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RESEARCH ARTICLE

GEOMORPHOLOGICAL AND COASTAL DYNAMICS STUDY USING RISK PARAMETERS IN KUTAI LAMA, ANGGANA SUB-DISTRICT, KUTAI KARTANEGARA REGENCY

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Abstract
The coastal area of Kutai Lama in Anggana Sub-district is a dynamic region facing increasing risks due to active fluvial processes and intense anthropogenic pressures. Specific studies integrating local geomorphological characteristics into spatial disaster risk zonation in this area remain limited. This research aims to identify geomorphological characteristics, analyze the dynamics of riverbank changes, and develop a coastal disaster risk zonation map using weighted parameters. The study employs a quantitative descriptive method integrating Geographic Information System (GIS) analysis and the Analytical Hierarchy Process (AHP). Eight risk parameters classifed into Hazard, Vulnerability, and Capacity components were identified and weighted. Riverbank dynamics were analyzed using multi temporal Landsat 8 imagery for 2019 and 2024. The results indicate that the consistent AHP analysis (Consistency Ratio = 0.028) is dominated by three key parameters with equal weight: Riverbank Changes (32%), Population Density (21%), and Protective Infrastructure (13%). The final risk zonation map divides the area into five classes. The Medium Risk Zone dominates, covering 51.4% of the total area. However, High and Very High Risk Zones are identified covering a cumulative area of 1.214 km² (8.7%), significantly concentrated along the southern banks of the Meriam River (Bukuan Village), where active erosion intersects with dense settlements. This study provides a scientifically valid risk map to support stakeholders in formulating adaptive disaster mitigation strategies and spatial planning.

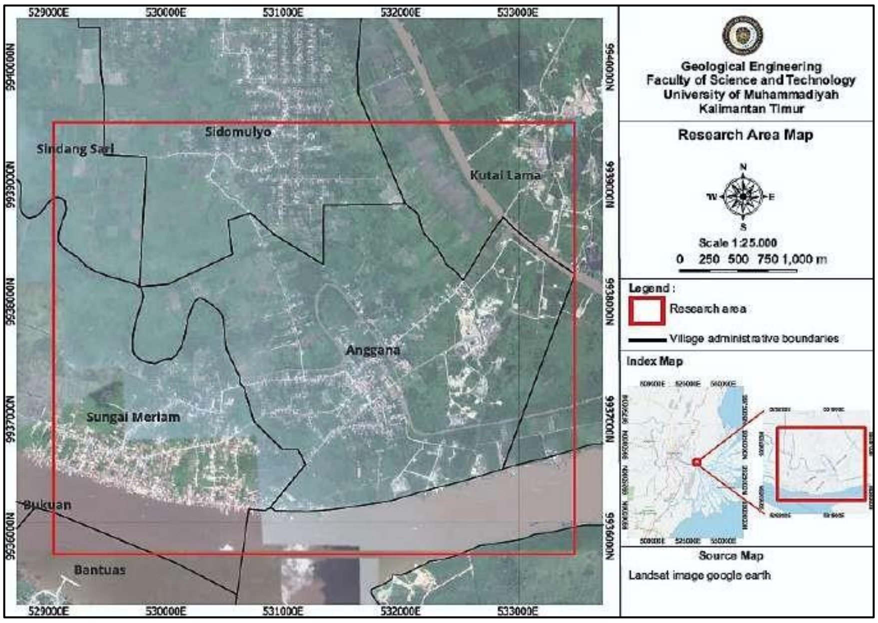
Keywords: *Geomorphology, Risk Zonation, AHP, Weighted Overlay, Kutai Lama*

1. Introduction

Global climate change and sea-level rise have become critical threats to the sustainability of coastal ecosystems worldwide, including in Indonesia. As an archipelagic nation, Indonesia's coastal zones face dual vulnerabilities arising from the dynamic interaction between oceanographic processes and massive anthropogenic pressures (Marfai & King, 2008). This condition is particularly critical in deltaic regions and alluvial plains composed of soft sediments, where the equilibrium between upstream sediment supply and marine redistribution determines shoreline stability. Imbalances in these processes often trigger environmental degradation, such as riverbank erosion and tidal flooding, which are exacerbated by land conversion in riparian zones (Syvitski et al., 2009).

