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Application Of Remote Sensing Technology And Geographic Information Systems For Tsunami Vulnerability Analysis In Mamuju District

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Abstract

This research aims to analyze the vulnerability to tsunami disasters in Mamuju District, West Sulawesi, using remote sensing technology and Geographic Information Systems (GIS). Mamuju District is at high risk of tsunamis due to its coastal location and its position between active tectonic plates. The analysis utilizes five main parameters: elevation, slope gradient, distance from rivers, distance from the coastline, and land cover. The GIS overlay analysis method is applied to map tsunami hazard zones, combining weighting and scoring for each parameter. The results indicate that 3% of the area has very high vulnerability, 7% of the area has high vulnerability, while 82% of the area has low to very low vulnerability. Areas with very high vulnerability include the coastal zone directly adjacent to the shoreline and residential areas. This study is expected to serve as a reference for local governments and disaster management agencies in efforts to mitigate and plan safer spatial arrangements against tsunami threats. Mitigation strategy recommendations include the construction of evacuation routes, safe shelters, and the regular enhancement of disaster education and simulations for the community. Furthermore, this research encourages the use of mountainous areas as primary evacuation zones and collaboration with research institutions for the development of more innovative mitigation technologies.

Keywords: Mapping; Tsunami; DEM; SWOT; Mamuju

1. INTRODUCTION

Coastal areas in Indonesia face potential natural disaster threats, particularly tsunamis, due to their geographical location at the intersection of active tectonic plates. One area with a high risk of tsunami disasters is Mamuju District, situated on the western coast of West Sulawesi. Tsunami disasters can cause significant damage, both in terms of material loss and casualties, as well as disrupt the social and economic life of the local community. Therefore, mitigation efforts and vulnerability analysis of tsunami threats are crucial to minimizing the impact of such disasters.

The use of remote sensing technology and Geographic Information Systems (GIS) is an effective method for analyzing the vulnerability of an area to tsunamis (Fachri et al., 2022). Remote sensing allows for rapid and accurate collection of spatial data, while GIS plays a role in mapping, processing, and analyzing this data to identify areas with high vulnerability levels. The combination of these two technologies enables comprehensive spatial analysis, which can assist relevant stakeholders in formulating disaster mitigation and management policies.

This research aims to apply remote sensing and GIS technology to analyze the tsunami vulnerability in Mamuju District. By conducting tsunami vulnerability mapping based on spatial data, this study is expected to provide accurate and relevant information for local governments, disaster management agencies, and the community in efforts to mitigate and prepare for potential tsunami disasters. This vulnerability analysis is also expected to serve as a basis for more precise decision-making in spatial planning to ensure safer areas against tsunami threats.

2. METHODS

The study area is located in Mamuju District, Mamuju Regency, West Sulawesi Province, geographically situated between 2°40' to 2°45' South Latitude and 118°45' to 119°00' East Longitude. In general, the geographical boundaries of Mamuju District include the Makassar Strait to the north, Tapalang District to the south, Simboro District to the west, and Kalukku District to the east.

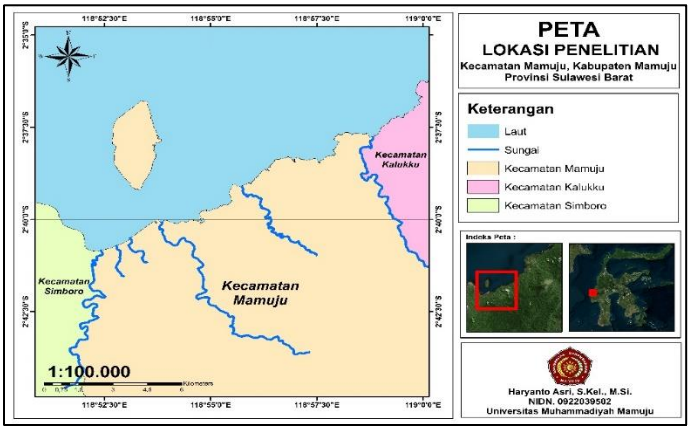

Figure 1. Research Location

The method used in this research is Geographic Information Systems (GIS), analyzed through a spatial approach. According to Susianto and Guntoro (2017), GIS is a computer-based data processing system that works to collect, examine, and analyze information related to geographic data on the Earth's surface.
The spatial approach in geographic analysis emphasizes the unique characteristics of a region and the importance of location and distribution aspects in studying spatial phenomena. This analysis allows the use of maps or visual media to examine locations and distribution patterns with geographic references (Susilo et al., 2021).
In the context of disaster risk research, spatial analysis using GIS can provide accurate information about the tsunami hazard level in an area. This is achieved through overlay analysis that combines weighting and scoring of various variables or parameters. The parameters used include elevation, slope gradient, land cover, and the distance from rivers and the coastline to the analysis unit area. Each of these parameters affects the tsunami hazard level and is closely related to the physical conditions of a region (Al Qossam et al., 2020).
The use of GIS methods in this study allows researchers to comprehensively understand disaster risk, as it can visualize data in the form of easily understandable and analyzable maps. Therefore, GIS is a highly useful tool in disaster mitigation planning, particularly in identifying areas vulnerable to tsunamis.

