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Utilization of Tsunami Modeling in Determining Temporary Evacuation Spots on the Labuan Coast

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Abstract

Indonesia is one of the countries with more water surface than land and, in addition, its territory is located between three plates: the Indo-Australian, the Eurasian and the Pacific. This makes Indonesia a country with high volcanic and seismic activity. The abundant news related to mega-earthquakes has made many Indonesians wary of these phenomena. The Sunda Strait is one of the places where megathrustings are expected to occur, and Banten, being a province located in the ocean of the Sunda Strait, makes the level of vigilance high. The modeling process related to tsunami is a representation that can visualize if a large earthquake occurs and causes a tsunami, especially in the coastal area of Labuan subdistrict. The objective of this research is to determine the temporary evacuation spots in tsunami affected areas using tsunami modeling performed with COMCOT (Cornell Multi-grid Coupled Tsunami Grid). The modeling results obtained a wave height to the shoreline of 15 meters with a period to the shoreline of 60 minutes. Twelve temporary evacuation spots (TES) were determined in this study, 9 of the 12 spots become safe TES because the point has a higher ground level and is out of the inundation range.

Keywords : Tsunami, TES, Megatrust, COMCOT

1. INTRODUCTION

Indonesia is a country with a wider water area than its land area [13]. Geographically, Indonesia is located at 6˚ N-11˚ S and 92˚ E-142˚ E with a coastline of 95,161 km which is designated as the country with the second longest coastline after Canada[4]. Indonesia is also a country whose territory lies between the Asian, Indo-Asian and Pacific plates [10]. the movement between the three places Indonesia in an area with quite high volcanic and earthquake activity [18]. Therefore, many natural disasters occur which cause movement and trigger earthquakes and tsunamis.

Tsunami is a natural phenomenon where sea waves propagate in all directions due to impulsive disturbances on the seabed [11]. Tsunamis can occur due to tectonic plate activity, volcanic eruptions, or underwater landslides [15]. One area that has a high level of seismic activity is the Sunda Strait [22].

Historically, the Sunda Strait has recorded tsunami events caused by volcanic eruptions and tectonic processes [19]. Coastal areas adjacent to the Sunda Strait are very prone to tsunamis due to earthquake activity caused by plate movements in the subduction zone or better known as Megathrust [3]. Recently, the Meteorology, Climatology and Geophysics Agency predicted that a Megathrust would occur. A megathrust event is a high-magnitude earthquake caused by a fault in a subduction zone where one plate is pushed under another tectonic plate. Subduction zones are areas that often release earthquake energy which can cause tsunamis [5]. It is impossible to predict the exact time when this Megathrust event will occur, but with the release of this news it is included in anticipatory steps if this happens as a way of mitigating disasters to reduce the impact that occurs.

Banten is one of the provinces that is prone to tsunami disasters [2]. The geographical location of several areas of Banten province itself is close to the waters of the Sunda Strait, which poses a threat to tsunamis [21]. In the last 10 years recorded in the BMKG catalog of damaging earthquakes in Banten province, there were 4 earthquake events with quite large magnitudes, such as in 2019 with the largest magnitude, namely 7.4 and a tsunami event was recorded in the BMKG tsunami catalog in 2018 which was caused by a landslide on the body of Mount Anak Krakatau, resulting in waves that damaged coastal areas near the Sunda Strait such as Cinangka with wave heights of 2-3 m, Tanjung Lesung as high as 4-5 m, Carita is 2-5 m high, and Teluk Labuan Village is around 1-3 m. With this incident resulting in 431 deaths, 7,200 people injured and 15 people missing and 46,646 people displaced, the damage caused by the tsunami was quite severe, starting from damage to houses, public places and fishermen's boats and ships [14].

Many villages in Labuan subdistrict, Pandeglang district, Banten province are located on the coast. Coastal areas are transitional areas between land and sea areas which have a strategic role in the lives of the surrounding communities [6]. With the news of the potential for a megathrust, local people are worried that another tsunami will occur. Even in an interview, the head of BMKG, Mrs. Dwikorita, said that the plate in Banten-Sunda Strait had never moved again after 200 years.

In the current era of increasingly developing technology, advances in information systems, especially in the marine sector, can be used as a supporting tool in making decisions [24], one of the technologies that can be used in the process of describing disasters in the form of modeling, especially tsunamis, is COMCOT (*Cornell Multi-grid Coupled Tsunami Grid*). This tsunami modeling process will help in describing a prediction if a tsunami occurs starting from how high the waves reach land, the time it takes for the water to reach land and how far the water spreads to land, with the results of this modeling the process of determining Temporary Evacuation Spots (TES) will be more optimal in selecting areas that are safe from inundation and suitable to be used as evacuation places. Evacuation is an effort to move victims from areas experiencing disasters to safe areas to save themselves. The aim of this research is to determine temporary evacuation spots for tsunami-affected areas through tsunami modeling created using COMCOT.

