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Analysis of Vulnerability Tsunami in Morowali Regency, Central Sulawesi

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ABSTRACT

Indonesia is a country located in the Pacific Ring of Fire, which has high tectonic activity and is vulnerable to various natural disasters, including earthquakes and tsunamis. The area in eastern Indonesia that has the potential for natural disasters such as tsunamis is Central Sulawesi Province. The potential for tsunami disasters in this area is caused by the presence of an active fault in the form of the Palu Koro fault which is connected to several minor faults, such as the Matano fault in the Morowali Regency area. Based on earthquake data from 2019-2024 originating from the USGS, the intensity of the earthquake in the Morowali Regency area is 2.9 - 5.1 SR. The Disaster Risk Assessment Document from the BNPB in 2021 Morowali Regency has a potential tsunami vulnerability that is included in the "High" class category with an affected hazard area of approximately 8,414 Ha. Meanwhile, the results of the study, the total area of the affected area with the assumption of a tsunami inundation of 10 m is ± 424,913 Ha. This study aims to determine the level of tsunami vulnerability based on social, physical, economic, and environmental parameters, as well as appropriate mitigation methods to reduce the impact of tsunami risk in Morowali Regency. The method used in this study is based on Geographic Information Systems (GIS) scoring and overlay. The results of the tsunami vulnerability assessment in Morowali Regency fall into the "High" vulnerability category with a vulnerability index value of >0.667. Meanwhile, Bungku Barat District has the highest vulnerability index weighting value, at 0.9200. Appropriate mitigation to reduce tsunami risk includes infrastructure engineering, the construction of waterbreak embankments and natural embankments (greenbelts) along the coast of Morowali Regency.

Keywords: matano fault, tsunami vulnerability, GIS, mitigation, Morowali

INTRODUCTION

Indonesia is an archipelagic country with an area of 1.9 million km2 and in 2019 it was recorded that it had approximately 17,000 islands with a land area of 1,922,570 km^2, and a water area of 3,257,483 km^2 [7]. Indonesia is one of the countries with very high and diverse potential dangers caused by natural disasters, non-natural disasters, or complex emergencies [8]. In addition, Indonesia is in second place as a country with the longest coastline in the world with a total length of 99,000 km. The geographical location and geological conditions of Indonesia are flanked by two continents and two oceans, namely the Asian Continent and the Australian Continent as well as the Indian Ocean and the Pacific Ocean. Indonesia is one of the countries located in the Pacific Ring of Fire region, which has high tectonic activity and is vulnerable to various natural disasters, including earthquakes and tsunamis. Morowali Regency, located in Central Sulawesi Province, is a coastal area that has a high potential risk of tsunami due to its location near the subduction zone and quite active seismic activity. Earthquakes that have the potential to cause tsunamis around the waters of Central Sulawesi have become a threat to the community, infrastructure, and coastal ecosystems in the region. Central Sulawesi is one of the earthquake-prone areas in Indonesia [12], especially Palu City which is crossed by the Palu Koro Fault, a major fault on Sulawesi Island and classified as an active fault [2]. The Central Sulawesi region has experienced at least 19 destructive earthquakes from 1910 to 2013 [12]. The geological structure of the Palu Koro Fault is connected to several minor faults, one of which is the Matano Fault, which stretches from the southern part of Central Sulawesi to Tolo Bay. Geologically, the Matano Fault has a left-lateral shear structure and has been active since the Quaternary period [3]. This fault is divided into 6 segments, namely the Kuleana, Pewusai, Matano, Pamsoa, Ballawai, and segments. The Matano Fault can be found in Morowali Regency.

Morowali Regency, located in Central Sulawesi Province, has a high potential risk of tsunamis. This is due to its proximity to the subduction zone and significant seismic activity in the region. Research conducted by [16] estimates the shear rate of the Matano Fault to range from 4-32 mm/year [14]. Overall, the area near the Matano Fault is a transpressive regime. The greatest locking occurs on the Matano Fault, indicating that this fault is active and has the potential to generate large earthquakes [13]. Based on this, one of the sources of threat in Morowali Regency is the Matano Fault, which is a source of energy that triggers high-magnitude earthquakes that can cause tsunamis.