This complex coastal dynamic is significantly observed in Anggana Sub-district, Kutai Kartanegara Regency, particularly in the Kutai Lama area. As an integral part of the active Mahakam Delta system, this region undergoes rapid morphological changes due to fluvial and tidal processes (Darlan, 2007). Geologically, the area is dominated by unconsolidated Quaternary sediments, making it highly sensitive to environmental changes. However, regional stability is disrupted by increasing human activities, such as dense settlement agglomeration along riverbanks, which heightens exposure risks. Although tangible threats like riverbank scouring and flood inundation are escalating, specific studies integrating local geomorphological characteristics with spatial-based disaster risk analysis in this area remain limited (Manu, 2023).

This research aims to bridge this gap by applying a spatial-based quantitative approach. The study integrates Geographic Information System (GIS) analysis and the Analytical Hierarchy Process (AHP) to construct a precise disaster risk zonation model. Specifically, this study focuses on identifying geomorphological and sedimentary characteristics, analyzing the rate of riverbank changes from 2019 to 2024, and mapping coastal disaster risk zones as a scientific basis for adaptive spatial planning.



Source : Landsat Image Google Earth

Figure 1. Map of the research area in Kutai Lama, Anggana Sub-district, The red box indicates the research area

This specific location was chosen based on several critical parameters. Physiographically, the area is a low-lying alluvial plain that is highly susceptible to hydro-meteorological hazards. It exhibits significant morphodynamic activity, characterized by continuous channel migration and sediment transport processes typical of the Lower Mahakam River.

2. Research Method

The research was conducted in the coastal areas of Kutai Lama, Bukuan, and Bantuas Villages, Anggana Sub-district, Kutai Kartanegara Regency, East Kalimantan as presented in the study area map (Figure 1). The study area covers approximately 4x4 km within the coordinates 0°32'49.89"S -0°34'49.57"S and 117°15'38.90"E - 117°18'3.10"E. Physiographically, this area is a low-lying alluvial plain influenced by the tides of the Mahakam River. The research was carried out over seven months, from May to November 2025.

Data Acquisition This study applies a quantitative descriptive method, beginning with the collection of primary and secondary data. Secondary data were obtained from relevant agencies, including the Indonesian Topographic Map (RBI) as a base map, DEMNAS for elevation and slope analysis, historical rainfall data (2019–2024) from CHIRPS satellite imagery, and demographic data from the Central Statistics Agency (BPS). The novelty of this research lies in the acquisition of primary data through the interpretation of multi-temporal Landsat 8 satellite imagery (2019 and 2024) to monitor physical environmental changes. Data validation was conducted through field surveys (*ground truth*), which included: (1) sediment sampling for granulometric analysis to validate riverbank resistance; (2) verification of fluvial geomorphological unit boundaries; and (3) updating existing land use and protective infrastructure data.

The data analysis process was carried out through three integrated approaches:

1. Spatial Analysis (GIS): Raw data were processed into eight key risk parameters: Riverbank Changes (PGS), Geomorphology Type (GEO), Slope (KLR), Rainfall (CH), Population Density (KP), Land Use (PL), Soil Type (JT), and Protective Infrastructure (IP). Each parameter was reclassified into five vulnerability score classes (1-5) referring to relevant literature standards (e.g., SE PU No. 08/2010 and USGS CVI).
2. AHP Analysis: The relative importance of each parameter was determined using the Analytical Hierarchy Process (Saaty, 1987). Pairwise comparison matrices were constructed to generate priority weight vectors. The validity of the weighting was tested using the Consistency Ratio (CR) with a threshold of < 0.10.
3. Model Synthesis: The final stage involved data integration using the Weighted Overlay technique. Score maps were multiplied by AHP weights to generate the Coastal Disaster Risk Zonation Map.

RESULT AND DISCUSSION

Parameter Analysis

The risk assessment in this study is constructed based on the integration of eight spatial parameters representing Hazard, Vulnerability, and Capacity components (BNPB, 2012).

a. Hazard Parameter

Spatial analysis reveals that physical threats in Kutai Lama are driven by the interaction between active fluvial dynamics and hydrological factors.

1. Shoreline Changes

The analysis reveals that most areas along the main Mahakam River, particularly within the study site, exhibit active abrasion and accretion patterns that are non-destructive, with average change rates ranging from 1 to 5 meters per year based on figure 2 (Lilipory&Pattiselanno, 2024). However, significant changes (> 5 m/year) were identified at specific locations, notably on the outer river bends and areas lacking bank-stabilizing vegetation. This indicates intense erosion driven by fluvial hydrodynamics, tidal currents, and anthropogenic activities, such as land clearing and riverside settlements. dissipate flow energy and stabilize sediments. This phenomenon underscores a complex

anthropogenic pressures, specifically uncontrolled land clearing and the expansion of riverside settlements, have significantly weakened the soil's cohesive strength, making the banks more susceptible to mass wasting. reas categorized as low-risk (exhibiting changes of less than 1 meter per year) are typically located within low-gradient terrains characterized by reduced flow velocities. These stable regions are almost exclusively associated with intact, dense mangrove ecosystems. The complex aerial root systems of the mangroves function as natural bio-shields that effectively dissipate turbulent energy and facilitate sediment entrapment.

