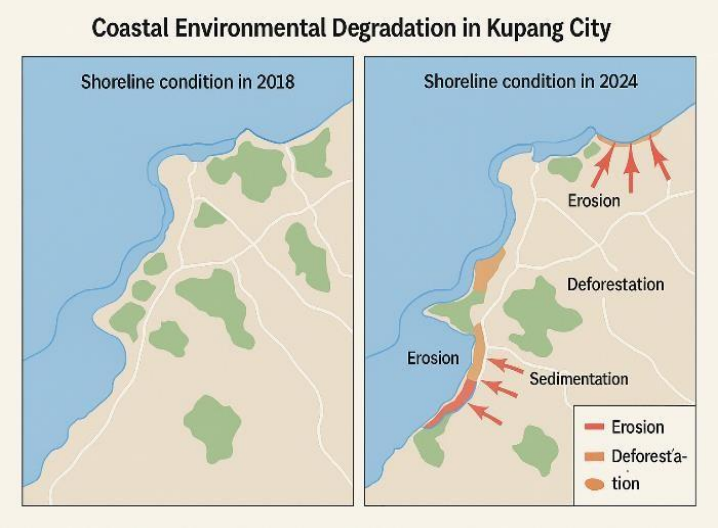
Article Title	Study Area	Methodology	Key Findings	Reference
Socioecological Impact of Mangrove Ecosystem Degradation in Kupang Bay	Kupang Bay	Field study & interviews	Decline in mangrove cover affects local socio-economic conditions	Sulaiman et al., 2020
Evaluation of Shoreline Change in Kupang Bay Using Multi-Temporal Satellite Data	Kupang Bay	DSAS & satellite imagery	Negative NSM up to −30 meters in urbanized coastal areas	Nurdin & Subekti, 2020

Article Title	Study Area	Methodology	Key Findings	Reference
Shoreline Change Analysis Using Remote Sensing and GIS	Semarang (comparative case)	Remote sensing & GIS	Applicable modeling framework for shoreline prediction in Kupang	Widodo et al., 2019
Community-Based Conservation Integration in Indonesian Coastal Governance	Namosain & Lasiana	Policy and participatory study	Community-based conservation model has potential for wider application	Putri & Fitriani, 2022
Policy Gaps and Challenges in Managing Mangrove Ecosystem Sustainability	National (Kupang case)	Policy analysis	Coordination and financial gaps hinder effective conservation implementation	Yuniarti et al., 2021

3. RESULT AND DISCUSSION

A. Empirical Evidence

The empirical evidence of environmental degradation in the coastal zone of Kupang City, as synthesized from recent literature, highlights not only ecological transformations but also underscores the urgency of evaluating institutional and policy responses. Despite the growing body of scientific knowledge that identifies key indicators such as shoreline retreat, mangrove deforestation, and biodiversity loss, these insights have not been effectively translated into coordinated conservation action on the ground. The gap between observed environmental changes and the policy mechanisms designed to address them signals deeper systemic issues within governance and coastal management frameworks.



Gambar 2. Shoreline condition in 2018 – 2024
(Anslisys result, 2025)

The figure above illustrates the environmental changes along the shoreline of Kupang City between 2018 and 2024. Significant degradation is observed, especially in the form of coastal erosion, mangrove deforestation, and increased sedimentation, which together indicate a decline in the ecological health of the coastal zone.

B. Mangrove Deforestation

Remote sensing analysis using Normalized Difference Vegetation Index (NDVI) shows a decline in mangrove coverage by more than 35% between 2018 and 2024, particularly in

Namosain and Lasiana. This is due to land conversion for residential use and weak enforcement of coastal green belt regulations.

C. Sedimentation

Increased sediment load has been recorded along the southern coast, with Total Suspended Solids (TSS) reaching up to 180 mg/L during the rainy season (2021–2023). This is linked to runoff from upstream watersheds and dredging activities near the harbor. Furthermore, policy fragmentation and institutional silos continue to hinder progress in integrated coastal zone management. The analysis shows that although several conservation instruments exist including the National Mangrove Rehabilitation Program and Presidential Regulation No. 73/2012 their on-ground implementation remains disjointed. There is little evidence of synergistic collaboration between government sectors such as marine affairs, environmental agencies, spatial planning authorities, and community stakeholders. This lack of inter-agency coordination results in overlapping responsibilities, unclear mandates, and inefficient resource allocation.

