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Flood Tidal Risk Modeling on the Coast of West Sulawesi Using Geographic Information Systems to Support Climate Change Adaptation Planning

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Abstract

Background: Coastal flooding or tidal inundation (*banjir rob*) is one of the visible impacts of climate change that increasingly affects coastal regions in Indonesia, including West Sulawesi Province. Sea-level rise, land-use changes, and mangrove degradation have intensified the vulnerability of coastal areas to tidal flooding.
Objective: This study aims to model the risk of tidal flooding along the coast of West Sulawesi using Geographic Information Systems (GIS) and to formulate climate change adaptation strategies through spatial and SWOT analyses.
Methods: The research utilized spatial datasets, including elevation, slope, distance from the coastline and rivers, land use, and mangrove density. The analysis was conducted using a scoring, weighting, and overlay approach to generate a tidal flood vulnerability map, which was validated using observed flood event data from 2021–2025.
Results: The results indicate that low-lying coastal zones below 5 meters above sea level with sparse mangrove cover (particularly in Polewali Mandar, Majene, and Mamuju Regencies) are highly vulnerable to tidal flooding. Spatial projections suggest a significant increase in inundation areas by 2075 in line with projected sea-level rise. Based on the SWOT analysis, the recommended adaptation strategy is an offensive (S–O) approach, emphasizing the utilization of coastal ecosystem potential and conservation policies to promote mangrove-based ecotourism, strengthen community adaptive capacity, and enhance collaboration among government, academia, and local communities.
Conclusion: The findings are expected to provide a scientific foundation for climate change mitigation and adaptation planning in the coastal regions of West Sulawesi toward sustainable coastal development.

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INTRODUCTION

Tidal flooding is a hydrometeorological hazard that has been occurring with increasing frequency in Indonesia's coastal regions, driven by a combination of sea-level rise and global climate change. This phenomenon has widespread impacts across social, economic, and ecological domains, particularly affecting fisheries, human settlements, and coastal infrastructure. Continued sea-level rise is likely to expand inundation extents and exacerbate the vulnerability of coastal areas to tidal flooding (Hsiao, 2024; Lorie et al., 2020).

At the global level, the Intergovernmental Panel on Climate Change (IPCC, 2007; Mohan, 2026) projects sea-level rise of 0.3–1.0 m by 2100 under medium- to high-emission scenarios, directly threatening more than 1 billion coastal inhabitants worldwide. The United Nations Office for Disaster Risk Reduction (Nooni et al., 2026; Reduction, 2020) reports that flood events accounted for approximately 44% of all global disaster occurrences between 2000 and 2019, with coastal communities in Southeast Asia experiencing disproportionately high exposure. In Indonesia, the Asia (2022) estimates that climate-related coastal flooding could reduce GDP by up to 1.5% annually by 2050 without adequate adaptation measures. These global trends underscore the critical need for spatially explicit, evidence-based assessments of tidal flood risk at the regional and subnational levels.

West Sulawesi Province exhibits high vulnerability to tidal flooding. The regencies of Polewali Mandar, Majene, Mamuju, Central Mamuju, and Pasangkayu are frequently affected, particularly during spring tides and extreme weather events. The period from 2021 to 2025 has been characterized by infrastructure damage, disruptions to fisheries activities, and declines in the economic productivity of coastal communities, highlighting the need for data-driven adaptation and mitigation efforts. Based on data from the West Sulawesi Provincial Disaster Management Agency (Badan Penanggulangan Bencana Daerah [BPBD] Sulawesi Barat), at least 47 tidal flood events were recorded across coastal regencies between 2021 and 2025, affecting more than 12,000 households and causing estimated economic losses exceeding IDR 85 billion. The most severely impacted areas include Simboro (Mamuju), Binuang and Campalagian (Polewali Mandar), and Banggae Timur (Majene), where tidal inundation annually disrupts agricultural, fisheries, and settlement functions. Geographic Information Systems (GIS) provide an appropriate approach for identifying spatial variations in tidal flood vulnerability by integrating environmental parameters such as topography, land use, distance from rivers and coastlines, and mangrove conditions (Zuhriah et al., 2022; Zulsfi et al., 2021). Such spatial analysis can also support the assessment of future inundation patterns under changing climatic conditions.

Several previous studies have applied GIS to assess tidal flood vulnerability in North Jakarta, Demak, and Padang (Salsabilah et al., 2024; Suanda et al., 2024). However, existing assessments have generally emphasized physical parameters, while the role of mangrove ecosystems as natural coastal buffers has received comparatively limited attention. Mangroves can attenuate wave energy and reduce the effects of coastal currents, making their condition relevant to the spatial assessment of tidal flood vulnerability (Permana & Andhikawati, 2023). Incorporating mangrove density alongside physical parameters can therefore provide a more comprehensive representation of coastal vulnerability, particularly in areas where coastal ecosystems contribute to natural flood protection.

Beyond identifying present vulnerability, effective climate change adaptation requires information on how flood exposure may change under future sea-level rise. Previous studies have provided spatial assessments of tidal flooding, but there remains limited integration of multiparameter vulnerability modeling, long-term spatial prediction, and adaptation planning. This study addresses this limitation by integrating elevation, slope, land use, distance from the coastline and rivers, and mangrove density into a GIS-based vulnerability model, followed by spatial prediction for 2035 and 2075. The analysis is further complemented by SWOT analysis to translate spatial vulnerability and risk information into strategic adaptation measures. This integrated approach is intended to strengthen the connection between quantitative spatial assessment and practical climate change adaptation planning in coastal areas.

The research gap addressed in this study is therefore the limited availability of an integrated tidal flood vulnerability assessment for West Sulawesi that combines biophysical parameters, mangrove ecosystem conditions, future inundation scenarios, and strategic adaptation planning. The study contributes to the application of a multiparameter GIS framework that incorporates both physical and socioecological considerations, while the integration of SWOT analysis provides a basis for developing context-specific adaptation strategies. The results are expected to support local governments and other stakeholders in coastal spatial planning, mangrove rehabilitation, disaster risk reduction, and the development of climate change adaptation programs in West Sulawesi.

This study aims to model tidal flood risk in the coastal areas of West Sulawesi using GIS and to formulate climate change adaptation strategies through spatial and SWOT analyses. The research findings are expected to provide a scientific basis for climate change adaptation and disaster risk reduction planning in coastal regions, while also supporting sustainable coastal development in Indonesia.

METHOD

The study was conducted along the coastal areas of West Sulawesi Province, encompassing five regencies: Pasangkayu, Central Mamuju, Mamuju, Majene, and Polewali Mandar. The study area was selected because of its high vulnerability to tidal flooding. The equipment used in the study included field devices, such as cameras, GPS receivers, and drones, for documentation and mapping, as well as laboratory equipment, including computers and GIS software such as ArcGIS and ER Mapper, for spatial analysis. The research materials comprised Digital Elevation Model (DEM) data, land-use data, coastline data, mangrove condition data, stationery, and questionnaires as supporting materials.