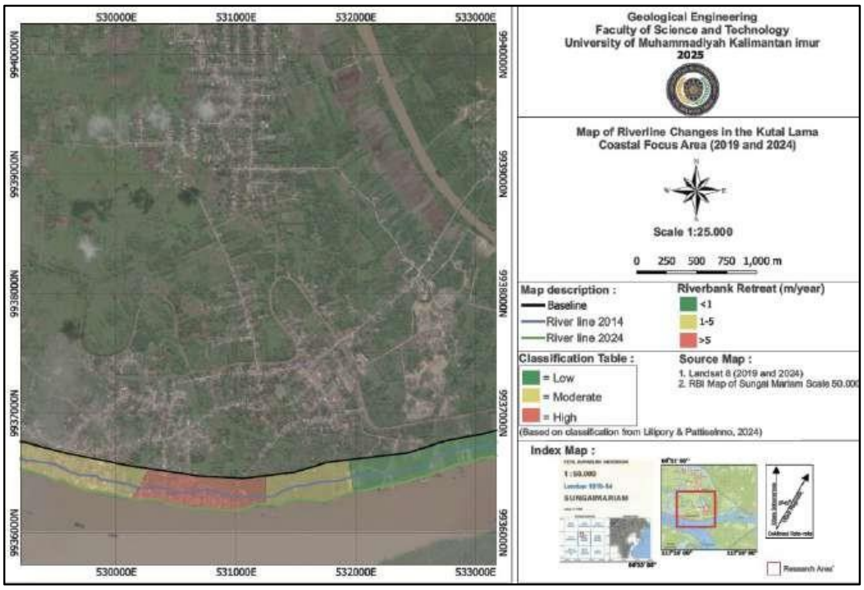


Figure 2. Map of riverline changes in the Kutai Lama coastal focus area (2019 and 2024)

2. Slope

The slope analysis in this study was conducted through the processing of Digital Elevation Model (DEM) data utilizing Geographic Information System (GIS) software. The resulting slope values were subsequently categorized into distinct classes based on percentage, following the standardized classification by Van Zuidam (1983). Findings indicate that the study area is predominantly characterized by a flat to very gentle slope class a diagnostic feature of the alluvial plains and coastal swamp geomorphology prevalent along the Mahakam River system (Figure 3). This topographical class covers the central and western portions of the research site, spatially correlating with floodplains and backswamp environments. Such nearly level terrain reinforces the interpretation of a low-energy fluvial environment where active sedimentation processes remain dominant in the present day.

In contrast, minor sections in the eastern and southeastern regions exhibit slopes exceeding, falling into the slightly sloping category (Van Zuidam, 1983). The spatial distribution pattern, which leans heavily toward flat and gentle gradients, suggests that the morphology of the Kutai Lama coastal area is primarily governed by fluvial sedimentation and tidal dynamics rather than significant tectonic activity or geological structures. This topographic homogeneity highlights the region's susceptibility to tidal inundation and suggests that the landforms are in a stage of mature geomorphological development. In the context of coastal risk assessment, this prevalent flatness is of paramount importance, while it facilitates agricultural land use and settlement, it also increases the vulnerability of the Kutai Lama region to tidal inundation and inland flooding.

