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Tsunami Hazard Analysis in Likupang Tourism Area, North Sulawesi

Febriani Saputri[1], Ping Astony Angmalisang[2], Wilmy Etwil Pelle[3], Indri Manembu[4], Anton Rumengan[5], Robert Bara[6], Deiske Sumilat[7]

[1]Aquatic Science Graduate Study Program, Faculty of Fisheries and Marine Science, Sam Ratulangi University, North Sulawesi, Indonesia
[2,3,4,5,6,7]Faculty of Fisheries and Marine Science, Sam Ratulangi University, North Sulawesi, Indonesia,

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Abstract— *The Likupang area, North Sulawesi is one of the super priority tourist destinations launched by the Central Government with the marine tourism sector as the axis. On the other hand, the potential for natural disasters originating from the sea is unavoidable so it needs to be one of the considerations in the process of developing disaster-responsive tourist areas. A tsunami hazard analysis study is first step in disaster mitigation planning. The study is in the form of tsunami modeling by identifying the worst possible scenario in the Likupang area using COMMIT modeling. The modeling is able to produce parameters such as arrival time, maximum height and tsunami inundation area. These three parameters are used as the basis for mapping the tsunami hazard map. The modeling produces the fastest arrival time, which occurs in the first minute after an earthquake occurs. The maximum height obtained from the modeling is 6.8 meters. The maximum inundation area reached by the tsunami wave is 23.57 km2. The combined results of the five scenarios are presented in hazard maps. The majority of public tourist sites are in the Warning status area, but some private resorts are still in the area with the Major Warning status.*

Keywords— *Likupang, North Sulawesi, Tsunami hazard map, Tsunami modeling.*

I. INTRODUCTION

One of the Ministry of Tourism programs is the development of super-priority tourist destinations. Out of the ten priority areas, Likupang is one of the areas listed [1] Likupang District, located in North Minahasa Regency, North Sulawesi Province, was selected as a candidate for a world-class tourist area with the main attraction of resort and cultural tourism. This theme is in accordance with the layout of the Likupang area, which is mostly beach and adjacent to the Wallace Conservation Center. The tourism concept in Likupang will develop premium and mid-range resorts, cultural, and the development of WaIlace Conservation [2].

Indonesia as an archipelagic country with a coastline of 108,000 km is suitable as a tourist destination based on the beach area. In addition, the added value of coastal areas in Indonesia comes from the diversity of flora, fauna, and the beauty of the scenery. On the other hand, beaches also harbor latent hazards such as tsunamis.

A tsunami is a natural disaster with little frequency but massive impact. In 2018, tsunamis occurred in Indonesia twice, namely in Palu, Central Sulawesi, and the Sunda Strait. The National Disaster Management Agency noted that the impact of the two tsunamis claimed 453 lives and damaged property for more than 2000 housing units [3].

The North Sulawesi region is not an exception. In 2019, the BMKG issued two early tsunami warnings, each in the Maluku Sea with the same magnitude of 7.1. The earthquake's tremors were felt in most areas of the northern Sulawesi peninsula and caused mass panic. The tsunami was recorded in Bitung with less than one-meter height [4].

The development of the tourism sector is one of the contributors to the national economy, especially in increasing the country's foreign exchange and in the local sphere can advance the community's economy around tourist areas [14]. Given these important factors, the development of the tourism sector should be carried out with good planning to provide optimal benefits.

The statement above reinforces the important factor in making a disaster response system where in this research will be carried out in the coastal area of Likupang. The disaster response system is an integrated system carried out when a disaster occurs to reduce the impact caused, especially victims and then property. A disaster response system requires comprehensive planning starting from the potential threats to tourist areas to produce a further consideration of decisions taken in making a disaster response system which is commonly referred to as a disaster mitigation plan [5] [15].

This research will carry out a series of activities to support decisions on disaster mitigation systems in tourist areas in Likupang, North Sulawesi, among others, by modeling a tsunami with several possible worst-case scenarios that may occur around the research area for hazard analysis based on the modeling results in the form of arrival time, tsunami height, and tsunami inundation.