The data used in this study consisted of primary and secondary data. Primary data were obtained through field observations and interviews with local communities and relevant institutions. Secondary data included spatial data obtained from the Geospatial Information Agency (BIG), the National Digital Elevation Model (DEMNAS), and Rupa Bumi Indonesia (RBI) maps, as well as relevant scientific literature.

This study employed a quantitative approach using survey and mapping methods. This approach is suitable for research covering extensive coastal areas within a limited research period. The research was conducted through five main stages: the preliminary stage, data collection, data analysis, climate change adaptation strategy formulation, and data validation. The preliminary stage included site surveys, a literature review, and preparation of the research equipment and materials. Data collection involved acquiring spatial data, including DEMNAS, RBI maps, tidal data, land-use data, and mangrove condition data, as well as conducting supporting interviews with local communities and relevant institutions.

Data analysis involved tidal flood vulnerability modeling using Geographic Information Systems (GIS) through scoring, weighting, and overlay analysis of parameters including elevation, tidal range, land use, distance from the coastline and rivers, slope, and mangrove density. The total vulnerability value was calculated using the specified weighted-overlay formula. The resulting values were classified into five vulnerability levels: very low, low, moderate, high, and very high. Future inundation was projected for two time horizons, 10 and 50 years into the future, using the specified logical function, where SLR represents projected sea-level rise. The analysis was performed using the Raster Calculator to identify areas potentially affected by tidal flooding. The results were subsequently presented as thematic maps illustrating the spatial distribution of tidal flood vulnerability.

Climate change adaptation strategies were formulated using SWOT analysis, comprising Strengths, Weaknesses, Opportunities, and Threats. Each SWOT factor was assigned a weight ranging from 0 to 1 and a score ranging from 1 to 4 according to its level of influence on sustainable coastal development (Prasetya, 2023). Finally, model validation was conducted by comparing the resulting vulnerability maps with documented tidal flood events that occurred during 2021–2025. The level of agreement between the modeled results and observed events was presented in tables or graphs to assess the accuracy and reliability of the tidal flood vulnerability model.

RESULTS AND DISCUSSION

Tidal Flood Vulnerability Parameters

Elevation Parameter

Land elevation directly influences tidal flood vulnerability. Analysis of the Digital Elevation Model (DEM) indicates that the coastal areas of West Sulawesi are predominantly situated at 0–50 meters above sea level, particularly in the regencies of Polewali Mandar, Majene, Mamuju, and Pasangkayu.

Flat regions such as Campalagian, Wonomulyo, Simboro, Rangas, and Budong-Budong, serving as centers of settlements and ports are at high risk of seawater inundation. Approximately 60–70% of the coastline lies below 50 meters above sea level, making low elevation a key factor determining tidal flood vulnerability (Bariroh & Surtikanti, 2024), particularly in the regencies of Polewali Mandar, Majene, Mamuju, and Pasangkayu, especially in areas directly facing the Makassar Strait.

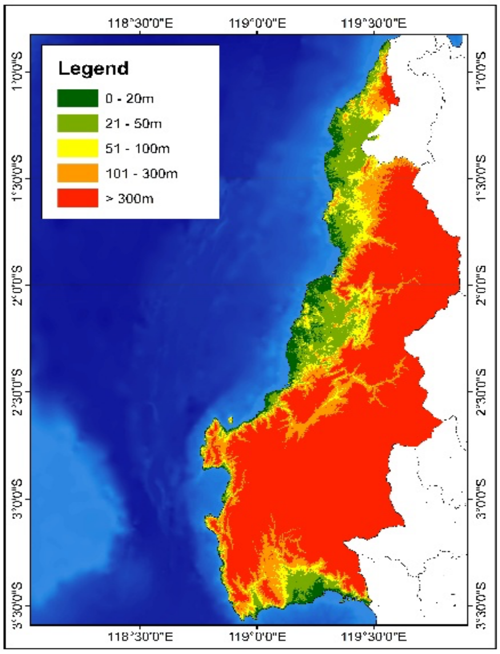

Figure 1. Elevation Parameter of West Sulawesi Province

Land Use Parameter

Land use influences the level of tidal flood vulnerability in coastal areas (Bariroh & Surtikanti, 2024). Spatial analysis results indicate that the central to hilly regions of West Sulawesi are dominated by forests and plantations, while the coastal areas are predominantly occupied by rice fields, fishponds, shrubs, and drylands. The rice field and fishpond areas in Campalagian, Balanipa, Simboro, Rangas, and Budong-Budong are at high risk due to their low-lying locations near the coast. In contrast, forests and plantations in the hilly regions exhibit low vulnerability. However, the conversion of forests into intensive plantations in coastal zones increases the potential for inundation as a result of the reduction of natural protective vegetation.

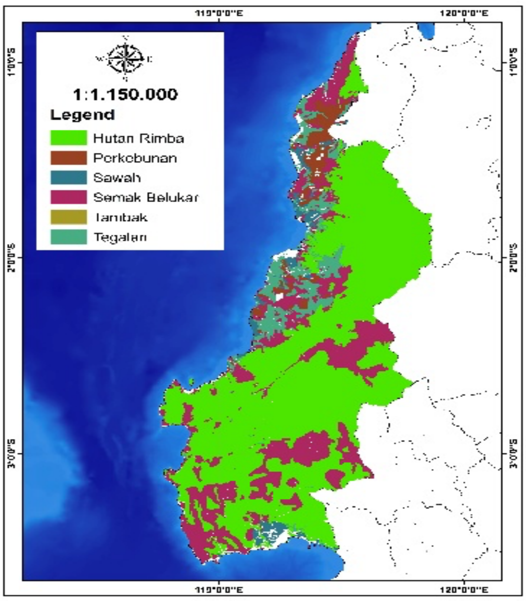

Figure 2. Land Use Parameter of West Sulawesi Province

Mangrove Presence Parameter

Mangrove ecosystems along the coast of West Sulawesi are distributed across all coastal regencies, with density levels ranging from very sparse to very dense. Based on the interpretation of Landsat 9 imagery from 2020 and 2025, as well as Google Earth imagery, mangroves are predominantly found in areas directly facing the Makassar Strait, particularly at river mouths and sheltered bays.

Mamuju Regency has the widest distribution of mangroves, with dense stands predominantly found at the mouth of the Mamuju River and around Karampuang Island (Asri, 2022). Majene is dominated by medium to sparse mangrove density due to the conversion of mangrove areas into fishponds and settlements, while Central Mamuju maintains dense mangrove cover in its natural zones. Pasangkayu exhibits a relatively even distribution of mangroves, although many areas have medium to sparse density, whereas Polewali Mandar has narrow and fragmented mangrove patches, particularly in the Binuang area.