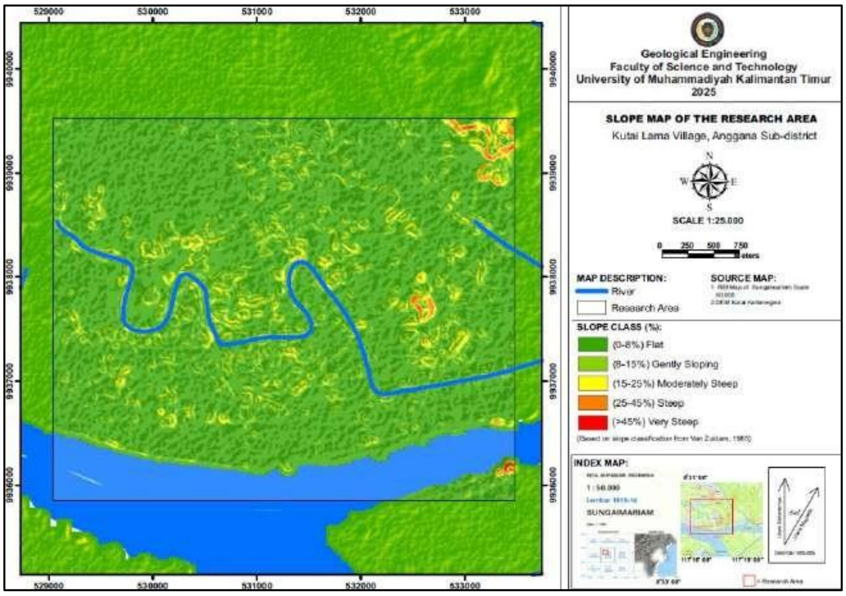


Figure 3. Slope map of the research area

3. Rainfall

The rainfall intensity parameter was derived from high-resolution satellite precipitation data spanning a five-year observation period from 2019 to 2024. Utilizing a spatial interpolation approach within a GIS framework, the cumulative annual rainfall values were categorized into specific risk classes based on the classification established by Amin (2024). The analytical findings demonstrate that the study area is situated within a high precipitation zone, with average annual rainfall ranging between 1,600 and 2,500 mm. This substantial volume of meteoric water indicates a persistent hydrological hazard, as the region is frequently subjected to high-intensity storm events. However, the complexity of the disaster risk in the Kutai Lama coastal zone is not solely dictated by the rainfall volume, but rather by its synergistic interaction with marine dynamics. In this coastal environment, a critical 'backwater effect' occurs during tidal peaks; the voluminous surface runoff which is intended to drain into the Mahakam River is effectively blocked and forced to stagnate by the incoming tidal currents.

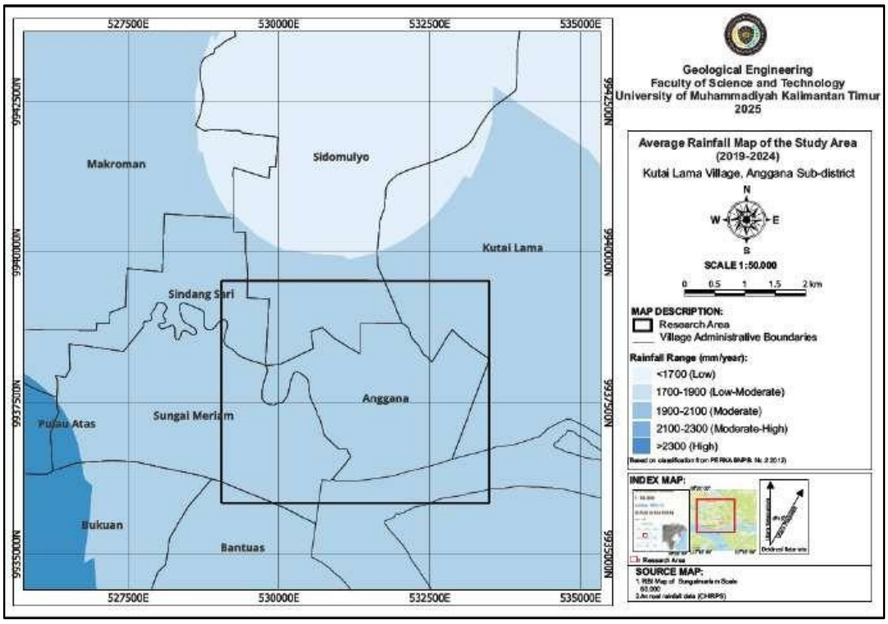


Figure 4. Average Rainfall Map of the Study Area

b. Vulnerability Parameter

Vulnerability parameters were analyzed to quantify the potential socio-economic losses resulting from coastal and fluvial hazards in the Kutai Lama area. While the preceding hazard analysis focused on the probability of physical events, the following vulnerability assessment identifies the elements at risk. Through the spatial analysis of demographic data and land utilization, this study delineates areas where the intersection of human presence and environmental instability creates the highest concentration of potential disaster impact.