Morowali Regency has a water area of 29,963 km2 with a coastline of approximately 650 km [11]. Most of the area is located in coastal areas consisting of small islands, this causes people living in coastal areas to be potentially affected by tsunami waves.

Tsunamis are fast-onset disasters, or a type of disaster with a rapid process. Tsunamis can originate from near-field locations, with propagation times of less than 30 minutes from the source to the monitored coastline, or from far-field locations, with propagation times longer than 30 minutes to the monitored coastline, or from tsunami sources greater than 1,000 km away [10].

Tsunamis are not a new phenomenon in human history. History records that several ancient civilizations have experienced significant damage from tsunamis. According to [15], "some archaeological evidence suggests that tsunamis struck civilizations in the Mediterranean coastal region around 1500 BC." These natural disasters, caused by tectonic movements on the seabed, such as underwater earthquakes or underwater volcanic eruptions, have the potential to create large waves capable of devastating coastlines and affected areas.

Vulnerability is a condition of a community or society that leads to decreased resilience due to external influences that threaten lives, livelihoods, natural resources, infrastructure, economic productivity, and well-being. The relationship between disasters and vulnerability creates a state of risk, where the higher the level of vulnerability to a disaster, the higher the level of risk caused by the disaster itself [1]. Several areas that have experienced the impact of tsunamis have significantly impacted environmental changes in those areas [6].

One approach that can be used in tsunami risk analysis is a Geographic Information System (GIS) using scoring and overlay methods. GIS methods enable spatial mapping that can identify areas with high levels of vulnerability based on various parameters, such as coastal elevation, distance from the coastline, population density, land use, and the presence of critical infrastructure. By utilizing scoring and overlay methods in GIS, the analysis results can be used to support spatial planning, disaster mitigation strategies, and more effective evacuation efforts in tsunami-prone areas [9]. According to [4], GIS is "a computer-based system or technology designed to collect, store, process, analyze, and present data and information about an object or phenomenon related to its location or presence on the Earth's surface."

Mitigation and early warning play a key role in protecting communities and the environment from the threat of future tsunamis [5].

RESEARCH METHODS

Materials

This research began with literature review, followed by primary and secondary data collection from several sources, such as population tabulation data and spatial data. Next, weighting was applied to each parameter based on BNPB Head Regulation No. 2 of 2022 [1]. To obtain the total vulnerability index, the weights of the parameters used were summed and overlaid to produce a tsunami vulnerability analysis map. The following are the detailed research stages.

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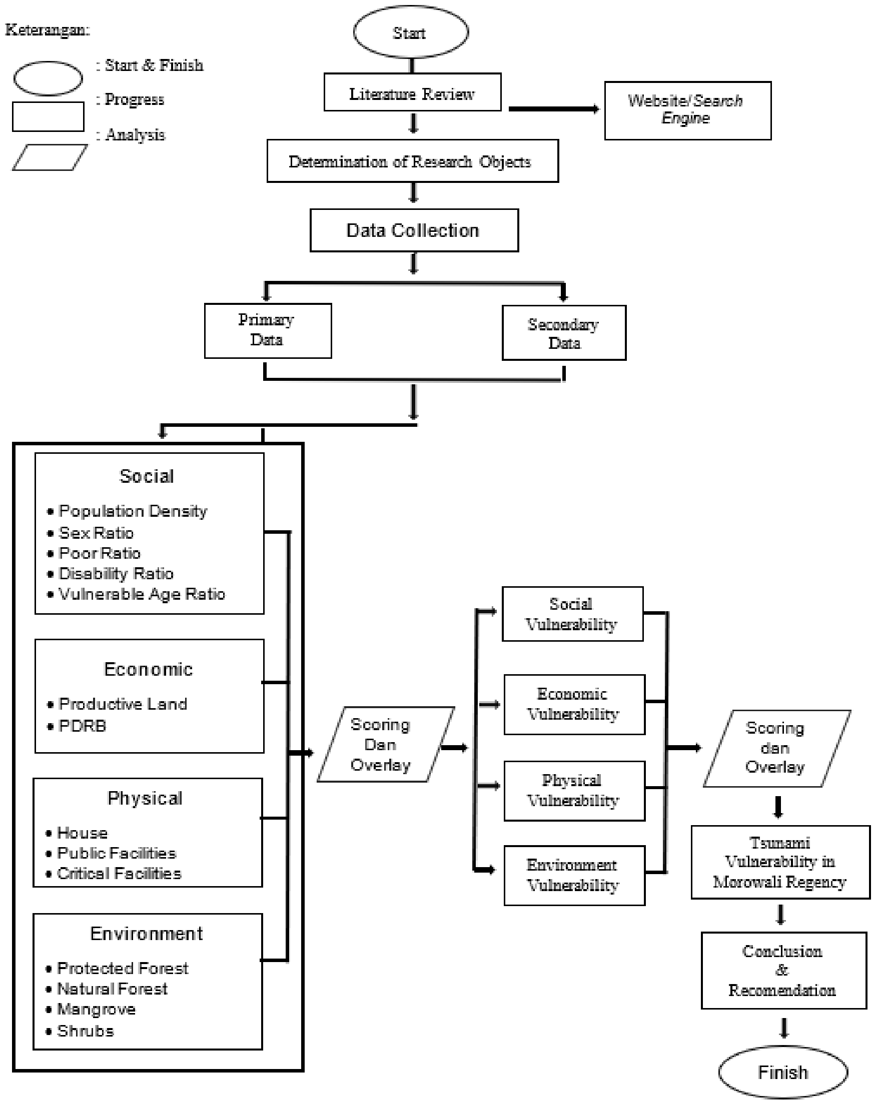

