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Artikel riset

Qualitative assessment of riparian vegetation and management options for flood mitigation in The Satui River, South Kalimantan

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Abstract

The Satui River in South Kalimantan, Indonesia, faces significant riparian landscape degradation due to settlements, erosion, and land-use changes, which have intensified flood and landslide risks. This study provides an exploratory assessment of the current ecological functions of the riparian landscape of the river and identifies potential strategies for flood risk mitigation. An exploratory, descriptive qualitative approach was employed, involving field surveys to evaluate the existing vegetation and a literature review of local management plans. Due to the current lack of detailed quantitative data, management strategies and vegetation effectiveness were evaluated using a qualitative rating scale of high (H), medium (M), and low (L) based on technical effectiveness, sustainability, and community adaptation criteria. Field observations revealed that the existing vegetation is dominated by fruit trees and shallow-rooted plants, such as *Mangifera indica* and *Musa paradisiaca*, which offer limited riverbank stabilization and habitat support. Qualitative analysis suggests that integrated strategies—combining watershed-scale conservation, riparian corridor restoration, and selective structural measures— should be prioritized for sustainable risk reduction over isolated hard-engineering solutions. Specific recommendations include implementing nature-based solutions, such as vetiver (*Chrysopogon zizanioides*) for edge reinforcement, reforestation of the upper watershed, and adaptive management involving local communities. While these strategies show high potential in a qualitative framework, the study notes that empirical data on the effectiveness of nature-based solutions in humid tropical regions remain limited, highlighting the need for further quantitative research and pilot projects to validate these findings.

Intisari

Sungai Satui di Kalimantan Selatan, Indonesia, menghadapi degradasi lanskap riparian yang signifikan akibat permukiman, erosi, dan perubahan penggunaan lahan, yang telah meningkatkan risiko banjir dan longsor. Studi ini memberikan penilaian eksploratif terhadap fungsi ekologi lanskap riparian sungai saat ini serta mengidentifikasi strategi potensial untuk mitigasi risiko banjir. Pendekatan kualitatif eksploratif dan deskriptif digunakan, melibatkan survei lapangan untuk mengevaluasi vegetasi yang ada serta tinjauan literatur terhadap rencana pengelolaan lokal. Karena saat ini data kuantitatif rinci masih minim, strategi pengelolaan dan efektivitas vegetasi dievaluasi dengan menggunakan skala penilaian kualitatif Tinggi (T), Sedang (S), dan Rendah (R) berdasarkan efektivitas teknis, keberlanjutan, dan adaptasi masyarakat. Observasi lapangan menunjukkan bahwa vegetasi yang ada didominasi oleh pohon buah dan tanaman berakar dangkal, seperti Mangifera indica dan Musa paradisiaca, yang hanya memberikan stabilisasi tepi sungai dan dukungan habitat yang terbatas. Analisis kualitatif menyarankan bahwa strategi terintegrasi—yang mengombinasikan konservasi skala daerah aliran sungai, restorasi koridor riparian, dan langkah struktural terpilih—diprioritaskan untuk penurunan risiko berkelanjutan dibandingkan solusi rekayasa keras yang berdiri sendiri. Rekomendasi spesifik meliputi penerapan solusi berbasis alam seperti vetiver (Chrysopogon zizanioides) untuk memperkuat tepian, reforestasi daerah hulu, dan pengelolaan adaptif yang melibatkan masyarakat lokal. Meskipun strategi-strategi ini menunjukkan potensi tinggi dalam kerangka kualitatif, studi ini mencatat bahwa data empiris mengenai efektivitas solusi berbasis alam di wilayah tropis lembap masih terbatas, sehingga menyoroti perlunya penelitian kuantitatif lebih lanjut serta proyek percontohan untuk memvalidasi temuan eksploratif ini.