2. METHOD

This research uses a quantitative descriptive method, which in quantitative research is a method that uses numbers and data analysis [23]. Quantitative descriptive is a data method that is in line with research variables and focuses on a problem or event that is currently occurring and the results obtained in the form of numbers can be explained descriptively [9].

2.1. Time and Location of Research

This research was carried out in 2 stages, the first stage was processing in creating tsunami modeling using an earthquake scenario of 8.9 mag. Then the second stage is to determine the temporary evacuation point from the impact which refers to the results of the tsunami modeling that was previously processed. The location for this modeling is around the coast of Pandeglang district and the focus of this research is on the coast of Labuan District. A map of the research location can be seen in Figure 1. This research was carried out for 4 (four) months from August – November.

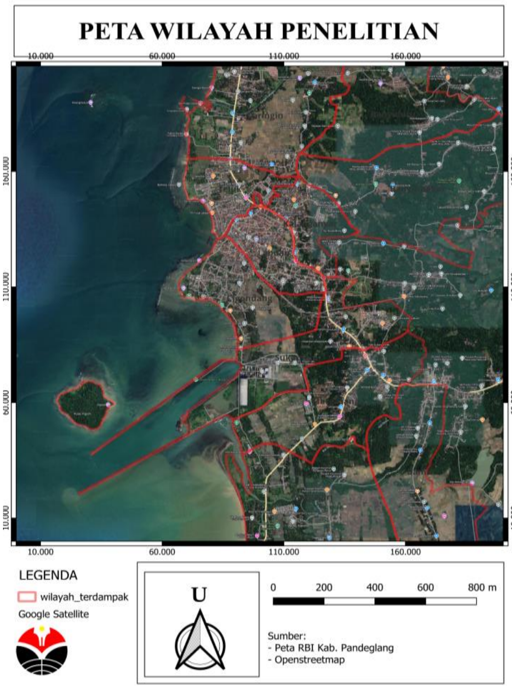

Figure 1. Research location map

2.2. Research Materials

The data used is land topography data obtained from FABDEM (*Forest And Buildings removed Copernicus* DEM) and bathrimetric data from the Geographic Information Agency (BIG) as well as administrative area boundaries were obtained from the RBI map of Pandeglang Regency. In modeling the tsunami propagation, it is assisted by *software* COMCOT (*Cornell Multi-grid Coupled Tsunami Grid*) with a final resolution of 20,781 m. In this research, earthquake parameters are needed as earthquake scenarios that can generate potential [20]. The earthquake scenario used here is the worst scenario with a magnitude of 8.9 mag with 156 *sub fault* which contains epicenter, strike, dip, rake, depth, length and width of fracture and dislocation value, when depicted will be as in figure 2, Apart from earthquake parameters, this modeling process also uses a roughness coefficient of 0.025 which is interpreted as *land* [17].

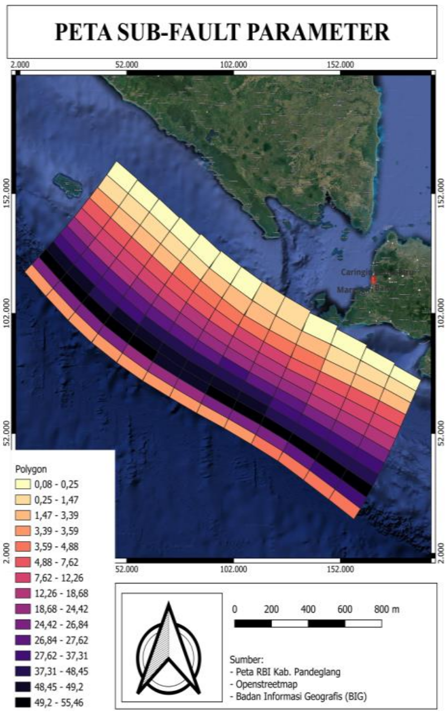

Figure 2. Map *Sub fault*

2.3. Tsunami Modeling Processing

Topographic data is the earliest data used, processing research spots on the map is done in Qgis first by determining the earthquake point and then creating *layer*. In this study, 4 were used *layer* with a smaller size for each *layer*it's like in figure 3. Information about *layer* And *grid* presented in table 1.