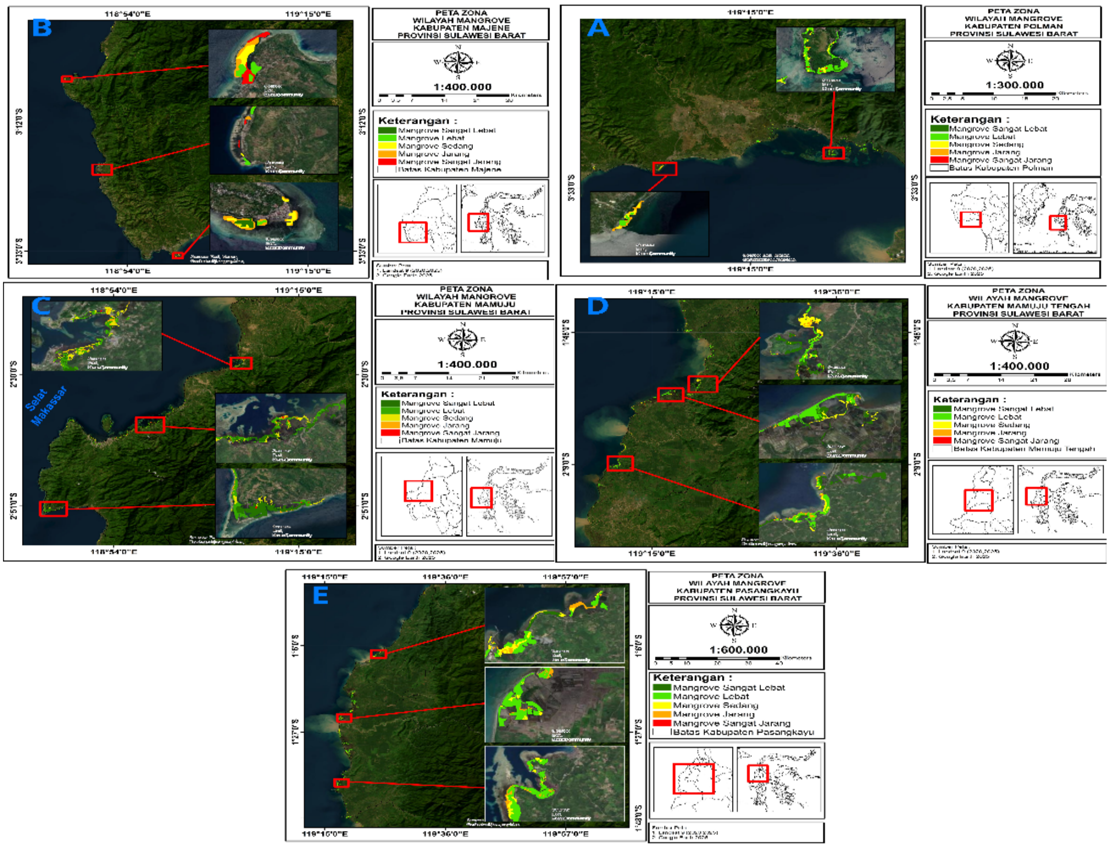

Figure 3. Mangrove Presence Parameter (A=Polman, B=Majene, C=Mamuju, D=Mateng, E=Pasangkayu)

Distance from the Coastline Parameter

The distance from the coastline is a key factor influencing the level of tidal flood vulnerability. In general, the closer an area is to the shoreline, the higher its potential for inundation caused by tidal surges or sea level rise (Hidayah et al., 2023). Spatial analysis results indicate that all coastal regencies in West Sulawesi (Polewali Mandar, Majene, Mamuju, Central Mamuju, and Pasangkayu) have high vulnerability zones within 0–500 meters from the coastline.

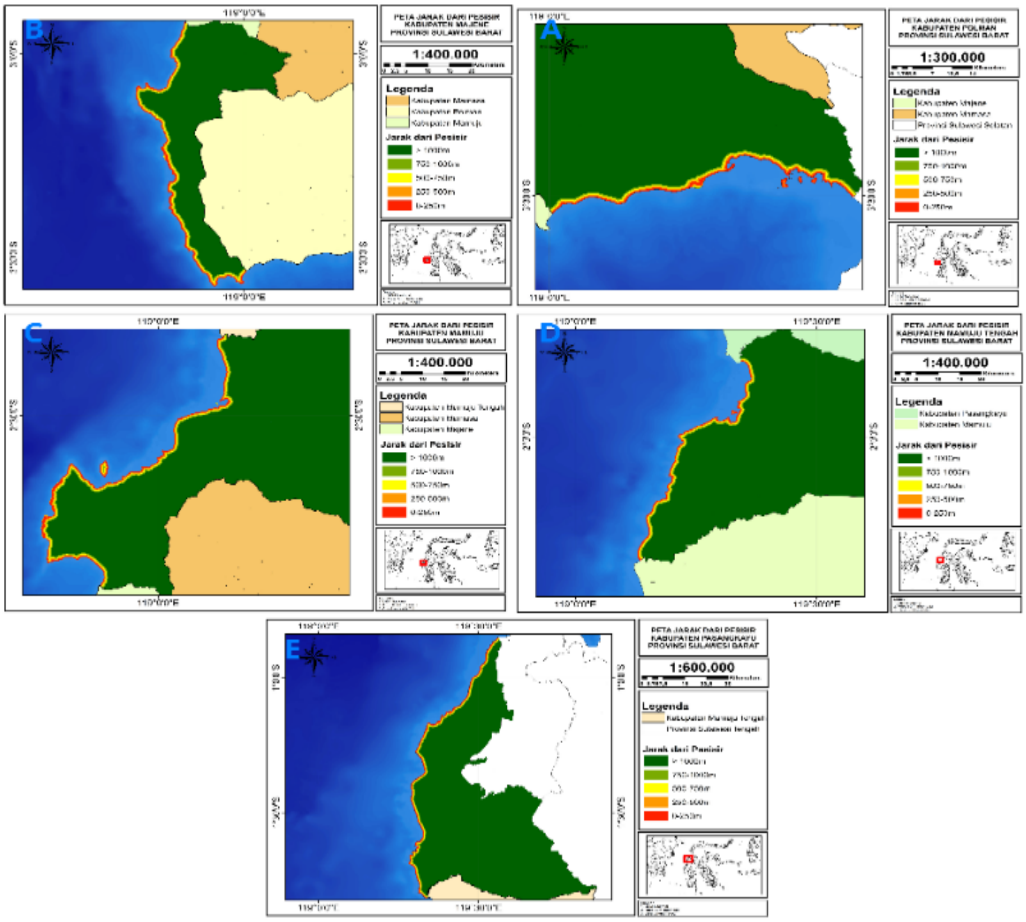

Figure 4. Distance from Coast Parameter (A=Polman, B=Majene, C=Mamuju, D=Mateng, E=Pasangkayu)

Distance from River Parameter

The distance from rivers plays an important role in determining the level of tidal flood vulnerability in the coastal areas of West Sulawesi. Areas located near river channels are at higher risk of inundation, particularly when increased river discharge coincides with high tide conditions (Yahya et al. 2023). Overlay analysis results show that all coastal regencies (Polewali Mandar, Majene, Mamuju, Central Mamuju, and Pasangkayu) exhibit a similar pattern, where high-risk zones follow the main river channels down to their estuaries.