Kata kunci:
Lanskap riparian, Mitigasi banjir, Adaptasi perubahan iklim, Sungai Satui, Ketahanan lingkungan

1. Introduction

Riparian landscapes, which are border zones between land and bodies of water, play a critical role in ecosystems by controlling erosion, filtering pollutants, providing habitat for biodiversity, mitigating floods, and supporting adaptation to climate change. Resilient landscape design principles emphasize the integration of green infrastructure (riparian vegetation and buffer zones) and blue infrastructure (water elements such as natural channels and floodplains) to create holistic and adaptive systems, in contrast to conventional approaches that rely on hard infrastructure such as concrete channels (Irvine et al., 2023; Rosa et al., 2020). The integration of green and blue infrastructure is not only effective in flood mitigation but also enhances environmental quality, provides wildlife habitat, and supports community well-being through multifunctional green open spaces by involving various stakeholders in long-term implementation and maintenance (Anguelovski et al., 2018; Symmank et al., 2020). The management of buffer zones in Indonesia is regulated by Law No. 32 of 2009 on Environmental Protection and Management and Government Regulation No. 21 of 2008 on Watershed Management. These regulations emphasize the importance of conserving protected areas and implementing vegetative buffer zones to reduce erosion. Despite the established ecological importance of riparian zones, the Satui River has experienced significant landscape degradation, where native vegetation has been largely replaced by residential settlements and cultivated species such as mango, banana, and oil palm. This shift has resulted in a riparian corridor with limited soil stabilization and increased vulnerability to the region's historically recurrent flooding, which has been recorded from 2006 to 2024. Although general restoration principles exist, there is a distinct lack of site-specific qualitative assessments for the Satui River to guide practical management when detailed quantitative data are not yet available. Therefore, this study aimed to assess the current condition of riparian vegetation in the Satui River, evaluate its qualitative role in flood mitigation, and formulate management recommendations to enhance the resilience of the riparian landscape. Overall, this study does not attempt to determine casual relationships quantitatively, but rather describes phenomena in order to formulate adaptive management recommendations for the government and local communities.

2. Materials and Methods

2.1 Study Area

This study focuses on The Satui River, which spans 3.000 m with coordinates 3°46'41.9"S 115°24'21.9"E, located in the Satui District, Tanah Bumbu Regency, South Kalimantan Province (figure 1). The river basin features flat topography and a dendritic drainage pattern, physical attributes that naturally make the area prone to hydrological complexity and recurring floods from 2006–2024. The impact of flooding on settlements along the river includes physical damage to homes and infrastructure. The main factors driving this degradation include the rapid expansion of settlements into riparian zones, intensive mining activities within the watershed area, and the accelerated riverbank erosion. These human pressures have led to significant fragmentation of the riparian corridor and a decrease in "edge roughness," which is crucial for reducing flow energy and maintaining ecological connectivity.

2.2 Field Survey Design

Field observations were conducted in November 2024 using a systematic approach. The variables observed included the types of vegetation and settlements along the riverbanks. The purpose of this study was to obtain a comprehensive overview of the river riparian resilience phenomenon based on the types of plants and riverbank conditions studied. The observation stage included identifying the types of vegetation growing along the riverbanks, observing environmental and social factors that influence riverbank conditions, such as riverbank erosion, mining activities, and riverside settlements, and documenting and mapping riverbank cover. The observation results will be qualitatively assessed to develop recommendations for environmental management and sustainable flood-risk mitigation.

2.3 Secondary Data Source

To ensure that the proposed strategies align with regional hydrological planning, this study integrated planning data and management targets from government agencies. The planning data is sourced from South Kalimantan Province in a report titled "Technical Study of Flood Mitigation for the Satui River in Tanah Bumbu Regency," as well as from Tanah Bumbu Regency in a report titled "Analysis of Hydrological and Hydrometric Characteristics of the Satui River Basin." The planning data were collected and classified based on the scope of interventions, then analyzed using a qualitative assessment scale based on risk level, impact, and effectiveness to identify the most urgent management priorities according to the level of risk faced, so that resources and mitigation efforts can be optimally directed.

2.4 Qualitative Scoring Criteria

In environments where granular quantitative data are limited, a systematic qualitative framework is essential for bridging the gap between ecological observation and infrastructure planning. This study employed a High, Medium, Low (H-M-L) rating scale to categorize the effectiveness and risks of both vegetation types and management interventions (Table 1).