II. METHODS

In general, the scope of the research area covers the entire coast of the East Likupang sub-district as the center of the tourist area. The observation points are placed in several public and private tourist attractions with the coordinates attached to the table 1

Table 1 The coordinate of observation point

Observation Point	Name	Latitude	Longitude
1	Kalinaun Resort	1°37’28.009”	125°8’41.662”
2	Sampiran Beach	1°37’32.585”	125°8’49.121”
3	Paal Beach	1°39’5.17”	125°9’42.88”
4	Pulisan Jungle Beach Resort	1°39’55.238”	125°9’48.571”
5	Pulisan Beach	1°40’56.654”	125°8’49.776”
6	Surabaya Beach	1°39’52.373”	125°6’23.378”
7	Murex Resort	1°44’8.387”	125°9’0.018”
8	Blue Bay Divers Resort	1°44’41.996”	125°9’20.959”
9	Mimpi Indah Resort	1°46’6.503”	125°9’57.794”
10	Bastianos Resort	1°44’27.24”	125°8’44.16”
11	Coral Eye Resort	1°45’4.198”	125°8’1.388”

Tsunami modeling was carried out with ComMIT. ComMIT is a web-based community tsunami model designed by the NOAA institution. The ComMIT system uses a precomputed database with a user-friendly interface and a MOST (Method of Splitting Tsunamis) modeling base [6]. ComMIT data set comes from 2 (two) sources. First, Bathymetry of 1 arc-minutes ETOPO1 produced by NOAA's National Geophysical Data Center. This data has been interpolated from 60 arc-second to 3 arc-second to match the topographic data set. Second, the topography is derived from the CGIAR SRTM 90m version 4 digital elevation model produced by the CGIAR Consortium for Spatial Information.

The modeling scenario includes five scenarios, namely North Sulawesi subduction, Philippine subduction, West Maluku Sea subduction, East Maluku Sea subduction, and Sulu subduction. The magnitude of the earthquake source is taken from various studies with the provisions of the largest magnitude [7] [8], assuming that it will have the worst impact in the research area. The fault geometry parameter, namely strike (the angle formed by the fault direction relative to the north direction (calculated clockwise)), will be taken from the database source from the tsunami history of each subduction location [9]. Meanwhile, the highest values for dip and rake were taken, namely, dip of 45° and rake of 90°, assuming that the earthquake mechanism was purely an upward fault. The area of the fault plane was typed manually in the ComMIT software according to the Scaling [10] Law, Wells & Coppersmith formula. The scenario of the earthquake and tsunami generator is attached in Table 2.

Table 2 Tsunami Generator Earthquake Scenario

Scenario	Subduction	M	L (km)	W (km)	U (m)	Strike
1a 1b	Northern Sulawesi Northern Sulawesi	8.5	250 74	75 75	15 15	92 231
2	West Molucca Sea	8.5	324	75	15	248
3	East Molucca Sea	8.1	190	51	9	231
4	Fillipina	8.2	217	56	10	330
5	Sulu	8.5	324	75	15	314

In preparing the tsunami hazard map, the components of the modeling results are mapped using GIS tools. The modeling results in arrival time, tsunami height, and tsunami inundation are then divided into 3 hazard classes, namely major warnings, warnings, and advisory [11], described in the Table 3.

Table 3 Components of the Tsunami Hazard Index

No	Alert Status	Tsunami Wave Height	Suggestions
1	Major Warning	>3 meters	Evacuate!
2	Warning	0.5 – 3 meters	Evacuate!
3	Advisory	<0.5 meter	Stay away from beach and riverbank.

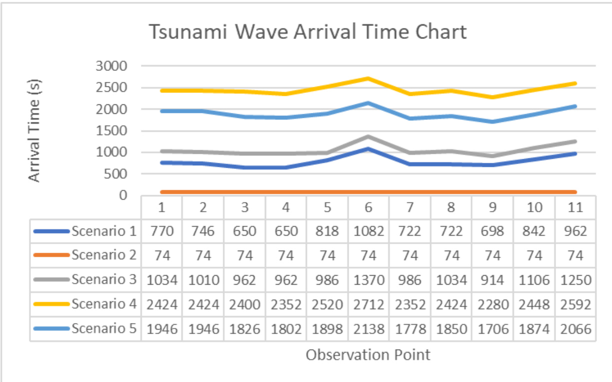

Fig 1. Tsunami Wave Arrival Time Chart

III. RESULT AND DISCUSSION

The arrival time of the COMMIT modeling results is presented in Fig. 1 below.