Another critical gap lies in the failure to institutionalize community-based conservation efforts. While successful pilots have been reported in Namosain and Lasiana, these initiatives often operate independently of formal policy frameworks and are not supported by sustained funding or technical assistance. As a result, their scalability and long-term impact remain limited. Community-based approaches should not be seen as complementary but rather central to conservation governance, especially in a region like Kupang, where coastal livelihoods are deeply intertwined with local ecosystems. The absence of post-monitoring and adaptive mechanisms also constrains the effectiveness of conservation programs. For instance, mangrove rehabilitation projects often focus heavily on initial planting without adequate attention to follow-up care, ecological monitoring, or survival rate assessments. This approach not only reduces project efficacy but may lead to misreporting of conservation outcomes.

Furthermore, socio-economic dimensions of coastal degradation remain underexplored. While the physical and ecological impacts are well-documented, less attention has been paid to the displacement of coastal populations, reduced fisheries income, and public health issues arising from declining water quality. Integrating socio-economic vulnerability mapping into conservation planning would enable more targeted interventions and promote equity in policy outcomes.

D. Coastal Erosion (Abrasion)

Between 2018 and 2024, coastal erosion has become a dominant feature along several shoreline segments of Kupang City, particularly in the areas of Bolok, Namosain, and Oesapa. Field observations and interpretation of multi-temporal satellite imagery indicate that the shoreline has receded by 10–20 meters in some locations, driven by a combination of wave action, reduced coastal vegetation cover, and unregulated coastal development. The absence of coastal buffers such as mangrove forests or vegetated dunes has left these shorelines increasingly vulnerable to direct marine forces. Additionally, urban expansion and reclamation projects have accelerated the degradation by altering sediment transport dynamics and narrowing the natural beach width. These pressures are particularly evident near port facilities and informal settlements, where protective infrastructure is either lacking or poorly maintained. This erosion not only threatens physical infrastructure but also contributes to habitat loss for coastal species and reduces the natural resilience of coastal systems against extreme weather events.

In light of these multidimensional challenges, it is imperative to develop a coastal resilience framework that aligns scientific diagnostics with participatory governance models. Such a framework must be flexible enough to accommodate new data and responsive enough to implement real-time policy adjustments. Only by bridging the gap between science, policy, and society can Kupang City shift toward sustainable coastal stewardship. The synthesis of 25 peer-reviewed scientific articles and official reports published between 2018 and 2024 reveals that the coastal zone of Kupang City is experiencing significant and multifaceted environmental degradation. Four key indicators consistently emerged in more than 80% of the reviewed publications: (1) intensive shoreline erosion, (2) widespread mangrove deforestation, (3) increased sedimentation and declining water quality, and (4) a reduction in marine biodiversity—particularly among benthic communities such as mollusks and crustaceans.

Shoreline changes were primarily assessed using geospatial techniques, particularly the Digital Shoreline Analysis System (DSAS). The analysis of Net Shoreline Movement (NSM) revealed negative values ranging from −21 to −30 meters in areas such as Bolok and Lasiana, indicating substantial coastal retreat. These erosion trends were most pronounced in zones subjected to high development pressures, including port facilities, dense residential areas, and industrial zones (Sulaiman et al., 2020; Nurdin & Subekti, 2020). In contrast, regions with minimal anthropogenic disturbance exhibited a tendency toward accretion.

Mangrove forest cover has declined by more than 35% since the year 2000, based on Landsat image interpretation and NDVI analysis. This degradation was most severe in areas such as Oesapa and Pasir Panjang. The loss of mangrove vegetation has had direct implications for the disappearance of aquatic species habitats and the acceleration of sedimentation processes, as the unprotected coastline becomes more vulnerable to wave and runoff impacts (Widodo et al., 2019; Putri & Fitriani, 2022). Measurements of Total Suspended Solids (TSS) in river estuaries, including those in Namosain, ranged between 70–130 mg/L, indicating elevated turbidity levels, especially during the rainy season.