Figure 1. Flow Chart

Methods

This research was conducted in Morowali Regency, Central Sulawesi, from January to August 2025. The data used in this study were obtained from the Morowali Regency Central Statistics Agency (BPS) for 2024, as well as spatial data from sub-district administration, coastlines, DEMNAS data, and several other spatial data. Prior to the tsunami vulnerability analysis, a tsunami inundation analysis was conducted using fuzzy logic, assuming a coastal wave height of 10 meters. The next step was to conduct a vulnerability analysis for each parameter, consisting of social, physical, economic, and environmental parameters, in accordance with BNPB Regulation No. 2 of 2012 [1]. Furthermore, weighting and map overlay were performed using a geographic information system (GIS)-based method.

Data Analysis

Data analysis involved calculating tsunami wave inundation, assuming a wave height of 10 meters, and determining the tsunami hazard class and the extent of the affected area. Next, several social, physical, economic, and environmental parameters are weighted, and the results are added together to obtain an overall weighted value. The next step is scoring the total weighted value to determine whether the vulnerability index falls into the low, medium, or high category.

RESULT AND DISCUSSION

The results of the tsunami-affected area calculation and the vulnerability index weighting are shown in Tables 1 and 2. The tsunami wave simulation results, with a 10-meter inundation, are divided into three hazard classes: low hazard (4,073 hectares), medium hazard (13,294 hectares), and high hazard (25,125 hectares). The total hazard area is 42,491 hectares. There is a difference in the tsunami hazard area compared to the Central Sulawesi Disaster Vulnerability Assessment document published by the National Disaster Management Agency (BNPB) in 2021, which stated that the total tsunami hazard area was 8,414 hectares. This difference in hazard area is due to the use of the latest land use data from 2019, which is updated every five years. Furthermore, this study used a 10-meter tsunami wave simulation.

Table 1. Results of measuring area of hazard

No	District	Hazard	Hazard Area (Ha)				Scoring
			Low	Medium	High	Total	
1	Bahodopi	Tsunami	3.844	5.224	4.484	13.552	High
2	Bumi Raya	Tsunami	0.044	2.001	2.324	4.369	Low
3	Bungku Barat	Tsunami	0.003	0.717	3.159	3.879	Low
4	Bungku Pesisir	Tsunami	-	-	3.391	3.391	Low
5	Bungku Selatan	Tsunami	-	-	0.735	0.735	Low
6	Bungku Tengah	Tsunami	0.159	1.954	3.850	5.963	Low
7	Bungku Timur	Tsunami	0.021	1.695	2.172	3.889	Low
8	Menui Kepulauan	Tsunami	-	-	2.045	2.045	Low
9	Wita Ponda	Tsunami	0.002	1.702	2.965	4.669	Low
	Morowali	**Tsunami**	**4.073**	**13.294**	**25.125**	**42.491**	

The inundation level study above revealed that Bahodopi District had the highest impact area, at 13,552 hectares, among the eight other districts. This is because Bahodopi District has the largest area compared to other districts, and also because of the large land use changes due to the need for land for the construction of a smelter for the laterite nickel ore extraction industry.