Table 1. Qualitative Rating Scale Definitions

Rating	Technical/Social Definition	Ecological Resilience & Sustainability
High (H)	High technical effectiveness; widely accepted by the community with minimal social friction.	It demonstrates long-term self-sustainability and provides significant habitat connectivity and stabilization.
Medium (M)	Moderate effectiveness; requires supplementary bioengineering (e.g., understory reinforcement) to achieve the target stability.	It provides partial ecological services and requires active management to prevent degradation or species invasion.
Low (L)	Minimal contribution to stabilization; high risk of structural failure under hydrological stress (e.g., Q1–Q5 peaks).	Limited ecological value; may lead to "disconnection" between the river and its floodplain.

Note: Qualitative assessment scale (Prepared by Author).

2.5 Analytical Workflow

The research was conducted through a three-stage integrated analytical workflow designed to move beyond conventional "hard infrastructure" toward Green-Blue Infrastructure and Nature-based Solutions (NbS): Stage 1: Data Acquisition: Synthesis of primary field survey results (vegetation and bank morphology) with secondary literature reviews concerning historical flood patterns and multi-agency management plans. Stage 2: Multidimensional Analysis: An evaluation phase in which vegetation conditions and disaster risks were cross-referenced with government design effectiveness. This stage utilized a qualitative scoring scale to evaluate how "edge roughness" and riparian corridor connectivity influence flood risk. Stage 3: Strategy Formulation: The Development of adaptive recommendations for the Satui River. This stage prioritized the identification of implementation challenges, including governance bottlenecks, land acquisition in settlement zones, and maintenance costs, while advocating for community-based riparian management. This workflow ensures that the resulting recommendations integrate ecological, social, and economic variables, providing a holistic framework for enhanced climate change resilience in the humid tropical context of South Kalimantan.

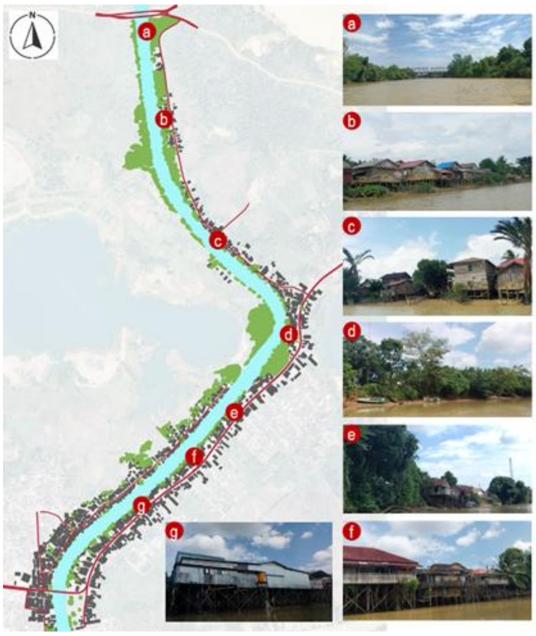

Figure 1. Vegetation condition
(Source: by Author)

3. Result and Discussion

Field observation results showed that the dominant vegetation was found along the banks of the Satui River. The field observation results classify the types of plants present based on their role and effectiveness in stabilizing soil, preventing riverbank erosion, and supporting riverine habitats (Table 2). Data were obtained through a systematic survey observing the condition of the vegetation and the surrounding environment to qualitatively assess the contribution of each plant species to the resilience of the riparian ecosystem and the mitigation of flood risk.

Table 2. Vegetation analysis of riparian zone resilience.

Local Name/ Binomial Name	Retaining wall/slope	Riverbank erosion barrier	River habitat support	Brief technical notes
Mangga/ *Mangifera indica*	M	L–M	M	Fruit trees provide shade and leaf litter input, but they are not known as primary species for riverbank bioengineering; their effectiveness on the bank depends greatly on the planting position and the strengthening of understory vegetation.
Pisang/ *Musa paradisiaca*	L	L	L–M	The root system is relatively shallow, and the pseudostem easily collapses, which is useful for rapid ground cover but is generally less reliable for slope stabilization during high flow.
Elais guineensis Jacq.	L–M	L	L	As a monoculture plantation crop, the contribution of riparian areas is usually limited, and it is not the primary choice for bank stabilization or riparian habitat restoration.
Lamtoro/ *Leucaena leucocephala*	M	M	L–M	Lamtoro can help with soil conservation/erosion on marginal lands and watersheds because it is able to reduce erosion.