In Polewali Mandar, high-risk areas are concentrated at the estuaries of the Mandar and Limbong Rivers, which are close to the coastal settlements of Polewali and Binuang. Majene exhibits high risk in East Banggae and Pamboang due to steep and short river flows toward the coast. In Mamuju, high vulnerability levels are found along the Karema and Kalukku watersheds, which discharge into the western coastline. Central Mamuju shows a similar pattern in the Pangale and Budong-Budong areas, while in Pasangkayu, the downstream regions of the Lariang and Dungkait Rivers are prone to inundation due to the combination of high tides and estuarine sedimentation.

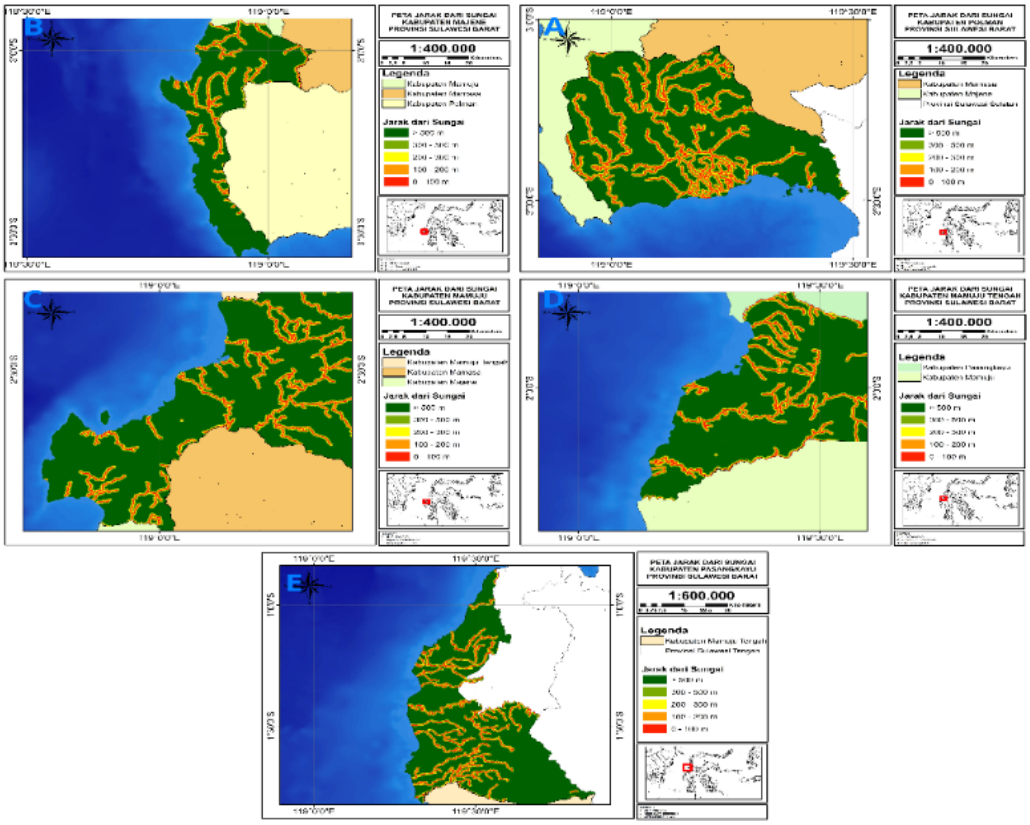

Figure 5. Distance from River Parameter (A=Polman, B=Majene, C=Mamuju, D=Mateng, E=Pasangkayu)

Slope Parameter

Land slope influences the level of tidal flood vulnerability, as it affects surface runoff velocity and the potential for water accumulation (Haryati & Andrian, 2023). Areas with gentle slopes have a higher risk due to the accumulation of seawater that cannot easily drain to lower elevations. (Ramdhany et al., 2021; Setiyorini, 2025).

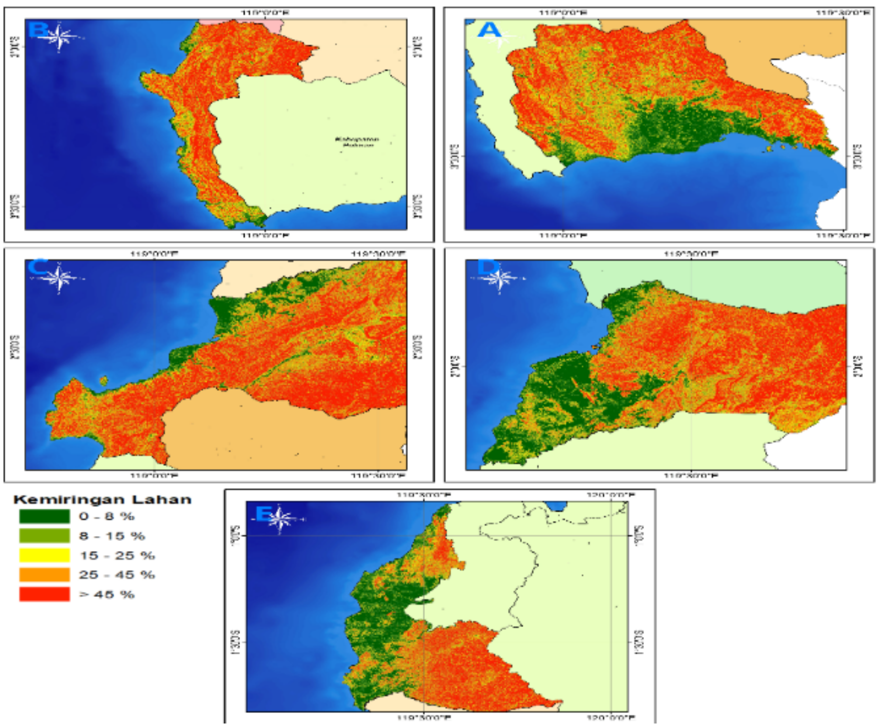

Figure 6. Slope Parameter (A=Polman, B=Majene, C=Mamuju, D=Mateng, E=Pasangkayu)