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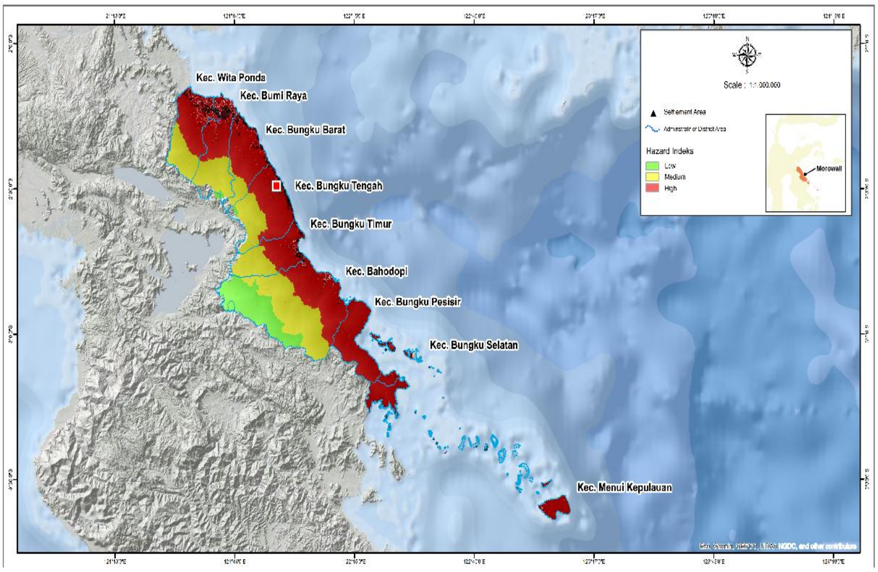

Figure 2. Map of Hazard Areas in Morowali District

Vulnerability is a condition of a community or society that leads to or causes an inability to cope with the threat of disaster (BNPB, 2012). The vulnerability assessment in this study used social, physical, economic, and environmental parameters. The results of the vulnerability scoring for these four parameters indicate that Morowali Regency has a high vulnerability level of >0.667. The sub-district with the highest potential vulnerability risk is West Bungku District, with a vulnerability index value of 0.9200. The following table shows the results of the tsunami vulnerability analysis:

Table 2. Results of Measurement of Vulnerability

No	District	Social Vulnerability		Physical Vulnerability		Economic Vulnerability		Environment Vulnerability		Vulnerability	
		Scoring	Weight	Scoring	Weight	Scoring	Weight	Scoring	Weight	Weight	Scoring
1	Bahodopi	High	0.7999	High	1	High	0.7332	High	1	0.8533	High
2	Bumi Raya	High	0.7999	High	1	High	0.7332	High	0.7332	0.8266	High
3	Bungku Barat	High	0.7999	High	1	High	1	High	1	0.9200	High
4	Bungku Pesisir	High	0.7999	High	1	High	0.7332	High	1	0.8533	High
5	Bungku Selatan	High	0.7999	High	1	High	0.8664	High	1	0.8866	High
6	Bungku Tengah	High	0.7999	High	1	High	0.7332	High	1	0.8533	High
7	Bungku Timur	High	0.7999	High	1	High	0.7332	High	0.9333	0.8466	High
8	Menui Kepulauan	High	0.7999	High	1	High	0.8664	High	1	0.8866	High
9	Witaponda	High	0.7999	High	1	High	0.8664	High	1	0.8866	High

CONCLUSION

The conclusion of this study is that Morowali Regency has a tsunami hazard area categorized as low (4,073 hectares), medium (13,429 hectares), and high (25,491 hectares), with a total hazard area of 42,491 hectares. The tsunami vulnerability index in Morowali Regency is categorized as high. Mitigation measures that can be implemented to reduce the impact of tsunami risk include infrastructure engineering through the construction of waterbreak embankments and greenbelt embankments made of mangrove plants in coastal areas.

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