Kelapa/ *Cocos nucifera S.*	M	L–M	M	Coconut fiber roots have the potential to bind soil to a limited extent, but for riverbanks experiencing active erosion, they are usually more effective when combined with bioengineering techniques (e.g., coir mat/coir log + riparian vegetation).
Jambu air/ *Syzygium aqueum*	M	L–M	M	The Syzygium genus is often used for shade and to enhance the vegetation structure of yards; its main habitat contributions are providing shade and leaf litter, while stabilizing riverbanks still requires riparian vegetation with strong and dense roots.
Sukun/ *Artocapus altilis*	M	L–M	M	Large trees provide shade and litter biomass; for riverbanks, their effectiveness increases when combined with lower strata (shrubs and grasses) to ensure more uniform soil reinforcement.
Rambutan/ *Nephelium lappaceum*	M	L–M	M	Generally, it functions as a yard tree; its riparian contribution lies more in providing shade and organic input rather than being a primary species for controlling bank erosion.
Nangka/ *Artocarpus heterophyllus*	M	L–M	M	Similar to breadfruit, good for shade and litter, but for bank stabilization, it requires support from understory vegetation and/or bioengineering solutions.
Jeruk/ *Citrus sinensis*	L–M	L	L–M	Cultivated garden plants, which are not typical riparian species for bank stabilization, can still contribute as agroforestry elements away from the riverbank.

Note: The analysis method uses a qualitative rating scale of High (H), Medium (M), Low (L), to categorize the level of risk, impact, or effectiveness when detailed quantitative data are not yet available (Prepared by Author).

The table of plants along the banks of the Satui River shows that most plants help hold the soil and support the habitat at a moderate level. However, their effectiveness in stabilizing riverbanks ranges from low to moderate. Fruit trees, such as mango, breadfruit, jackfruit, and water guava, provide shade and shed leaves but do not directly contribute to stabilization. Plants with shallow roots, such as bananas, are less effective when river water levels are high. When planted individually, oil palms have a limited contribution to the ecosystem. Leucaena can help with soil conservation, but it can become an invasive species.

The concept of managing the Satui River was analyzed by classifying assessment scales for development. This step aimed to provide a systematic basis for intervention decisions that align with the characteristics of the Satui River. Additionally, it helps determine action priorities based on short- and long-term impacts, as well as social-ecological sustainability. This concept also supports adaptive recommendations by considering technical effectiveness, community acceptance, costs, and environmental risks (see Table 3).

Table 3. Analysis of the Satui River concept development.

Flood Management Strategies	Scope Classification	Technical Effectiveness	Social Effectiveness	Sustainability	Condition Adaptation	Key risks/ issues
Dredging of the Satui River channel + spoilbank (35.727 m; 1.164.383 m³)	River (inchannel)	M	M-L	L	M	Ecological risks (turbidity/resuspension) and “lock-in” maintenance costs; this solution rarely serves as the most effective flood risk reduction measure when implemented alone.
Construction of CCSP/sheet pile embankments	River (riverbank/ corridor)	H	M-L	M	L-M	The potential for "disconnection" between the floodplain and riparian areas, the loss of