Tidal Flood Vulnerability

Polewali Mandar Regency

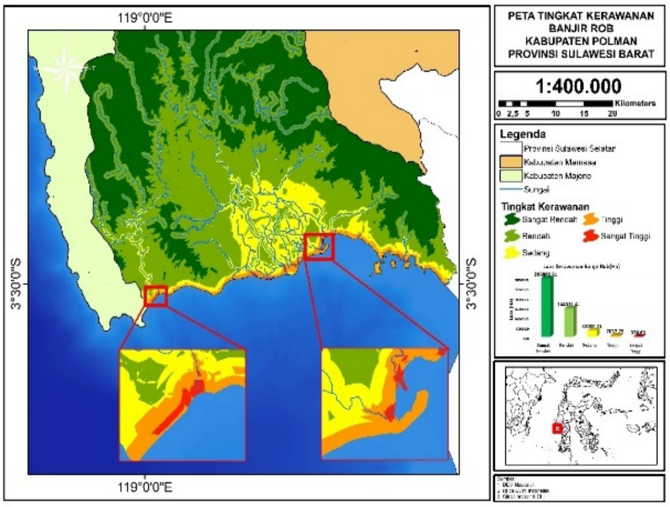

Figure 7. Tidal Flood Vulnerability Map of Polewali Mandar Regency

Spatial analysis results indicate that Polewali Mandar Regency exhibits varying levels of tidal flood vulnerability, ranging from very low to very high. Very high and high vulnerability zones are concentrated along the coasts of Binuang, Campalagian, and Mapilli, which are low-lying areas (0–5 meters above sea level) located near major river estuaries. The areas classified as very high vulnerability cover approximately 974.60 hectares, while high vulnerability zones encompass about 7,037.79 hectares, predominantly consisting of dense settlements, fishponds, and open lands near the shoreline. Moderate vulnerability zones cover around 32,055.71 hectares along the central coast, which are relatively protected by mangrove vegetation and slightly higher topography. Meanwhile, low to very low vulnerability areas are found in the central and northern regions, consisting mainly of agricultural land and hilly areas above 10 meters in elevation.

Majene Regency

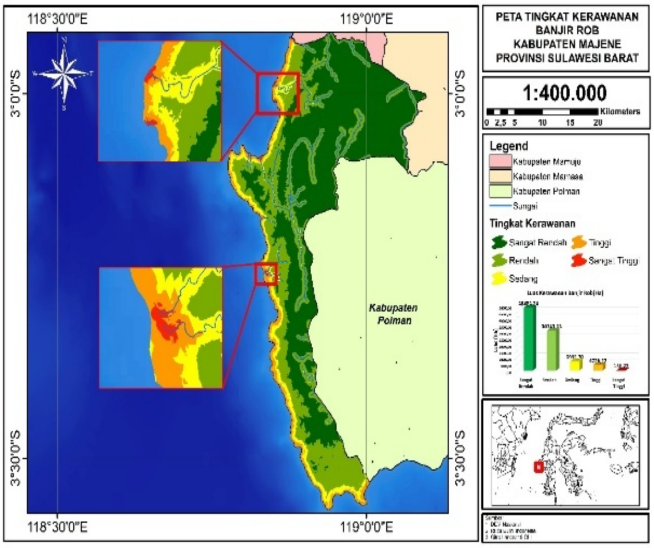

Figure 8. Tidal Flood Vulnerability Map of Majene Regency

Spatial analysis indicates that the level of tidal flood vulnerability in Majene Regency varies from very low to very high. The very high vulnerability zones are concentrated along the coasts of East Banggae and Pamboang, covering an area of approximately 158.23 hectares. These areas have flat topography (0–5 meters above sea level), are located near river estuaries, and are dominated by fishponds and dense settlements. Such conditions increase the potential for inundation during high tides or when high tides coincide with heavy rainfall.

The high flood risk zone covers an area of 4,226.67 ha, distributed along the southern to northern coastal areas, including Sendana, where human activities such as coastal development and mangrove conversion exacerbate tidal flood exposure. The reduction of mangrove cover decreases the natural capacity of the coastline to attenuate wave energy. Meanwhile, the moderate-risk zone, covering 6,995.70 ha, is in the transitional area between coastal and hilly regions. The low and very low categories, with areas of 30,743.13 ha and 43,484.24 ha respectively, are generally found in regions with elevations above 10 meters and steep slopes in the central to eastern parts of Majene.

Mamuju Regency

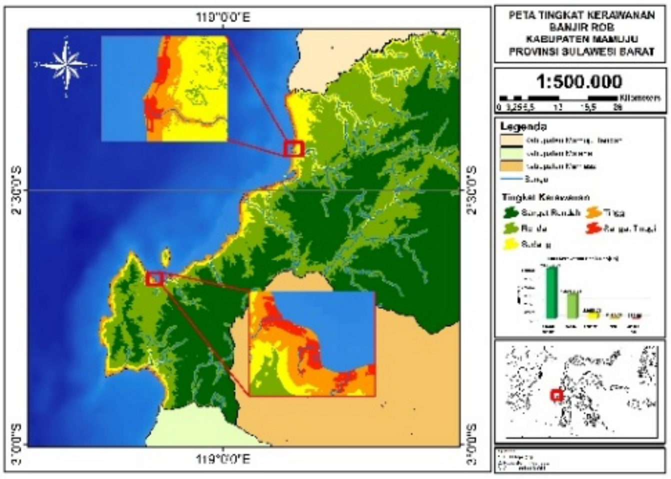

Figure 9. Tidal Flood Vulnerability Map of Mamuju Regency

Spatial analysis indicates that tidal flood vulnerability in Mamuju Regency varies from very low to very high. The very high vulnerability zone, covering an area of 974.60 ha, is located along the coasts of Mamuju and Kalukku Districts. This zone consists of alluvial lowlands (<5 m above sea level) near the shoreline and the estuaries of the Karema and Kalukku Rivers, dominated by dense settlements and coastal economic activities.

The high tidal flood vulnerability zone, covering an area of 7,037.79 ha, is distributed along the central to northern coast, including parts of Simboro District. This area is influenced by low slopes, loss of protective vegetation, and maximum tidal events driven by sea level rise. The moderate vulnerability zone, covering 32,055.71 ha, lies in transitional coastal–hilly areas, while the low and very low vulnerability zones, covering 144,911.41 ha and 238,982.81 ha respectively, are located in the eastern and southeastern parts of Mamuju, which are higher and more undulating.