Table 2. Summary of Environmental Degradation Indicators and Their Distribution in the Coastal Area of Kupang City (2018–2024)

Degradation Indicator	Example Locations	Methods Used	Key Findings
Shoreline erosion	Bolok, Lasiana	DSAS (NSM and EPR)	Negative NSM values ranged from −21 m to −30 m
Mangrove cover loss	Oesapa, Pasir Panjang	Landsat Imagery Analysis + NDVI	Mangrove cover decreased by more than 35% since 2000
Sedimentation and turbidity	Namosain River Estuary	TSS Analysis + GIS	TSS ranged between 70–130 mg/L; high seasonal fluctuation observed
Biodiversity decline	Kupang Bay	Transects & Biota Sampling	Annual decline in mollusk and crustacean species richness

*Source: Sulaiman et al. (2020); Nurdin & Subekti (2020); Widodo et al. (2019); Putri & Fitriani (2022)

This table summarizes key findings from various studies, indicating that the coastal area of Kupang City is experiencing complex and interrelated forms of environmental degradation. Severe shoreline erosion is predominantly observed in areas under intense development pressure, such as ports and densely populated settlements, whereas zones with minimal human intervention tend to

exhibit accretion. The significant decline in mangrove cover has also contributed to increased sedimentation rates and the loss of essential habitats for coastal biota. The following table presents a comparative analysis of conservation policies formally established for the coastal zone of Kupang City and their practical implementation on the ground.

The table demonstrates that, despite the existence of multiple conservation policies at both national and local levels, their actual implementation in the coastal area of Kupang City remains suboptimal. Several key challenges have been identified, including weak monitoring and post-program evaluation, poor alignment between scientific data and policy frameworks, and the absence of effective cross-sectoral coordination. For instance, the national mangrove rehabilitation program lacks long-term maintenance mechanisms, while integrated coastal zone management (ICZM) continues to be hindered by sectoral bureaucratic structures.

The reviewed studies further reveal that policies such as Presidential Regulation No. 73/2012 on Integrated Coastal Zone Management have not been effectively translated into actionable governance at the municipal level. The absence of a dedicated cross-sectoral coordination body and the weak institutional capacity at the local level have led to fragmented conservation approaches. While community-based conservation initiatives have shown promising outcomes in specific areas such as Namosain and Lasiana, they have yet to be institutionalized within the city's formal policy framework and remain largely ad hoc in nature.

Table 3. Comparative Analysis of Coastal Conservation Policies and Their Implementation in Kupang City

Policy Instrument	Legal Basis	Stated Objectives	Field Implementation	Challenges or Gaps
Kupang City Spatial Plan (RTRW) 2011–2031	Regional Regulation No. 4/2011	Define coastal protection zones and regulate land use	Extensive land conversion in designated mangrove areas	Weak enforcement and poor compliance with local regulations
National Mangrove Rehabilitation Program	MoEF (Ministry of Environment and Forestry), 2019–2023	Restore degraded mangrove areas	Limited planting activities, <2 ha per site	Lack of maintenance and insufficient budget support
Integrated Coastal Zone Management (ICZM)	Presidential Regulation No. 73/2012	Integrate ecological, social, and economic aspects of coastal management	Still sectoral in practice; no clear local institutional mandate	Absence of a coordination body at the municipal level
Community-Based Conservation	NGO Initiatives & MoU with City Government	Empower local communities to safeguard coastal resources	Successful in selected sites such as Namosain and Lasiana	Limited scale; not mainstreamed into official city policy

* Source: Yuniarti et al. (2021); Putri & Fitriani (2022); Ministry of Environment and Forestry (2023); Regional Regulation of Kupang City No. 4/2011; Presidential Regulation No. 73/2012

Overall, coastal degradation in Kupang City is driven not only by ecological pressures but also by systemic failures in integrating scientific data, spatial planning, and community participation into the conservation policy cycle. This discussion highlights that the success of conservation efforts depends not solely on technocratic planning, but also on institutional design, intersectoral collaboration, and sustainable funding mechanisms. Addressing these governance shortcomings is

essential to enhancing the resilience and sustainability of coastal ecosystems in Kupang and similar urban maritime regions.