Table 1. Tsunami Hazard Level Parameters

Parameters	Class	Description	Score	Weight
Elevation	0 - 20 m	Very High	5	25%
	21 - 50 m	High	4	
	51- 100 m	Moderate	3	
	101 – 300 m	Low	2	
	>300 m	Very Low	1	
Slope Gradient	0 - 8	Flat	5	20%
	8 - 15	Gentle	4	
	15 - 25	Slightly Steep	3	
	25 - 45	Steep	2	
	>45	Very Steep	1	
Distance From River	0 - 100	Very High	5	20%
	100 - 200	High	4	
	200 - 300	Moderate	3	
	300 - 500	Low	2	
	>500	Very Low	1	
Land Cover	Permukiman, hutan rawa	Very High	5	15%

	kebun, vegetasi darat	High	4	
	Ladang, tengalan, swah, tambak	Moderate	3	
	semak belukar, alang alang	Low	2	
	hutan, batuan cadas, gamping	Very Low	1	
Distance From Coastline	0 - 500	Very High	5	20%
	500 -1000	High	4	
	1000 - 1500	Moderate	3	
	1500 - 3000	Low	2	
	>3000	Very Low	1	

(Source: Modified from Faiqoh et al., 2014)

Various studies have been conducted on mapping tsunami hazard levels, vulnerability, and evacuation routes using Geographic Information Systems (GIS). One such study by Fachri et al. (2022) mapped the tsunami hazard levels along the coast of Bengkulu City using several parameters analyzed through GIS technology. The results of this study showed hazard zones ranging from low to high, with coastal areas being more vulnerable due to low land elevation and gentle morphology.

Similarly, Paramita et al. (2021) used GIS to examine tsunami vulnerability in coastal settlements in the western part of Serang Regency. They employed three vulnerability categories: slope gradient, land use, and distance from the coastline.

Another study by Fijra (2018) focused on determining the locations of Final Evacuation Sites (TEA) for tsunami evacuees in Padang City using linear programming models. The results indicated the need for ten TEA sites under a major disaster scenario, while medium and low scenarios did not utilize TEA 9. TEA 10 had the largest evacuee population. This optimization model took into account the number of evacuees, vulnerable groups, and travel distances to the TEA to minimize disaster risks.

From the various studies conducted, it is evident that GIS plays a crucial role in identifying and mapping hazard levels and determining appropriate mitigation measures. This method not only aids in data processing but also facilitates the visualization of information regarding hazard zones and evacuation routes. Therefore, the application of GIS is essential in disaster mitigation efforts, particularly in emergency response planning and tsunami risk reduction.

3. RESULTS AND DISCUSSION

3.1. Overview of the Research Location

Mamuju District, located in Mamuju Regency, serves as the capital of West Sulawesi Province, covering an area of approximately 206.64 km². This district features a diverse topography consisting of mountains, hills, plains, as well as coastal and marine areas. Geographically, Mamuju District is situated at coordinates 118°53'30" South Latitude and 2°40'28" East Longitude, with elevations ranging from 0 to 500 meters above sea level.

This region holds a strategic position that facilitates interaction between Mamuju Regency and other regions at the national level, primarily due to its adequate transportation facilities. This strategic potential is evident from its geographical location, which is closely connected to a broader area. Most of the land in Mamuju District is hilly, with varying slopes, where more than 12% of the area has steep inclines. Only a small portion of the region is flat, mainly along the coastal areas spanning approximately 4 km.

This geographical potential presents significant opportunities for regional development in terms of economy, society, and infrastructure. However, the topographical challenges dominated by hills with steep slopes require special attention in development planning, particularly in disaster risk mitigation and sustainable natural resource management. The presence of adequate transportation facilities serves as a key supporting factor in maximizing the potential for interaction and connectivity of this region with other areas in West Sulawesi and on a national scale.