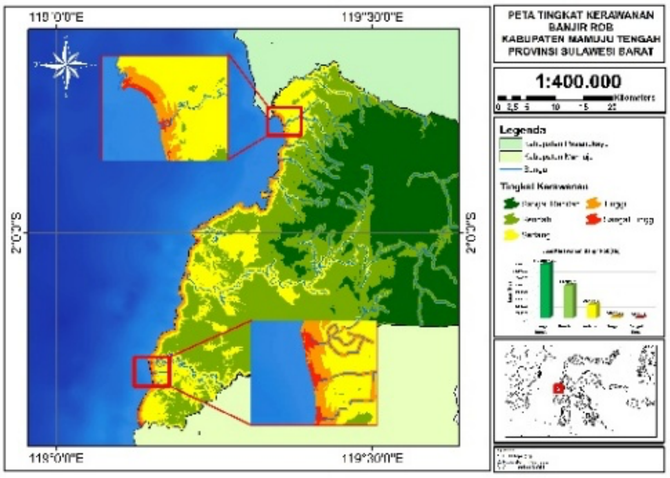

Figure 10. Tidal Flood Vulnerability Map of Central Mamuju Regency

Central Mamuju Regency

Spatial analysis in Central Mamuju Regency indicates that tidal flood vulnerability is predominantly classified as very low to moderate, with increasing risk along the western coast bordering the Makassar Strait. The very high vulnerability zone (502.01 ha) is in the coastal areas of Topoyo and Budong-Budong, near river mouths and fishponds, while the high vulnerability zone (5,027.47 ha) extends along the western to southwestern coast. The moderate zone (38,217.76 ha) occupies the coastal–hilly transition areas, whereas the low and very low zones, covering 93,289.39 ha and 153,947.42 ha respectively, are found in the eastern and southeastern regions with elevations above 10 meters above sea level. Mangrove logging has further reduced the area's natural capacity to resist tidal inundation.

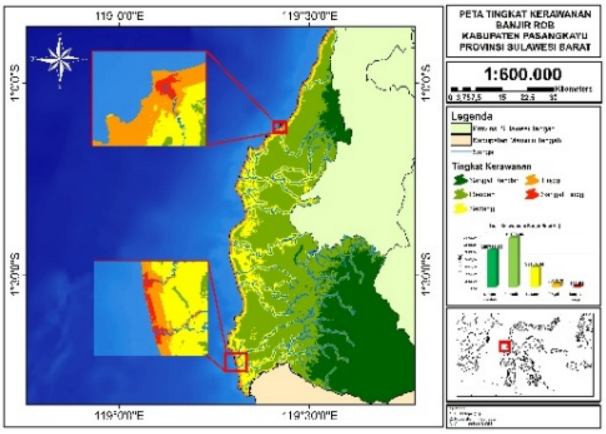

Figure 11. Tidal Flood Vulnerability Map of Pasangkayu Regency

Spatial analysis in Pasangkayu Regency shows that tidal flood vulnerability is predominantly classified as very low to low, with high to very high zones distributed along the western and southwestern coasts. The very high vulnerability zone (511.51 ha) is in Sarjo and western Pasangkayu, near river mouths facing the Makassar Strait. The high vulnerability zone (8,010.20 ha) extends along the Bambalamotu–Sarudu coast, while the moderate zone (53,136.44 ha) lies 1–3 km inland from the shoreline. The low and very low zones, covering 100,777.32 ha and 135,138.06 ha respectively, are found in the central to eastern parts of the regency, which are characterized by undulating topography and greater distance from the coast.

Predicted Tidal Flood Vulnerability

Tidal Flood Vulnerability in 2035

Spatial modeling results indicate that the entire coastal zone of West Sulawesi Province is potentially exposed to tidal flooding by 2035, with varying levels of vulnerability across regencies. The affected areas are generally located at elevations below 5 meters above sea level, encompassing settlements, fishponds, and coastal agricultural lands.

In Polewali Mandar, the most vulnerable zones are found along the coasts of Binuang, Wonomulyo, and Campalagian, which are characterized by flat terrain and extensive aquaculture areas. In Majene, inundation is projected to expand in Banggae and Pamboang, particularly in densely populated areas experiencing land subsidence.

Mamuju is predicted to face high risk in Simboro and Kalukku, especially around river mouths and gently sloping sandy beaches. In Mamuju Tengah, flood potential is identified in Pangale and Topoyo, driven by land conversion into open areas. Meanwhile, in Pasangkayu, inundation is projected in Pasangkayu, Bambalamotu, and Sarudu, which have long, low-lying coastlines.

Overall, coastal vulnerability in western Sulawesi Barat is projected to increase by 2035, necessitating adaptation strategies such as mangrove rehabilitation, elevation of coastal infrastructure, and sustainable coastal spatial planning.

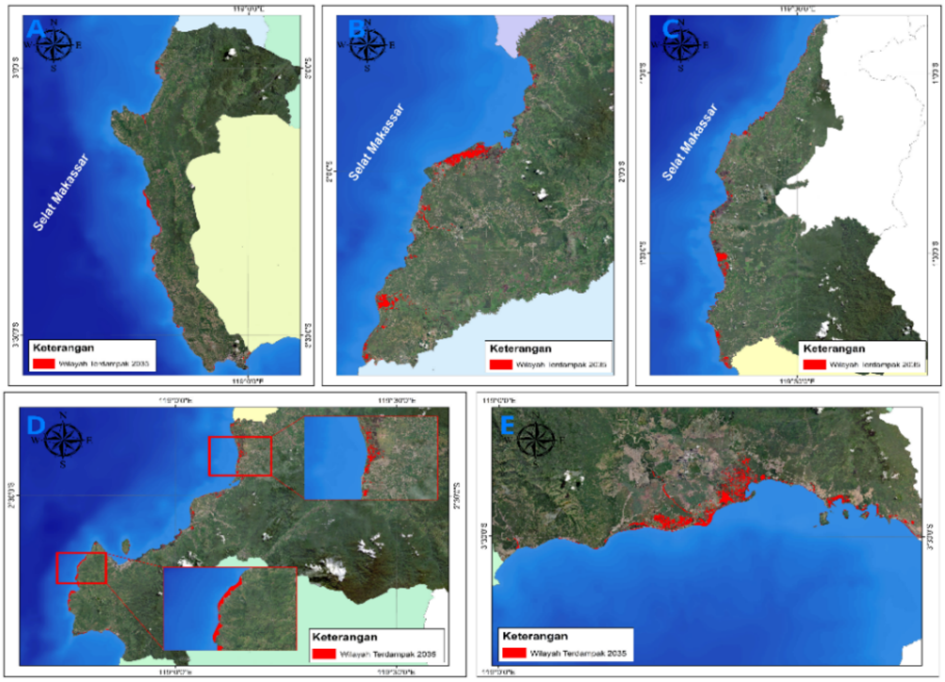

Figure 12. Tidal Flood Vulnerability Prediction for 2035
(A=Majene, B=Mateng, C=Pasangkayu, D=Mamuju, E=Polman).

Tidal Flood Vulnerability in 2075

Spatial modeling for the year 2075 indicates a significant increase in the extent of tidal flood inundation across the coastal areas of West Sulawesi Province compared to 2035. Sea-level rise and the predominance of low-lying coastal morphology are the main factors driving the expansion of high-vulnerability zones into settlement and aquaculture areas.

In Polewali Mandar, high to very high vulnerability zones in Binuang, Polewali, and Campalagian are projected to extend up to approximately 2 km inland from the coastline, indicating a growing socio-economic risk in the absence of ecosystem-based mitigation efforts. In Majene, high-vulnerability areas are expected to expand by more than 30%, particularly in Banggae, Banggae Timur, and Pamboang, due to rising sea levels and reduced coastal vegetation cover.