1. Population Density

The quantification of social vulnerability within the study area was conducted by integrating demographic datasets from the Central Bureau of Statistics (BPS) 2019 into a high-resolution Geographic Information System (GIS) framework. This methodological approach allowed for the conversion of static census data into a dynamic spatial model, enabling a precise evaluation of how population distribution intersects with the region's physical hazards. Spatial analysis of the resulting density maps reveals a profound correlation between human habitation and the riparian corridors of the Mahakam River. High-density clusters are overwhelmingly localized along the river's primary embankments, forming a distinct linear settlement pattern. From a disaster management perspective, this concentration represents a critical 'exposure hotspot.' These communities are not only vulnerable due to their high population count but are also strategically disadvantaged by their immediate proximity to active fluvial processes, such as lateral erosion and tidal-driven inundation (Amin 2024). The socio-economic fabric in these areas is inextricably linked to the river, yet this dependency creates a heightened susceptibility to hydro-meteorological shocks that can lead to significant structural and economic disruptions.

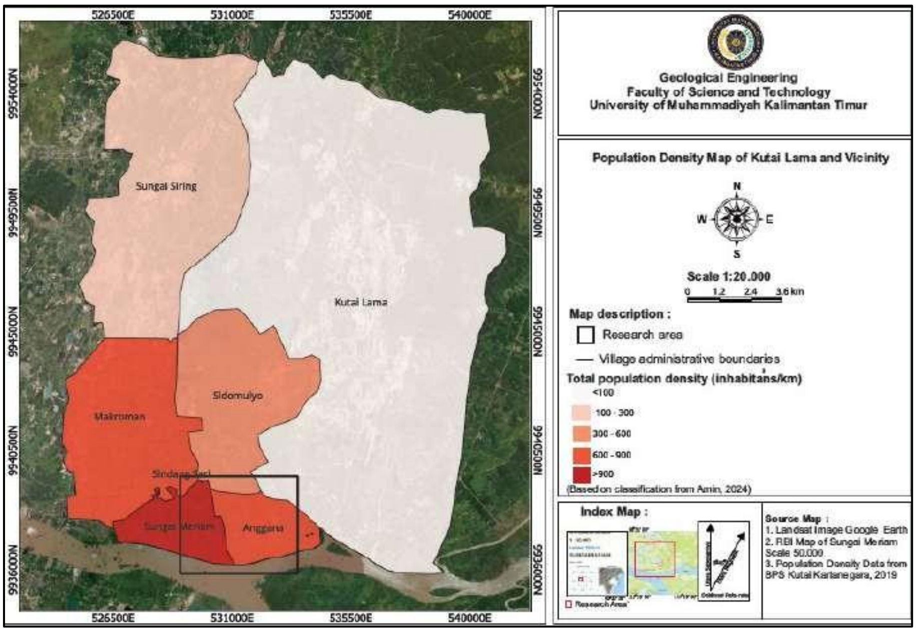


Figure 4. Average Rainfall Map of the Study Area

2. Soil Type

The soil classification for this study was developed using the Coastal Soil Types framework, adapted from the USGS Coastal Vulnerability Index (Thieler & Hammar-Klose, 1999). This specific classification was selected for its high representativeness in characterizing the unique pedological conditions of coastal and estuarine environments. Within the Kutai Lama research site, the areas adjacent to the active river channels are predominantly composed of fine sand and silt sediments, a direct result of rapid depositional processes within high-energy fluvial currents. In contrast, the extensive floodplains are characterized by a silt-clay texture, originating from the settling of fine-grained particles during overbank flooding events. The marshlands and backswamp regions are further distinguished by ultra-fine textures and high organic matter content, signifying prolonged water saturation and the continuous accumulation of anaerobic sediments. Specifically, the western and southern reaches are characterized by water-saturated clays and organic-rich soils, which exhibit low shear strength and high compressibility (Figure 5). These variations in soil texture provide critical insights into the geomorphological vulnerability of the riverine-coastal system. While fine-textured soils (clays and silts) are highly susceptible to inundation and saturation-related instability, areas with coarser textures tend to be more vulnerable to mechanical erosion and bank collapse due to their non-cohesive nature.