3.2. Tsunami Hazard Level Parameter Map in the Coastal Areas of Mamuju District

In this study, the tsunami hazard level in the coastal areas of Mamuju District was determined using five key parameters: elevation, distance from the coast, distance from rivers, slope, and land cover. These parameters were analyzed using Geographic Information System (GIS) technology through an overlay analysis method, which enables the integration and weighting of each parameter to produce a zonation map of tsunami hazard levels.

The findings of this research indicate that the combination of these five parameters provides a more comprehensive depiction of areas vulnerable to tsunami threats. For instance, areas with low elevation, proximity to the coast and rivers, and gentle slopes tend to have a higher hazard level. Meanwhile, regions with dense land cover, such as mangrove forests or other natural vegetation, may help mitigate the impact of tsunami waves.

This approach allows the resulting tsunami hazard map to be used as a guide in disaster mitigation planning and decision-making, such as determining evacuation routes and safer infrastructure development locations (Tanra et al., 2023). This underscores the importance of utilizing GIS in disaster risk management efforts in coastal areas, particularly in minimizing losses and enhancing community preparedness against tsunami threats. Below are the analyzed parameters:

a) Elevation Parameter

The analysis results indicate that most of the Mamuju District area has an elevation of over 300 meters, suggesting that this region falls within a low-risk zone for tsunami threats. Meanwhile, areas with an elevation between 101 to 300 meters are located in the central part of the Mamuju District, which is farther from the coastline. Based on the analysis, Mamuju District itself is predominantly characterized by a very high tsunami hazard zone, covering an area of approximately 6.299 km². On the other hand, areas with a very low tsunami hazard zone are found in the Selebar District, with a total area of around 108.3954 km².

To ensure the accuracy of the analysis results from the Digital Elevation Model (DEM), the author also conducted field validation (ground-check). The results of this validation are consistent with the DEM analysis, showing that the coastal area of Mamuju District has an elevation ranging from 0 to 20 meters. Additionally, areas with this elevation are also found around the Karema River and Mamuju River, located in the western and eastern parts of Mamuju District.

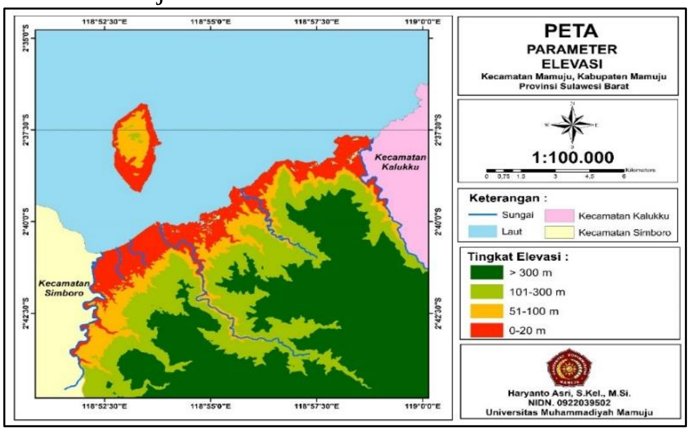

Figure 2. Elevation Map of Mamuju District

b) Slope Gradient Parameter

Based on the analysis of Digital Elevation Models (DEM), Mamuju District is predominantly characterized by areas with very steep slopes, greater than 45%, indicating that this region falls within a very low tsunami hazard zone. In contrast, areas with gentle slopes (0-8%) or low gradients, which fall into the category of very high hazard zones, are observed in the northern part of Mamuju District. According to the area calculations, Mamuju District has a significant portion of its territory in the very high tsunami hazard zone, due to relatively flat and gentle slopes. Meanwhile, the southern part of Mamuju District is dominated by very steep slopes, indicating that this region belongs to the very low tsunami hazard zone.

These findings are consistent with field observations conducted by the author, where the coastal areas generally have flat to gentle slopes, thereby increasing the risk of greater tsunami impact.

The relationship between slope gradient and tsunami hazard level shows a strong correlation. When an area has steep slopes, the potential for tsunami wave run-up is lower, resulting in a smaller hazard. Conversely, if the area has a flat slope, the tsunami wave run-up will be higher, ultimately increasing the potential tsunami hazard in that area (Adilang et al., 2022). Therefore, the slope gradient parameter plays a crucial role in determining how far the tsunami waves will sweep inland, making it an essential consideration in coastal disaster mitigation planning.