Mamuju shows a drastic change in Simboro, Mamuju, and Kalukku, where previously high-vulnerability zones evolve into very high, encompassing settlements and public facilities. In Mamuju Tengah, high to very high vulnerability zones begin to dominate the coastal areas of Karossa and Budong-Budong due to seawater intrusion into productive aquaculture and agricultural lands.

Pasangkayu exhibits the most significant increase, with the coastal regions of Bambaira, Bambalamotu, and Sarjo transforming into high to very high vulnerability zones as a result of combined factors including sea-level rise, flat coastal topography, and river mouth sedimentation.

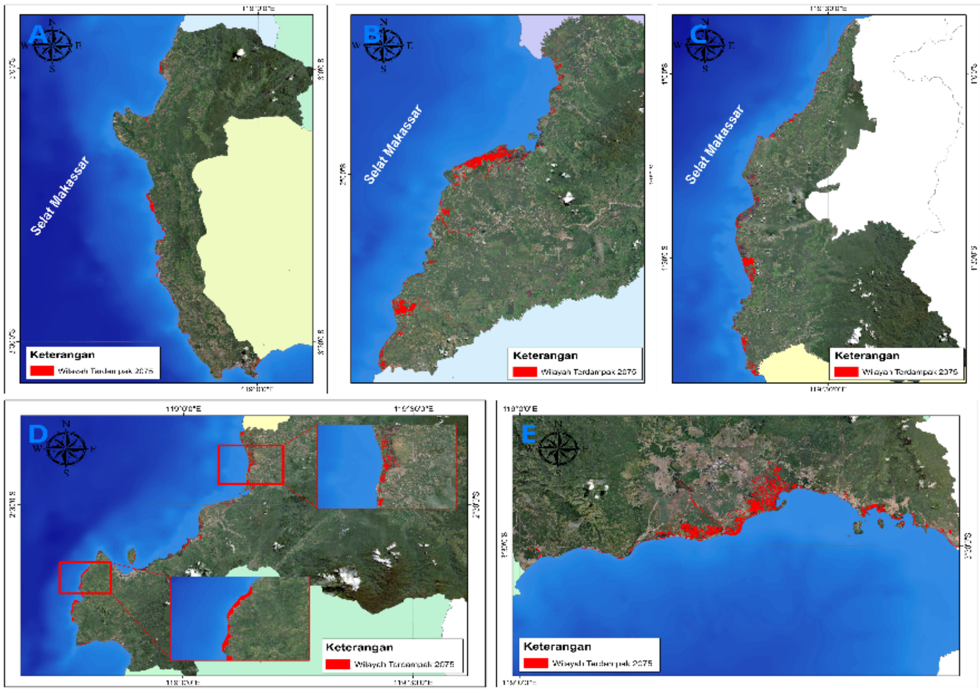

Figure 13. Tidal Flood Vulnerability Prediction for 2075 (A=Majene, B=Mateng, C=Pasangkayu, D=Mamuju, E=Polman).

Data Validation

Data validation was carried out by comparing the results of tidal flood inundation modeling from spatial analysis with actual field events based on official agency reports and observations from coastal communities. The objective was to ensure that the mapped results correspond accurately to real conditions in the coastal areas of West Sulawesi Province.

The overlay between inundation maps and recorded events indicates that most spatially identified inundation points overlap with actual tidal flood occurrences in recent years. In Polewali Mandar Regency, inundation was detected in Ujung and Takatidung Villages, locations that are empirically known to experience tidal flooding during transitional seasons. In Majene, the modeling results correspond to reported tidal flood incidents in Banggae Timur, which have disrupted port operations and coastal public facilities. In Mamuju, the Simboro area shows a strong correlation between modeled and observed inundation, where seawater frequently floods residential areas, particularly around Bhayangkara Police Hospital, a location repeatedly affected by tidal floods each year.

Similarly, the Budong-Budong area (Mamuju Tengah) and Bambalamotu (Pasangkayu) exhibit a high degree of consistency, supported by local reports of flooding due to simultaneous extreme tides and high rainfall. Overall, the validation results demonstrate good spatial accuracy, as the modeled inundation patterns reflect real-world events. Minor discrepancies are likely due to shoreline changes, temporal variations in tides, and the limited resolution of satellite imagery.These validation results are consistent with the findings of Hidayah et al. (2023), who reported 78% spatial accuracy in their GIS-based tidal flood model for the southern coast of Tulungagung using a similar DEM-overlay methodology. Compared to Salsabilah et al. (2024), who relied exclusively on tidal height and proximity to the coastline, the present study's inclusion of mangrove density as a buffering parameter improved the delineation of moderate-risk transition zones, particularly in regencies where mangrove cover partially attenuates wave energy (e.g., Mamuju and Pasangkayu). This finding is theoretically aligned with Permana and Andhikawati (2023), who demonstrated that mangrove root systems reduce current velocity and sediment resuspension, thereby decreasing inundation depth in protected areas. Furthermore, the long-term prediction of 2075 scenario in this study demonstrates that without ecosystem-based adaptation, the expansion of high-vulnerability zones in West Sulawesi could increase by more than 30%, a magnitude comparable to projections reported for Demak Regency by Zuhriah et al. (2022) under similar sea-level rise scenarios. The SWOT analysis complements the quantitative spatial outputs by providing a structured strategic framework that translates risk information into actionable policy recommendations, bridging the gap between scientific modeling and adaptive governance, an approach increasingly advocated in the climate adaptation literature (IPCC, 2007; Mohan, 2026).

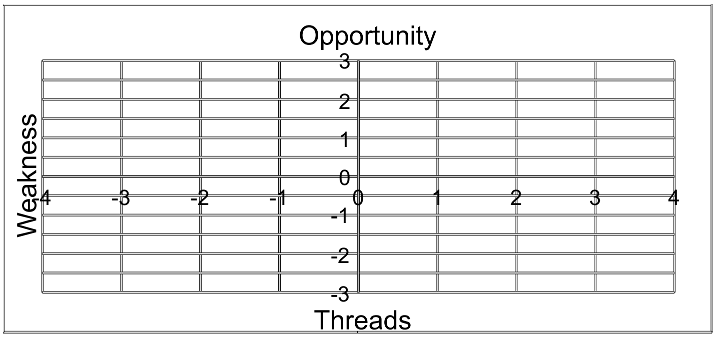

Figure 14. Validation of Historical Tidal Flood Vulnerability (A= Polman, B=Majene, C=Mamuju, D=Mateng, E=Pasangkayu).

Climate Change Adaptation Strategies to Reduce the Impact of Tidal Flooding in Coastal Areas

The following are the IFAS (Internal Factors Analysis) and EFAS (External Factors Analysis) presented in Table 1.