(urban) + earthfill embankments (other segments)						riparian habitat, and accelerated flow along the edges can increase erosion in unprotected segments.
Floodway / direct "outlet to the sea" (large budget option)	River–Watershed	H	M-L	M	M	Ecological exchanges, such as the disruption of connectivity and changes in sedimentation/estuaries, as well as the risk of "impact displacement" in recipient areas (downstream/estuaries).
Satui River Restoration 14 km (Q1–Q5)	River (reachscale)	M-H	H	M-H	H	The obstacles encountered are generally not technical in nature but rather relate to institutional aspects, land management, and coordination among stakeholders.
Shortcut Satui Barat–Sinar Bulan (Q1–Q5)	River (local–area)	M-H	M	M	M	The risk of the formation of new channels that can attract permanent flow (avulsion) increases if the inlet design is uncontrolled; therefore, thorough morphological control and assessment are required to avoid this risk.
Normalization/ dredging of the Jempana River (tributary) (Q1–Q5)	River (tributary)	M	M	L-M	M	Risks similar to dredging: dependence on O&M, and ecological impacts if the sediment source is not controlled.
Regulating weir on the Baruna River (Q1–Q5)	DAS (sub-DAS; flow/ retention control)	M	M	M	M	Risks related to safety and operations, as well as reservoir sedimentation, require standard operating procedures and strict monitoring.
Dams/reservoirs upstream (Q25; "requires further study")	DAS (catchment; large reservoir)	H	M-L	M	M	Significant impact on upstream riparian systems and changes in flow/sediment patterns; a cumulative impact assessment is required.
Reforestation + forest conservation in the upper watershed (Q25)	DAS (catchment management)	M	H	H	H	Performance is strongly influenced by governance, including enforcement and incentives, and the selection of priority locations, particularly in areas experiencing critical erosion.

Note: The analysis method uses a qualitative rating scale of high (H), medium (M), and low (L) to categorize the level of risk, impact, or effectiveness when detailed quantitative data are not yet available (Prepared by Author).

The analysis above formulates several points, including that the most "durable" management concepts are generally a combination from the watershed to the river, involving upstream conservation to reduce sedimentation and runoff, as well as riparian corridor restoration that includes floodplains and bank vegetation, thereby reducing the need for massive dredging and embankment construction. If embankments or CCSP are needed in urban areas, selective protection at critical nodes is a more adaptive approach while maintaining riparian corridor segments that can be inundated to preserve ecological and social functions. This is important because fully hardened bank structures tend to disrupt riparian functions and reduce edge roughness. For bypass or floodway options, social value and sustainability can be increased if the corridor is designed as a green floodway, that is, an open space that can be inundated rather than a narrow canal, thus providing daily benefits and reducing resistance from the community.

The vegetation type along the Satui River played a minor role in enhancing the sustainability of ecological functions and in reducing the risk of landslides. A combination of plants with different root systems strengthens the soil structure and improves the quality of riparian habitats. Improving riparian habitat quality by extending riparian corridors is an effective strategy for connecting fragmented riparian corridors, thereby creating a more continuous and functional ecological network. By expanding riparian corridors, ecological functions such as providing habitats for flora and fauna, controlling erosion, and filtering pollutants can be significantly improved.

This strategy was designed by integrating the results of the analysis and classification of river management areas, technical recommendations, climate resilience enhancement, and vegetation recommendations (Tables 4 and 5).

Table 4. strategy for increasing the resilience of the Satui River riparian.

Scope	Main recommendation	Technical objectives	Brief description	Climate resilience recommendations	Recommended types of vegetation
Satui urban river	River corridor improvement in the city area (as part of the "14 km restoration")	Lowering local floodwater levels, improving channel capacity and overflow space in densely populated areas	This package may include increasing flow capacity, boundary arrangements, embankment reinforcement, and open spaces appropriate for inundation areas.	Apply the “safe-to-fail” concept (areas that can be temporarily inundated) and phased modular design to make it easy to increase capacity as rainfall intensity rises	Zone 1: vetiver (Chrysopogon zizanioides) for edge reinforcement
Satui urban river	Selective protection with embankments/CCSP at critical points	Protecting important assets in very confined or high-risk areas	A 2020 study directed the use of the CCSP/sheet pile system for mitigation in urban areas.	Avoid continuous protection; prioritize "critical nodes" and leave other segments as flood energy buffer zones to reduce the risk of impact transfer	Vegetation outside the structure: vetiver at the foot of the slope + ground-cover shrubs on the slope to reduce surface erosion; riparian trees above the slope as shade and habitat corridors
Satui urban river	Local dredging (spot dredging) at the bottleneck	Removing sediment/constrictions that control local floodwater levels	A 2020 study mentioned a dredging plan along a 35.727-meter stretch of the river with a volume of 1.164.383 m³.	Treat dredging as a risk-based maintenance activity (prioritizing critical points) with a sedimentation monitoring plan to avoid making it a	After dredging, it is mandatory to revegetate the banks with vetiver/fast-growing ground cover in the lower zone, followed by