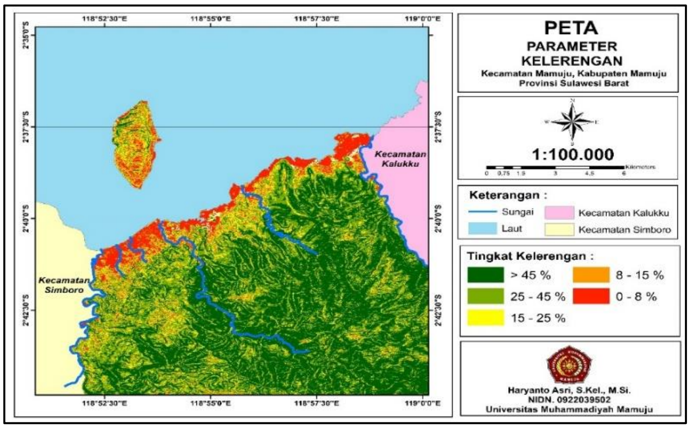

Figure 3. Slope Gradient Map of Mamuju District

c) Distance from River Parameter

The processing of the distance from river parameter is carried out using the Multiring Buffering tool in ArcGIS software to calculate the distance from the river to the land (Al Qossam et al., 2020). In Mamuju District, there are six major rivers: Mamuju River, Karema River, Simboro River, Anung River, Taparia River, and Anusu River. All of these rivers flow into the same district. The river mouth serves as the downstream part of the river flow, acting as the meeting point between the river water discharge and the ocean.

These river flows can have negative impacts on the surrounding areas, particularly by increasing the risk of tsunami disasters. This is because rivers can become pathways for tsunami waves to carry water inland. The condition of the rivers in Mamuju District, all of which empty into the coast, can lead to an increase in river water volume during a tsunami, which may eventually cause the rivers to overflow onto the land.

According to local residents, several rivers in Mamuju District frequently overflow and cause flooding during heavy rains. They also associate these floods with upstream construction activities, deforestation, river narrowing, and high sediment levels in the downstream areas. This situation indicates that, in addition to natural factors, human activities also contribute to the increased risk of flooding and, indirectly, the tsunami hazard in the area.

From these conditions, it can be concluded that the presence of rivers in Mamuju District has the potential to exacerbate the impact of tsunami disasters on the surrounding areas.

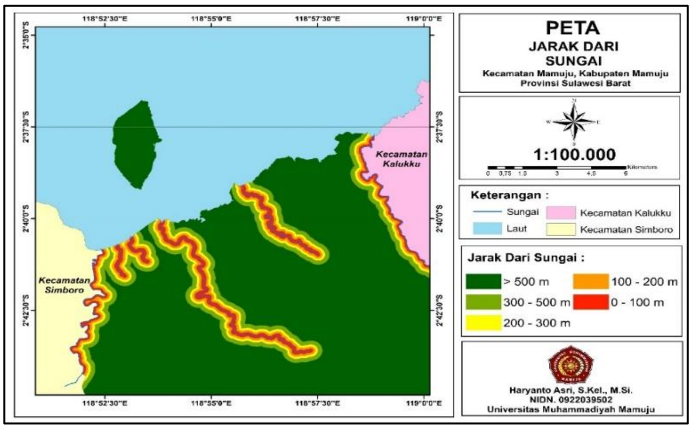

Figure 4. Distance from River Parameter Map

d) Distance from Coastline Parameter

Based on the distance from coastline parameter map, it is evident that Karampuang Island has a radius ranging from 0–500 meters and 500–1000 meters from the coastline, indicating that the area falls within high to very high tsunami hazard zones. This means that Karampuang Island is vulnerable to tsunami threats, primarily due to its proximity to the coastline.

On the other hand, the coastal area of Mamuju District on the mainland shows a similar condition, with a 500-meter radius from the coastline filled with residential areas and various tourist activities. Several key locations in this area include Arteri Beach, Manakarra Beach, Karampuang Island Beach, as well as the shopping center Mall MATOS (Mamuju Town Square). The high population density and intensive activities along this coastline further increase the tsunami disaster risk, as the dense infrastructure and population elevate the potential for material losses and casualties.

The presence of settlements and economic activities along the coastline, which are very close to the sea, places this area at high risk of tsunami impacts. Therefore, more intensive mitigation measures are necessary, such as the development of disaster response infrastructure, the establishment of safe evacuation zones, and the dissemination of information and training for the community on emergency evacuation procedures (Tanra et al., 2023).