In general, it can be seen from the chart indicated that the scenarios that produce arrival times are sequentially from the fastest, namely the second, first, third, fourth, and fifth scenarios. The modeling results show that the fastest arrival time for each observation point is in the second scenario. The arrival time required for the tsunami waves to reach the twelve points is 1 minute. The second scenario is the source of an earthquake in the western part of the Maluku Sea with an estimated maximum magnitude of 8.5.

The modeling results cannot be proven concretely because so far, there has been no record of past tsunami events that hit the coastal area of Likupang.

Considering the results of modeling that have been carried out with an average arrival time of around one minute at observation points, the decision to wait for an evacuation order from the competent government is irrelevant. The GITEWS organization in the "Tsunami Evacuation Planning Handbook" [12] provides a solution for self-evacuating. Self-evacuation is a community initiative that responds to earthquakes and tsunami. Armed with an understanding of the dangers of earthquakes and tsunamis, people, especially coastal areas, who feel an earthquake with a relatively strong vibration of more than 20 seconds are urged to carry out self-evacuation by securing themselves to a high place.

The modeling also produces parameters for the estimated tsunami height. The tsunami height described in this study is focused on the maximum height generated by the tsunami waves entering the coastal area. The tsunami height obtained by COMMIT modeling is presented in Fig.2.

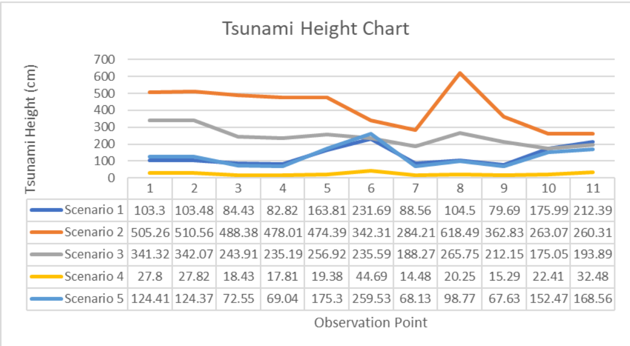

Fig 2. Tsunami Height Chart

The maximum height obtained from the observations is generated from the second scenario modeling, which is in the western part of the Maluku Sea with an earthquake magnitude of 8.5. The height obtained is in the range of 200-600 cm.

The height of the tsunami which has a maximum potential at the alert level accompanied by a very short probability of arrival time are two important points for considering what type of evacuation tends to be recommended [16]. Horizontal evacuation which is the type that is more familiar to the community. This type emphasizes the strength of the furthest distance that can be reached away from the beach with limited time needed to reach a safe point. Meanwhile, vertical evacuation is a type that requires a higher cost because it is based on the construction of structures / buildings with disaster resistance and heights that exceed the high probability of a tsunami.

The tsunami inundation is the furthest distance traveled by a tsunami that reaches land. Concerning an irregularly shaped area, the COMMIT model represents the tsunami inundation in space units (km2) regarding grid A covering the entire research area. The following table of tsunami inundations based on each scenario.

Table 4 Inundation Area based on Tsunami Modeling

Scenario	Inundation Area (km^2)
1	10.77
2	23.57
3	4.42
4	3.24
5	7.62

Based on Table 4 above, it can be seen that the five earthquake sources have a probability of having a relatively significant impact on the tsunami inundation. The second scenario, in particular, provides the most considerable immersion area impact. This shows that the source of the earthquake in the second scenario has the most significant potential to cause tsunami damage. Tsunami inundation obtained from the modeling results in this study does not involve land cover differences according to the field due to modeling limitations. The modeling is equated to one roughness model, namely the type of soil with a value of 0.009.

Information on tsunami inundation at an advanced level can be used as a reference as a horizontal evacuation route, especially decision-makers can see blind spots that are not affected by the tsunami to be used as an efficient and effective evacuation site.