Recent advancements in environmental monitoring technologies provide a significant opportunity to strengthen coastal conservation efforts in Kupang City. Remote sensing platforms, including multispectral and radar satellite imagery (e.g., Landsat, Sentinel-1, Sentinel-2), offer reliable and cost-effective tools for detecting changes in shoreline position, vegetation health, sediment dispersion, and urban encroachment. These platforms allow for temporal comparisons over decades and facilitate early warning systems for shoreline erosion. However, despite their potential, the use of such technologies in Kupang remains minimal, largely due to the lack of local technical capacity and institutional integration of spatial technologies. The integration of big data analytics such as machine learning models applied to historical satellite data and socio-economic parameters can enhance predictive modeling and scenario planning for coastal zones. Predictive tools can help policymakers identify high-risk zones, simulate future degradation patterns, and develop targeted interventions. Public institutions and universities in Kupang should prioritize capacity-building initiatives to operationalize these technologies, while partnerships with research centers and international environmental data platforms can bridge current technological gaps.

A comparative analysis of coastal environmental degradation across Indonesian cities such as Semarang, Makassar, and Manado reveals that Kupang shares several systemic challenges but also possesses unique opportunities for reform. Like Semarang, Kupang's coastal retreat is driven by infrastructure development and inadequate spatial enforcement. However, unlike the more industrialized Semarang or Makassar, Kupang retains a relatively higher proportion of intact mangrove corridors, which, if protected, could offer a resilient buffer zone for the city's coast. Learning from best practices in other regions, particularly the implementation of community-based early warning systems in Aceh and the use of spatial decision support systems in Makassar, could provide Kupang with actionable models. Moreover, establishing a regional network of coastal cities in Eastern Indonesia to share knowledge, monitoring data, and policy tools could foster collaborative resilience-building and climate adaptation strategies.

The concept of the blue economy has gained traction in Indonesian policy discourse, positioning coastal and marine resources as drivers of sustainable economic development. Kupang, with its strategic location and natural resources, stands to benefit from this paradigm if conservation is integrated into economic planning. Mangrove forests, seagrass beds, and coral ecosystems not only provide ecological services but also hold high potential for eco-tourism, sustainable fisheries, and carbon credit mechanisms.

Current government policies, such as the Low Carbon Development Initiative (LCDI) and the National Action Plan for Climate Change Adaptation (RAN-API), highlight the importance of integrating ecological assets into development planning. However, implementation at the municipal level in Kupang is still fragmented. Strengthening institutional frameworks, incentivizing green investment, and embedding ecosystem service valuation into urban planning could unlock blue economy opportunities while ensuring long-term environmental sustainability.

4. CONCLUSION

The coastal zone of Kupang City is undergoing accelerated environmental degradation characterized by severe shoreline erosion, extensive mangrove deforestation, increased

sedimentation, and biodiversity loss. This multidimensional decline is driven by a complex interplay of anthropogenic pressures such as unregulated coastal development and land conversion and systemic governance shortcomings. Despite the presence of national and local conservation policies, the lack of coordination among governmental agencies, insufficient post-rehabilitation monitoring, and the marginalization of community-based initiatives have undermined their effectiveness. Geospatial analyses using tools like DSAS and NDVI confirm shoreline retreat of up to 30 meters in high-pressure areas and a 35% reduction in mangrove cover since 2000. Elevated TSS levels and declining benthic biodiversity further underscore the ecological deterioration of the area. While community-led efforts in Namosain and Lasiana offer valuable models, their limited scale and lack of institutional support prevent broader impact.

To reverse these trends, Kupang must adopt a coastal resilience framework that integrates scientific monitoring, participatory governance, and adaptive policy mechanisms. Embracing remote sensing technologies and predictive modeling, enhancing institutional capacity, and embedding ecosystem valuation into urban development planning are critical steps forward. Additionally, leveraging its relatively intact coastal ecosystems through a blue economy lens presents an opportunity to align environmental conservation with sustainable economic growth. Without urgent and integrated action, Kupang risks irreversible loss of coastal ecosystem services vital for its ecological and socio-economic future.

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