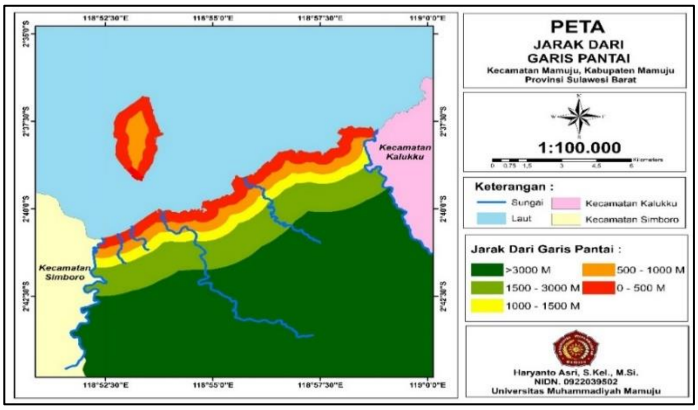

Figure 5. Distance from Coastline Parameter Map

e) Land Cover Parameter

Based on the land cover data analysis in the Mamuju District, Mamuju Regency, West Sulawesi Province, it is evident that coastal areas dominated by mangroves serve as a natural barrier that can mitigate the impact of tsunami waves. Mangroves play a significant ecological role in reducing wave velocity and preventing coastal erosion, making their presence crucial for coastal protection (Waif et al., 2021). On the other hand, forested areas and vegetation located further inland contribute to soil stabilization and reducing the potential for landslides, which also influences the vulnerability to disasters.

However, the presence of dense settlements along the coastline, as indicated by the purple areas on the map, suggests a high level of risk to tsunamis. The high population density in coastal areas not only increases the potential for material losses and casualties but also adds complexity to mitigation and evacuation efforts during a disaster. Settlements adjacent to tourist areas and public infrastructure, such as Arteri Beach and Manakarra Beach, require special attention in disaster risk mitigation planning.

The agricultural and plantation areas scattered throughout the region also need to be considered, particularly in terms of natural resource management that can affect the environment's capacity to withstand disasters. Fishponds and dryland farming areas, which are more vulnerable to flooding due to river flows, need to be managed properly to reduce negative impacts on coastal ecosystems and productive agricultural land.

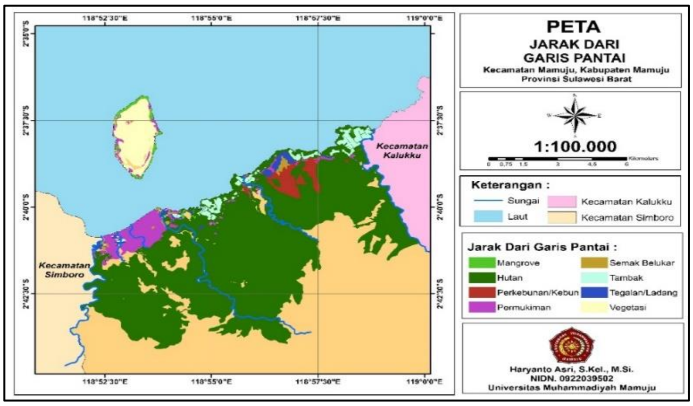

Figure 6. Land Cover Parameter Map of Mamuju District

3.3. Tsunami Vulnerability Level in Mamuju District

Based on the results of the overlay analysis using weighting and scoring of the five parameters, it is found that the coastal areas in Mamuju District are generally divided into five hazard zone classes: very low, low, moderate, high, and very high. This division of hazard zones is shown in Figure 7. Typically, the very high hazard class is found in coastal areas near the Mamuju District shoreline, where natural factors such as geomorphological conditions and the vulnerability level of the area to natural disasters contribute to the risk level in the region.

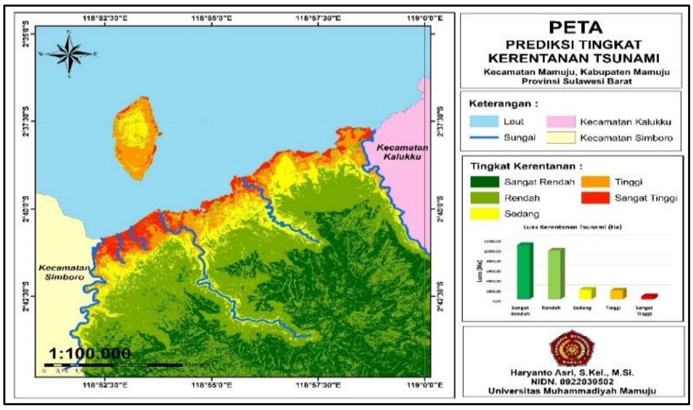

Figure 7. Tsunami Vulnerability Level Map of Mamuju District

The very high hazard level is identified along the coastline of Mamuju District, while the high hazard level follows a pattern in areas outside the very high hazard zone. Meanwhile, the very low hazard level is only observed in a few areas, particularly in the mountainous regions located in the southern part of Mamuju District. The area coverage based on the tsunami hazard level categories along the Mamuju District coastline is presented in the following table:

Table 2. Tsunami Hazard Class Area in Mamuju District

Description	Area (Ha)
Very Low	10839,54
Low	9725,77
Moderate	1947,30
High	1785,85
Very High	629,90

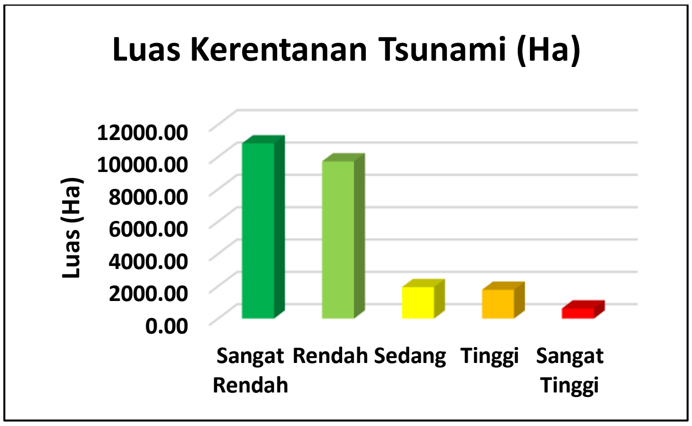

Figure 8. Graph of Tsunami Vulnerability Area in Mamuju District

Based on the data presented, the Mamuju District exhibits significant variation in tsunami vulnerability levels. Below is a more detailed discussion regarding the distribution of tsunami vulnerability:

a) Very High Vulnerability (629.9 Ha)

The areas with very high vulnerability cover 629.9 hectares, or approximately 3% of the total area of Mamuju District. These locations are mostly situated along the coastline directly adjacent to the sea. Some of the sub-districts included in this category are Binanga, Mamunyu, Tadui, Bambu, Karema, Rimuku, and Karampuang. The flat geographical conditions, elevation of less than 20 meters, and proximity to the coastline make these areas highly susceptible to severe tsunami impacts.
This is consistent with the statement by Benazir et al. (2023), which asserts that areas with flat geographical conditions, elevations of less than 20 meters, and proximity to the coastline are indeed highly vulnerable to major tsunami impacts. A case study in Aceh following the 2004 Indian Ocean tsunami showed that flat areas with low elevation, such as Gampong Lambaro Neujid, experienced significant tsunami impacts with wave heights reaching up to 20 meters. This area requires special attention in mitigation efforts, such as the construction of sea walls, provision of evacuation routes, and public education on emergency response measures.

b) High Vulnerability (1785.85 Ha)

The high vulnerability area covers approximately 1785.85 hectares or 7% of the total area of Mamuju District. This area is generally located near the coastal region but does not directly border the sea. It also has relatively flat topography and an elevation below 20 meters. Although it is not as hazardous as areas with very high vulnerability, this region still has the potential to be affected by a large-scale tsunami, especially if strong waves penetrate further inland. This is in line with the statement by Chen et al. (2023), which indicates that although this area is not considered highly vulnerable, significant damage potential still exists if a tsunami occurs.

c) Moderate Vulnerability (1947.30 Ha)

The moderate vulnerability area spans 1947.30 hectares, covering around 8% of the total area. It is situated further from the coast compared to areas with high and very high vulnerability, but it still has a risk potential due to its slightly higher topography and possibly being located in river flow paths that could channel tsunami waves. This aligns with Koshimura et al. (2020), who noted in their research that tsunamis can propagate further inland through river channels, which can cause damage in higher regions. Moderate mitigation efforts are needed, such as developing risk-reducing infrastructure and spatial planning that considers water flow and potential flooding due to tsunamis.

d) Low Vulnerability (9725.77 Ha)

The low vulnerability area covers 9725.77 hectares, comprising around 40% of the total area of Mamuju District. It encompasses areas further from the coast with higher topography, making it safer from the direct impact of tsunami waves. Although the risk is low, this area should still be considered as an evacuation or refuge area in the event of a tsunami. The main focus of mitigation efforts in this area should be on enhancing the capacity and accessibility of evacuation facilities and routes connecting with more vulnerable areas (Bonilauri et al. 2021).

e) Very Low Vulnerability (10839.54 Ha)

The very low vulnerability area covers 10839.54 hectares or around 42% of the total area of Mamuju District. This area is located in the mountainous regions or quite far from the coast, with significant elevation, making it almost unaffected by tsunami waves. It can serve as a safe zone or gathering point for residents from higher-risk areas. This aligns with Voulgaris and Aleksejeva (2017), who stated that safe points for residents living in tsunami-prone areas could include high-rise buildings and mountainous locations as evacuation sites. The primary focus for this area is the provision of evacuation infrastructure, such as temporary shelters and well-planned, safe transportation routes.