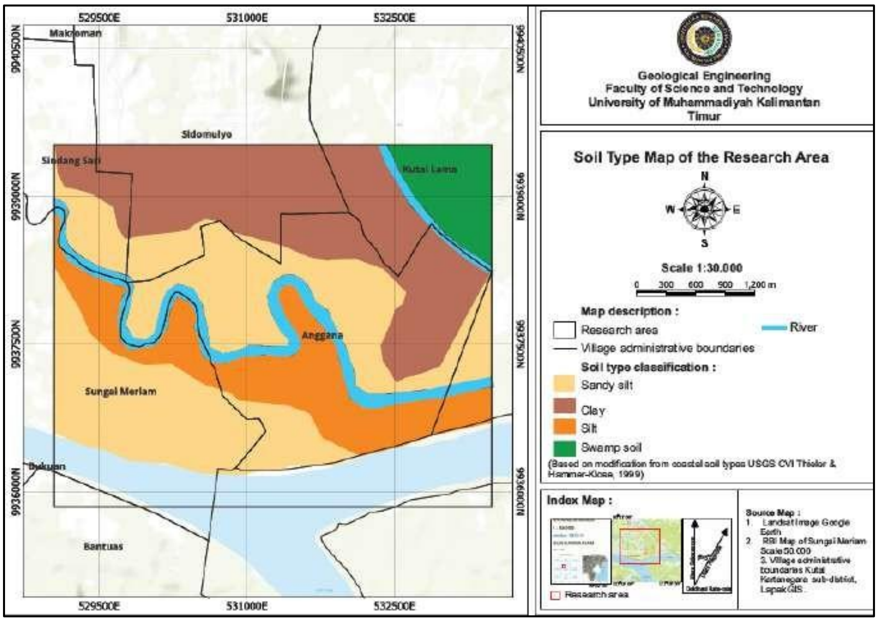


Figure 5. Soil types of the research area

3. Land Use

The classification of land use in this study follows a modified framework of the USGS Coastal Vulnerability Index (Thieler & Hammar-Klose, 1999), specifically adapted to the deltaic characteristics of the Mahakam region. Spatial observations indicate that residential areas are strategically, yet precariously, localized along the riverbanks and near primary water transportation nodes (Figure 6). These built-up zones are assigned the highest vulnerability scores due to their immediate proximity to active inundation zones and areas highly susceptible to shoreline fluctuations. From a risk perspective, the concentration of physical assets and human presence in these areas significantly amplifies the potential for structural and economic loss.

The overall land-use configuration in Kutai Lama reveals a stark spatial dichotomy. On one hand, there are high-activity zones primarily settlements and agricultural plots—that exhibit extreme vulnerability due to their geographical exposure. On the other hand, naturally vegetated areas provide a degree of regional stability. This pattern confirms that the human-environment interaction in the Mahakam delta is a primary determinant of the area's risk profile, where the conversion of natural buffers into built environments has historically escalated the vulnerability of the local population.

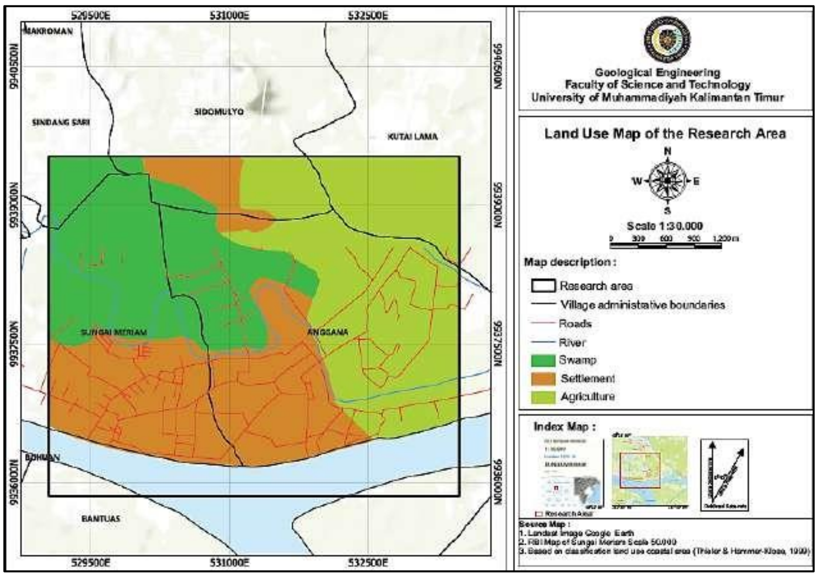


Figure 6. Land use map of the research area

c. Capacity Parameter

The capacity parameter evaluates the existing strengths and resources available to minimize or offset those risks. In the context of the Kutai Lama coastal zone, capacity is measured by the presence of physical and structural interventions designed to withstand the hydro-geomorphological pressures of the Mahakam River. This component is pivotal in the final risk equation, as high capacity can significantly lower the overall disaster index of an area, even when faced with high vulnerability. By analyzing the spatial distribution of these resources, the study identifies safety pockets where anthropogenic or natural interventions provide a critical line of defense against erosion and flooding.