				routine dependency.	riparian trees/shrubs in the upper zone to reduce the supply of resediment.
Along the Satui River (upstream–downstream)	Gradual implementation of “Satui River Restoration 14 km”	Increasing capacity, reducing erosion on the banks, and improving the function of the riparian corridor	The Regional Government has set a target to restore the Satui River along a 14 km stretch (Q1–Q5).	Use the corridor approach (river corridor) with local floodplain space (floodable terrace/floodable bench) and gradual adaptation according to climate scenarios	Corridor vegetation package: a combination of ground cover (vetiver), riparian shrubs, and riparian trees for shade/habitat; if the segment approaches an estuary/brackish area, add local mangrove associations
Along the course of the Satui River (upstream–downstream)	Normalization/dredging of the Jempana River (tributary control)	Reducing backwater/constriction in tributaries that exacerbates flooding	The local government has instructed the normalization of S. Jempana in Satui Timur Village (Q1–Q5).	Apply the “source-control” principle: reduce the supply of sediment from sub-watersheds so that normalization does not need to be repeated too quickly	Riparian streamside vegetation: vetiver on the toe + wet-tolerant riparian shrubs/trees; bamboo can be used selectively in actively eroding segments with density management
Along the course of the Satui River (upstream–downstream)	Shortcut Satui Barat–Sinar Bulan (diversion/shortcut flow)	Diverting part of the peak flow from the city center	The local government is directing a shortcut at the border between Satui Barat and Sinar Bulan Villages (Q1–Q5).	Design as a “green floodway”: a green corridor that can be inundated, with edge storage space and defined flow routes to reduce the uncertainty of new channels	Corridor vegetation in the shortcut: ground cover for erosion control (vetiver) + riparian tree/shrub belts; if there are brackish segments, use local mangrove species according to salinity zoning
Along the course of the Satui River (upstream–downstream)	Large floodway directly to the sea	Diverting major flood waves from urban areas	A 2020 study indicated that the floodway/diversion channel option requires a very large budget.	Mandatory trade-off analysis: do not transfer risk to receiving areas (downstream/outlet), and establish multi-functional corridors so that social benefits	“Disturbance-resistant” vegetation along the corridor: layered riparian belts; in estuarine/brackish segments, use local

downstream)				exist outside of flood periods	mangroves; in freshwater segments, use flood-tolerant riparian species + ground cover for erosion control
Satui Watershed (catchment & sub-watershed)	Reforestation + forest conservation upstream	Increase retention or capture and reduce sediment to the main river	The local government considers reforestation and forest conservation to be long-term control strategies (Q25).	Focus on critical areas (sources of sediment/rapid runoff) and design adaptation-based programs (maintenance, enrichment, and cover monitoring)	Use a mixture of local upstream species (fast-growing pioneer + climax species) to form forest structure; add riparian buffer vegetation along tributaries to interrupt sediment supply
Satui Watershed (catchment & sub-watersheds)	Bendali or control dam on the Baruna River	Reducing the peak flow of the sub-watershed and regulating the flow towards Satui	The local government has instructed the construction of a detention dam or control weir on the Baruna River (Q1–Q5) to mitigate flooding.	Ensure adaptive operations (rule curve) and anticipate reservoir sedimentation (sediment management strategies) so that performance does not decline	Vegetation in reservoir/buffer areas: flood-tolerant riparian belts for bank stabilization; ground cover for erosion control on slopes/construction access
Satui Watershed (catchment & sub-watershed)	Dam or reservoir in the upstream Satui (feasibility study)	Controlling major floods (Q25) and potential multiple benefits	The local government has proposed the construction of a dam or reservoir in the upper part of the Satui River and has emphasized the need for a more in-depth study.	Scenario-based feasibility tests using climate and sediment yield; make sure not to replace the more adaptive watershed/corridor-based approach as the "baseline"	Supporting reservoir vegetation: rehabilitation of the buffer zone and "green belt" for bank stabilization; sub-watershed reforestation to reduce sediment yield to the reservoir

Note: This strategy was formulated through descriptive qualitative analysis, which included the results of analyses to identify vegetation conditions and evaluate the effectiveness of the measures applied (Prepared by Analysis Result).