3.4. TSUNAMI DISASTER MITIGATION STRATEGY

To determine the priority for tsunami disaster mitigation strategies in Mamuju District, it is essential to conduct an IFAS and EFAS analysis. IFAS (Internal Factors Analysis Summary) is a strategic analysis of internal factors aimed at identifying strengths and weaknesses. EFAS (External Factors Analysis Summary) is a strategic analysis of external factors aimed at identifying opportunities and threats faced. This analysis is crucial for understanding the level of preparedness and response in dealing with internal strengths and external pressures (Agussaini et al. 2022).

Table 3. Internal Factor Analysis Summary (IFAS) Matrix

	Internal Strategy Factors	Weight	Ranking	Score
A	**Streght**			
1	Mamuju District has a fairly large mountainous area with very low to low tsunami vulnerability categories, which can be utilized as evacuation and temporary shelter areas for affected communities	0,15	4	0,6
2	A good understanding of the topographical and geological characteristics of the region allows for more targeted disaster mitigation planning.	0,05	3	0,15
3	There is sufficient land available for the construction of mitigation infrastructure such as seawalls, evacuation routes, and shelters that are safe from tsunami risks.	0,10	3	0,3
4	The community is beginning to show awareness of the importance of disaster preparedness and is willing to participate in training and disaster simulation programs.	0,10	4	0,4
5	Mamuju District's proximity to the new capital city (IKN) in Kalimantan provides an opportunity to receive more attention from the central government, especially related to the development of mitigation infrastructure and logistical support.	0,15	5	0,75
	Sub Total	**0,55**		**2,2**
B	**Weakness**			
1	Mitigation facilities and infrastructure, such as early warning systems, evacuation routes, and temporary shelters, are inadequate to address the existing disaster risks.	0,10	3	0,3
2	Limited budget and human resources at the regional level hinder the optimal implementation of mitigation projects.	0,10	3	0,3
3	There are still gaps in disaster knowledge and preparedness among certain communities, especially in remote areas that are difficult to reach.	0,10	2	0,2

4	Some areas with moderate to high vulnerability have difficult accessibility, such as inadequate roads and long distances from logistical or assistance centers.	0,15	2	0,3
	Sub Total	**0,45**		**1,10**
	TOTAL	**1,00**		
	IFAS Score 2,2 – 1,1 = 1,1			

Source: Processed Data, 2024

Table 4. External Factor Analysis Summary (EFAS) Matrix

	External Strategy Factors	Weight	Ranking	Score
A	**Opportunity**			
1	Potential to receive support from the central government, non-governmental organizations, and international organizations in the form of financial aid, technology, and disaster mitigation training, especially with increased attention to areas around the new capital city (IKN).	0,10	3	0,3
2	Opportunity to improve and expand mitigation infrastructure, such as the construction of evacuation routes, strengthening buildings in coastal areas, and providing more advanced early warning equipment.	0,05	2	0,1
3	Chance to organize more intensive educational programs, disaster simulations, and mitigation training, so the community becomes more prepared and trained in facing potential disasters.	0,10	3	0,3
4	Opportunity to collaborate with research institutions and academia in conducting scientific studies on disaster mitigation and developing innovative mitigation technologies.	0,10	3	0,3
5	Proximity to the new capital city (IKN) provides opportunities to utilize better infrastructure and logistics facilities, including transportation access, communication, and more adequate healthcare facilities.	0,15	4	0,6
	Sub Total	**0,5**		**1,6**
B	**Threats**			
1	The impact of global climate change, which increases the frequency and intensity of natural disasters such as tsunamis, adds to the risks faced by this area.	0,10	2	0,2
2	Population growth and development in coastal areas without accompanying disaster mitigation planning can increase the number of people vulnerable to tsunamis.	0,10	2	0,2
3	Limited human, material, and financial resources to implement mitigation strategies comprehensively and sustainably.	0,05	4	0,2
4	Mamuju District is located in an earthquake-prone zone, which is one of the main triggers for tsunamis. Significant magnitude earthquakes can damage infrastructure, cause underwater landslides, and trigger dangerous tsunami waves.	0,15	1	0,15
5	The level of uncertainty in predicting tsunami and earthquake events, as well as the difficulty in determining the exact timing, can affect the effectiveness of early warning systems and community preparedness.	0,10	2	0,2
	Sub Total	**0,5**		**0,95**
	TOTAL	**1**		
	EFAS Score 1,6 – 0,95 = 0,65			