1. Protective Infrastructure

The protective infrastructure parameter is fundamentally recognized for its pivotal role in mitigating the destructive kinetic energy exerted by fluvial currents and tidal surges. Consequently, this study evaluates the physical resilience of the Kutai Lama coastal zone by identifying the extent of its structural defenses. he spatial assessment, conducted through the Coastal Infrastructure Vulnerability Model (Kantamaneni, 2016), reveals that the research site along the Mahakam River banks is characterized by a relatively deficient level of structural capacity.

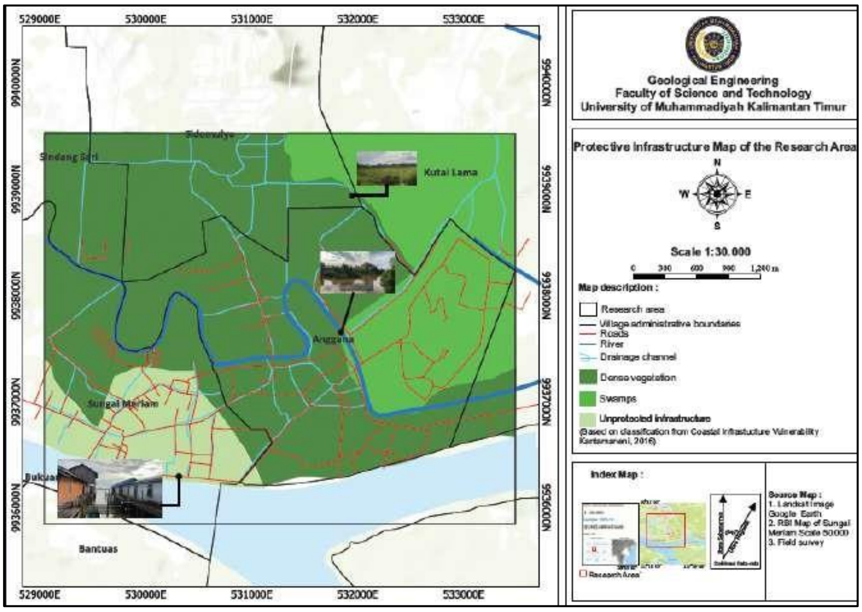


Figure 7. Protective infrastructure map of the research area

AHP Weighting and Risk Determination

The Analytical Hierarchy Process (AHP) was employed as the primary multi criteria decision making tool. The methodological soundness of the pairwise comparisons was validated through the calculation of the Consistency Ratio (CR). The resulting CR value of 0.028 serves as a strong testament to the logical coherence of the expert judgments, falling well beneath the maximum permissible threshold of 0.10. This confirms that the assigned weights are mathematically consistent and scientifically reliable for delineating risk zones (Saaty, 1983). The derived priority vectors, as presented in Table 1, delineate a pronounced hierarchy among the risk drivers in the Kutai Lama region. The analysis identifies Riverbank Changes as the preeminent determinant, commanding the highest weight of 32%. This is immediately followed by Population Density at 21% and Protective Infrastructure at 13%. Collectively, these three pivotal parameters constitute a substantial 66% of the cumulative risk weight. This statistical dominance highlights a critical finding: the disaster risk profile in this area is not evenly distributed across all factors but is fundamentally shaped by the convergence of three critical issues active fluvial instability (hazard), intense social exposure (vulnerability), and insufficient physical mitigation (capacity). Meanwhile, supplementary variables such as Geomorphology, Land Use, and Slope function as secondary contributors, providing the necessary environmental background to the overall risk architecture. his mathematical consistency check inherent in the AHP method ensures that the assigned weights are logical and minimize potential biases in the spatial modeling.

The integration of these derived weights into the GIS-based overlay analysis facilitates a more nuanced 'Disaster Risk Index.' In this framework, parameters such as shoreline dynamics and geomorphological landforms are weighted according to their empirical influence on coastal instability. This hierarchical approach moves beyond simple additive models, providing a sophisticated weighted-linear combination that more accurately reflects the complex environmental realities of the Mahakam delta. The following table presents the final prioritized weights for each parameter, which serve as the foundational coefficients for the final disaster risk zoning.