Table 1

Presents the analysis of internal (IFAS) and external (EFAS) factors.

Internal Strategic Factors		Weight	Rating	Score
A	Strength			
1	The Provincial Government of West Sulawesi has designated the Balabalakang Islands as a marine conservation area	0,05	4	0,2
2	Coral reefs covering an area of 8,049.26 hectares in the waters of West Sulawesi function as blue carbon ecosystems	0,4	5	2
3	Initiatives from local communities in developing agroecology-based farming systems	0,04	3	0,12
4	West Sulawesi has abundant natural resources, such as mangrove forests and coral reefs	0,05	5	0,25
5	Collaboration between the government and Muhammadiyah University of Mamuju in the coral reef rehabilitation program in the Karampuang Islands	0,1	3	0,3
	Sub Total	0,64		2,87
B	Weakness			
1	Many coastal areas still lack infrastructure for tidal flood mitigation	0,1	2	0,2
2	Several coastal areas still lack an effective early warning system for tidal flooding	0,06	3	0,18
3	Coastal communities, especially fishermen, still face challenges in accessing technological information	0,05	2	0,1
4	Human activities, such as land conversion into fishponds, have caused damage to coastal ecosystems	0,1	2	0,2

Internal Strategic Factors		Weight	Rating	Score
5	Limited budget and resources for climate change adaptation programs	0,05	2	0,1
	Sub Total	0,36		0,78
	TOTAL	1		
	Score IFAS 2,87 – 0,78 = 2,09			

	External Strategic Factors	Weight	Rating	Score
A	Opportunity			
1	Collaboration between the government, non-governmental organizations, and universities to strengthen adaptive capacity	0,1	4	0,4
2	Potential development of conservation-based ecotourism (coral reefs, mangroves)	0,05	3	0,15
3	Interest from the private sector to invest in climate change adaptation projects	0,05	3	0,15
4	The presence of national and international programs supporting climate change adaptation	0,15	4	0,6
5	Increasing public awareness of coastal conservation and climate change	0,15	4	0,6
	Sub Total	0,5		1,9
B	Threats			
1	Sea-level rise and global climate change increase the frequency of tidal flooding	0,2	2	0,4
2	Uncontrolled development activities reduce the function of coastal ecosystems as natural protective barriers	0,1	2	0,2
3	Low public awareness of the importance of coastal conservation	0,05	2	0,1
4	Changes in extreme weather patterns, such as tropical storms, increase the risk of tidal flooding	0,05	1	0,05
5	Competition in the use of natural resources among the fisheries, agriculture, and tourism sectors	0,1	2	0,2
	Sub Total	0,5		0,95
	TOTAL	1		
	Score EFAS 1,9 – 0,95 = 0,95			

The analysis shows that the IFAS (internal factors) score for strengths and weaknesses is 2.87 – 0.78 = 2.09, while the EFAS (external factors) score for opportunities and threats is 1.9 – 0.95 = 0.95. When plotted on a quadrant diagram, this position falls in Quadrant I (development and growth quadrant). In this quadrant, the existing strengths outweigh the weaknesses, and the growth opportunities are very favorable. Therefore, performance enhancement is required to support development and pursue growth. This indicates that Mamuju District is in a stage of development and growth, making the most appropriate strategy an offensive strategy (S-O strategy).

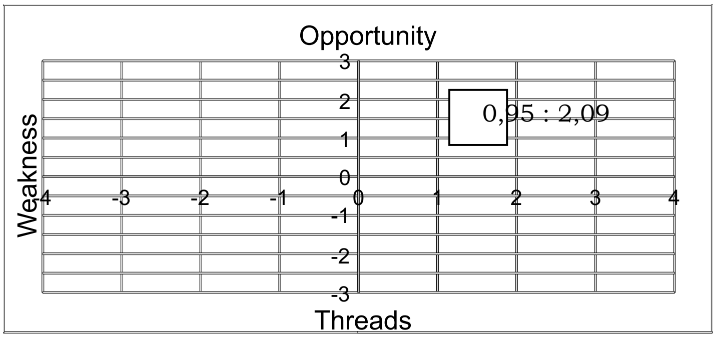

Figure 15. IFAS and EFAS Strategies

Strategic factors are key elements encompassing strengths, weaknesses, opportunities, and threats that influence a particular condition or situation, and can become advantages if appropriately addressed. Strategy formulation, also known as strategic planning, is the process of designing long-term plans that require in-depth analysis (Mujito et al., 2025). After strategies are established through the SWOT matrix, the next step is to determine priority strategy programs by referring to the IFAS–EFAS matrix quadrant. Based on the quadrant analysis, the most appropriate strategy for both internal and external conditions

1) Utilize government support and conservation policies to develop mangrove- and coral reef-based ecotourism that can enhance the local economy.
2) Optimize the involvement of local communities and academics in implementing climate change adaptation training programs based on agroecology and sustainable fisheries.
3) Leverage blue carbon ecosystems and coastal natural resources as living laboratories for climate change adaptation research and innovation.
4) Strengthen government–local–academic collaboration to secure support from national and international programs related to climate adaptation.
5) Promote community participation by capitalizing on the increasing public awareness of conservation and climate change.

CONCLUSION

This study demonstrates that the coastal areas of West Sulawesi Province are vulnerable to tidal flooding, particularly in Polewali Mandar, Majene, and Mamuju. The vulnerability is primarily associated with low elevation, gentle slopes, proximity to coastlines and rivers, land-use characteristics, and mangrove conditions. Spatial modeling indicates that tidal flood vulnerability is projected to increase by 2035 and become more extensive by 2075 as sea-level rise intensifies exposure in low-lying coastal areas. The validation results indicate that the modeled vulnerability patterns are generally consistent with recorded tidal flood events, supporting the applicability of the GIS-based approach for identifying areas requiring priority attention.

The integration of GIS-based vulnerability modeling and SWOT analysis provides a basis for developing context-specific climate change adaptation strategies in West Sulawesi. The resulting S–O strategy emphasizes the utilization of coastal ecosystem potential, particularly mangrove and coral reef resources, strengthening community adaptive capacity, and improving collaboration among government agencies, academic institutions, and local communities. In practical terms, these findings can support coastal spatial planning, ecosystem rehabilitation, disaster risk reduction, and climate change adaptation programs. Future research should incorporate more detailed hydrodynamic and sea-level-rise scenarios, higher-resolution spatial data, and broader socioeconomic variables to improve the accuracy of future tidal flood projections and strengthen adaptation planning.

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AUTHOR CONTRIBUTION STATEMENT

Haryanto Asri: Conceptualization, Methodology, Formal Analysis, GIS Analysis, Software, Validation, Writing Original Draft Preparation. Hardianti Nur: Data Collection, Field Survey, Visualization, Supervision, Writing and Editing. All authors have read and agreed to the published version of the manuscript.

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