Source: Processed Data, 2024

The analysis results indicate that the IFAS strength and weakness score is 2.2 - 1.1 = 1.1, and the EFAS opportunity and threat score is 1.6 - 0.95 = 0.65. If illustrated in a quadrant form, this position falls in Quadrant I (development and growth quadrant). In this quadrant, strengths outweigh weaknesses, and the potential for growth is very promising. Therefore, performance enhancement is needed to support development and pursue growth. This suggests that Mamuju District is in the development and growth stage, making the most appropriate strategy an Offensive Strategy (S-O Strategy).

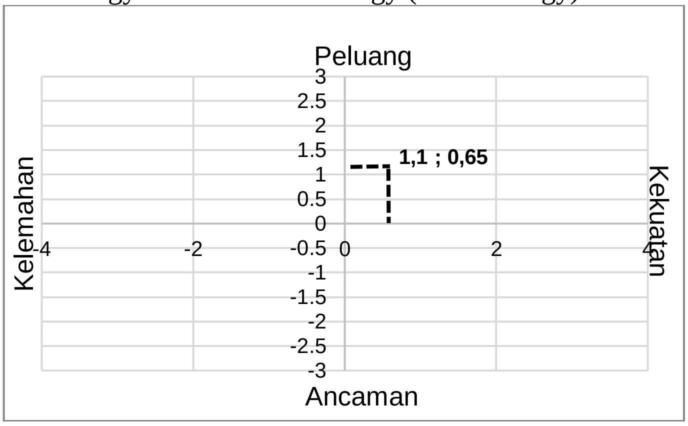

Figure 9. IFAS-EFAS Quadrant

Strategic factors are the dominant factors of strengths, weaknesses, opportunities, and threats that influence existing conditions and situations and can provide benefits if positive actions are taken. Strategy formulation, often referred to as strategic planning, is the process of developing long-term plans and involves more in-depth analysis. After determining the strategy through the SWOT matrix, the next step is to establish priority strategic programs based on the IFAS-EFAS matrix quadrant. Based on the IFAS-EFAS matrix quadrant, the priority strategy suitable for the internal and external conditions of tsunami disaster mitigation is the Offensive strategy (S-O strategy), namely:

1. Utilizing mountainous areas with very low to low vulnerability as the main evacuation points with infrastructure support from the central government and international organizations. These locations can be further developed as safe and strategic shelters to evacuate communities affected by tsunamis.
2. Leveraging proximity to the National Capital (IKN) as an attraction to gain more attention from the central government regarding infrastructure development for mitigation. Support in the form of evacuation routes construction, early warning system equipment, and strengthening coastal infrastructure can enhance disaster preparedness.
3. Optimizing the increasing community awareness by conducting community empowerment programs, mitigation training, and regular disaster simulations. This will strengthen community involvement in disaster preparedness and response.
4. Taking advantage of a deep understanding of the area's topography, collaboration with academic and research institutions can be conducted to develop innovative technology for tsunami mitigation, such as more accurate tsunami prediction modeling.
5.

4. CONCLUSION

Based on the research conducted in Mamuju Subdistrict, Mamuju Regency, it can be concluded that:

1. The coastal area of Mamuju Subdistrict has a significant variation in tsunami vulnerability levels, with 3% of the area classified as very high, particularly along the coast directly bordering the sea, and 7% of the area classified as high. Areas with low to very low vulnerability cover around 82% of the total area, located in mountainous and highland regions far from the coast.
2. The strategies required for tsunami disaster mitigation in Mamuju Subdistrict include the development of mitigation infrastructure such as evacuation routes and safe shelters, utilization of mountainous areas as the main evacuation zones, regular enhancement of disaster education and simulations for the community, and collaboration with research institutions to develop more accurate tsunami mitigation technology.
3. This research has limitations, including the exclusion of the "small island presence" parameter due to technical constraints in modeling its impact using ArcGIS. Additionally, limitations in population data and subjectivity in parameter weighting may also affect the results. Nevertheless, this study provides a risk zoning map that can serve as a reference for disaster mitigation planning in the Mamuju District. Collaboration with research institutions is also needed to develop data-driven mitigation technologies.

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