Table 1. *Final risk parameter weights derived from AHP analysis.*

No	Category	Parameter	Weight	Percentage (%)
1	**Hazard**	Riverline Changes	0.32	32
		Slope	0.21	21
		Rainfall	0.13	13
		Geomorphology Type	0.11	11
2	**Vulnerability**	Population Density	0.10	10
		Soil Type	0.07	7
		Land Use	0.04	4
3	**Capacity**	Protective Infrastructure	0.02	2
	Total	[redacted]	1.000	100%

Disaster Risk Zonation

The spatial distribution of disaster risk zonation using Weighted Overlay produced the coastal disaster risk zonation map (Figure 4), divided into five risk classes. area analysis shows that quantitatively, the study area is dominated by the medium risk zone, covering 7.151 km^2 (51.4%). However, mitigation efforts must focus on the High and Very High Risk Zones, which cumulatively cover 1.214 km^2 (8.7%). The spatial distribution of the red zone (High Risk) is specifically concentrated in the southern part of the study area (Bukuan and Bantuas Villages) (Figure 7).

Ultimately, the spatial distribution of risk in Kutai Lama confirms that the highest threats are localized where anthropogenic expansion meets active geomorphological processes. This zonation provides a crucial spatial baseline for local authorities to prioritize mitigation efforts, emphasizing that structural reinforcements and land-use regulations should be focused on the high-exposure corridors along the Mahakam riverbank.

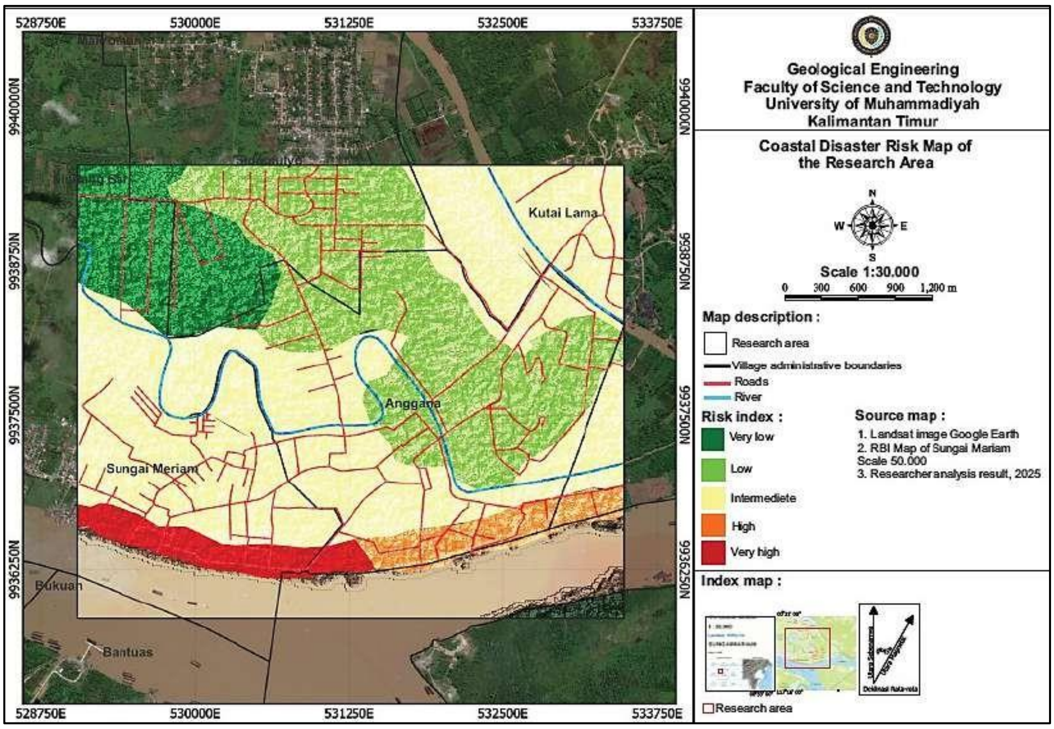


Figure 7. Coastal disaster risk map of the research area

CONCLUSION

This study concludes that fluvial geomorphological characteristics and surface sediment types play a determinant role in controlling hazard distribution in the coastal area of Kutai Lama. The disaster risk zonation generated through the AHP and GIS model proves that 8.7% of the study area is in critical condition. The high risk in the southern zone is caused by the synergistic combination of abrasion dynamics on non-cohesive sandy sediments, population pressure exceeding environmental carrying capacity, and the absence of protective infrastructure. The validity of this model is supported by the mathematical consistency of the AHP (CR=0.028), which identifies riverbank changes, population density, and protective infrastructure as the primary controlling parameters with a cumulative weight of 66%. Based on these findings, it is recommended that the Kutai Kartanegara Regency Government integrate this zonation map into the revision of the Regional Spatial Plan (RTRW) as a basis for establishing riverbank protected areas. For the local community, increased awareness and participation in preserving riparian vegetation are essential. Academically, future research is suggested to complement this model with hydrodynamic parameters.

Acknowledgements

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