Table 5. Challenges and Opportunities of Implementation.

Challenge	Opportunity
Governance and cross-sectoral coordination involve numerous stakeholders (local governments, River Basin Organizations, Disaster Management Agencies, Watershed and Protected Forest Management Agencies, communities, and the private sector), each with different authorities and interests, and there are often bureaucratic inefficiencies and conflicting priorities between agencies.	A multi-stakeholder-based coordination forum model for the Satui watershed with a clear mandate and adaptive decision-making mechanisms.

The land along the banks of the Satui River has been occupied by settlements, gardens, or productive land, making land acquisition or compensation the main obstacle in terms of cost and community acceptance.	Prioritize river segments with state/public-owned land for the "pilot project" so that results can be seen quickly. Develop ecosystem-based incentive schemes (payment for ecosystem services) or non-monetary compensation (access to clean water, infrastructure, etc.) for riparian areas maintained by the community.
The technical design of corridor restoration, riverbank bioengineering, and hydraulic-morphological modeling requires hydrological data (discharge, sediment), detailed topography, and experts, which are often limited at the regional level.	Investment in hydrology and sediment monitoring systems (AWLR and sediment yield stations) at several key points in the Satui watershed. Involving universities/research institutions as technical partners for modeling, detailed design, and project performance evaluation is also recommended.
Infrastructure-based strategies, such as levees, reservoirs, and dredging, require significant routine operation and maintenance costs, whereas nature-based strategies, such as vegetation restoration and upstream conservation, require different types of maintenance, including thinning, replanting, and management of species invasions.	Involve the local community in the maintenance of riparian vegetation through community-based riparian management schemes

Note: Challenges and opportunities in implementing flood mitigation strategies in the Satui River (prepared by analysis results).

This study found that the riparian vegetation along the Satui River, which is dominated by fruit trees and shallow-rooted plants such as Mangifera indica and Musa paradisiaca, is less effective in stabilizing riverbanks and supporting habitats and is therefore insufficient to reduce the risks of flooding and erosion. The recommended management approach involves integrating watershed conservation, riparian corridor restoration, and selective structural measures, with an emphasis on nature-based solutions, such as the use of vetiver, upstream reforestation, and adaptive management involving local communities. Management should not rely solely on hard infrastructure, as it can disrupt the ecological functions of riparian zones. The main challenges include cross-sectoral coordination, land acquisition, and a lack of hydrological data. This study is limited by a lack of quantitative data; thus, further research and pilot projects are needed to test the effectiveness of NbS in humid tropical regions such as South Kalimantan.

4. Conclusion

The study found that the Satui River's riparian vegetation, mainly fruit trees and shallow-rooted plants such as Mangifera indica and Musa paradisiaca, is inadequate for riverbank stabilization and habitat support, thus failing to effectively reduce flood and erosion risks. An integrated management approach is advised, combining watershed conservation, riparian restoration, and selective structural measures, emphasizing nature-based solutions such as vetiver for bank reinforcement, upstream reforestation, and adaptive management with local community involvement. Management should integrate strategies beyond hard infrastructure, focusing on restoring riparian ecological functions and conserving upstream areas to mitigate sedimentation and rapid water flows. Community involvement and cross-sectoral coordination are crucial for achieving long-term success. The main limitation of this study is the lack of quantitative data on the effectiveness of vegetation and nature-based solutions in humid tropical areas, particularly the performance of local species in stabilizing riverbanks and reducing sedimentation. Further exploration of social participation and acceptance of riparian management is, therefore, needed. Future research should include quantitative studies and pilot projects testing nature-based solutions, such as local species such as vetiver, bamboo, Melaleuca, and mangroves on various soil types in South Kalimantan, and explore community perceptions and involvement in managing flood-prone riparian areas.

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