East Likupang District has 18 villages with a geographical structure consisting of coastal villages, mainland villages, and villages on separate islands, namely Bangka Island [13]. The hazard level map shown in Fig 3 shows the hazard level, which varies with the predominance of the Alert status. Villages included in the Major Warning level include Lihunu, Kahuku, Likupang Satu and Sarawet. Meanwhile, the remaining coastal villages, namely Pinenek, Runondoran, Kalinaun, Marinsow, Pulisan, Maen, Wineru, and Kampung Ambong, are at the Warning level.

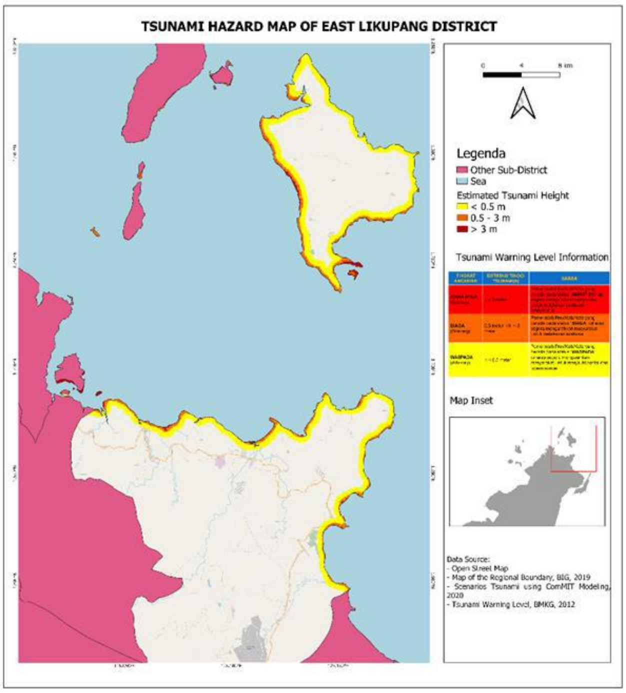

Fig 3. Tsunami Hazard Map of East Likupang District

The level of tsunami hazard in the East Likupang sub-district varies from Major Warning, Warning, and Advisory status. The tsunami hazard level is presented in the Hazard Map with three color representations. Red symbolizes Major Warning level status with the criteria for a tsunami height exceeding 3 meters. Orange symbolizes Warning level status with the criteria of a tsunami height between 0.5 and 3 meters. Yellow symbolizes the status of Advisory level with the criteria of a tsunami height. less than 0.5 meter.

The Warning category includes several public tourist areas scattered in Kalinaun, Marinsow, and Pulisan villages. Meanwhile, several resorts need attention, especially those included in the Major Warning area, namely Bastianos Resort, Coral Eye, Sea Soul Dive, Blue Bay, Murex, and Mimpi Indah.

Based on the combination of tsunami modeling results and hazard level analysis, it can be seen that the coastal area of Likupang is a tsunami-prone area with the characteristics of a fast arrival time, relatively high tsunami height, and wide inundation. This situation makes Indonesia's tsunami information dissemination system still ineffective considering the period required and alternative access that can be relied on. Alternatives proposed in the tsunami disaster mitigation plan in several cases similar to the Likupang coastal area include self-evacuation.

Self-evacuation is a form of evacuation that relies on a quick response from the community in responding to signs of a tsunami, especially those originating from nature, such as a strong earthquake shaking for more than 20 seconds, a sudden rise/decrease in sea level, as well as sounds such as booms coming from the sea. The community response expected from an independent evacuation system is to recognize the signs of a tsunami quickly, without direction from the local government, and decide to evacuate by running away from the beach or going up to the highlands. Meanwhile, residents who are at sea can make decisions to sail towards the sea, not towards the mainland.

IV. CONCLUSIONS

tsunami modeling in the coastal area of Likupang, North Sulawesi, produce three main parameters: the arrival time, height, and area of the tsunami inundation. The fastest time of the arrival of the tsunami is the first minute after the earthquake. The maximum tsunami height generated by the modeling is 6.8 meters. The largest area of immersion that tsunami waves can achieve is 23.57 km^2. The majority of public tourist sites are in the Warning status area, but some private resorts are still in the area with the Major Warning status.

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