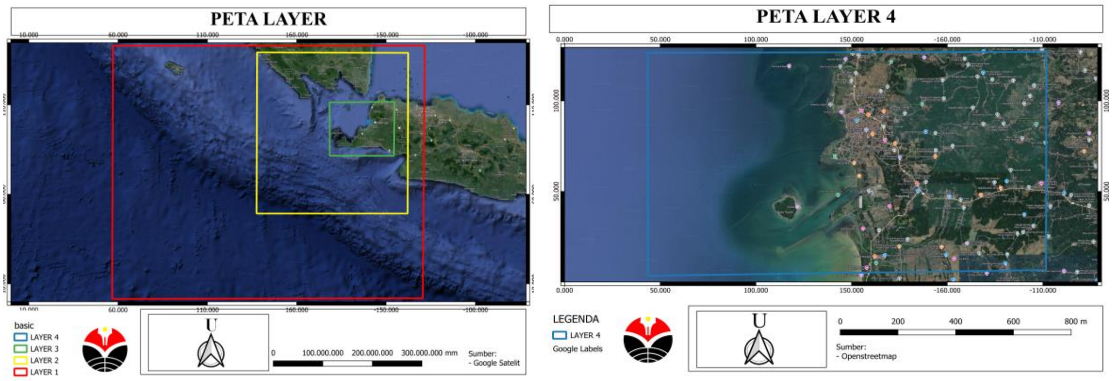

Figure 3. Map *Layer*

Table 1. Size *layer*

layer	Longitude	Latitude	Resolution (m)
1	101.101 106.846	-9.635 -4.984	1330
2	103.754 106.541	-8.066 -5.108	332,5
3	105.096 106.291	-7.006 -6.014	83,125
4	105.773 105.872	-6.413 -6.355	20,781

FABDEM and BATNAS are cut according to needs and then translated into ASC format so they can be input into COMCOT. When using COMCOT, it must be adjusted to the data used, such as entering data in the form of ASC and TXT files as parameters. After that, you can directly use it. *run* if there is no error. In this study, the final resolution of 20,781 m was used. To display the results of COMCOT plotting use *software* Octave. The results of the running process can be transferred to Qgis to see the results in the area that was created previously.

2.4. Determination of Evacuation Spots

In data analysis related to determining temporary evacuation spots, we utilize modeling results that have been obtained previously using COMCOT. From these results, the process of determining the TES will also look at the extent of the impact that will occur, then the comparison of areas affected by inundation and those that are not certain to have differences in land height and this can be a reference for determining the TES. Selection of TES in areas that have higher land elevation values will be more effective than just looking at areas that were not affected by waterlogging from the tsunami that occurred. In determining the evacuation point in this research, it also refers to the tsunami disaster evacuation site owned by the District BPBD. Pandeglang [8].

3. RESULTS AND DISCUSSION

The validation of the modeling results is proven by several previous studies that conducted research using COMCOT, such as research by Mahfud (2024) which compared the 2006 Pangandaran tsunami event with the results of modeling carried out in Cilacap using COMCOT. Research by Zhou et al. (2009) also stated that the results of the COMCOT model are a simple model but produce an effective model in predicting waves. The research instrument used by the author to validate the modeling results that have been produced

is a questionnaire that has been filled in by several expert judgments from BMKG, especially in the Operations Division, Earthquake and Tsunami Center. The results of the accumulated eligibility obtained an average score of 3.7/4, where this score is included in the 'Very Good' category.
Based on the modeling process carried out using COMCOT software using the scenario of an earthquake measuring 8.9 mag which resulted in a tsunami, the results obtained are as shown in Figure 4. In the results of this modeling there are 11 villages in the district. Of Pandeglang, 8 of which were affected by the tsunami were in Labuan District.

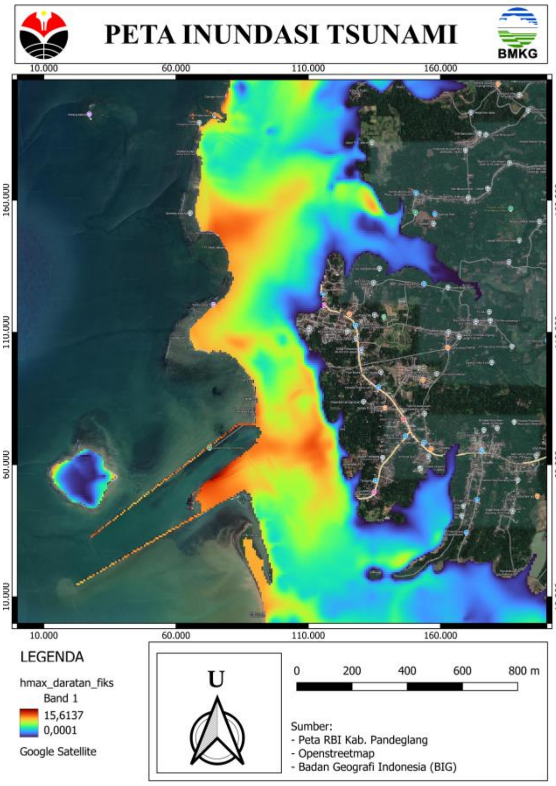

Figure 4. Inundation results

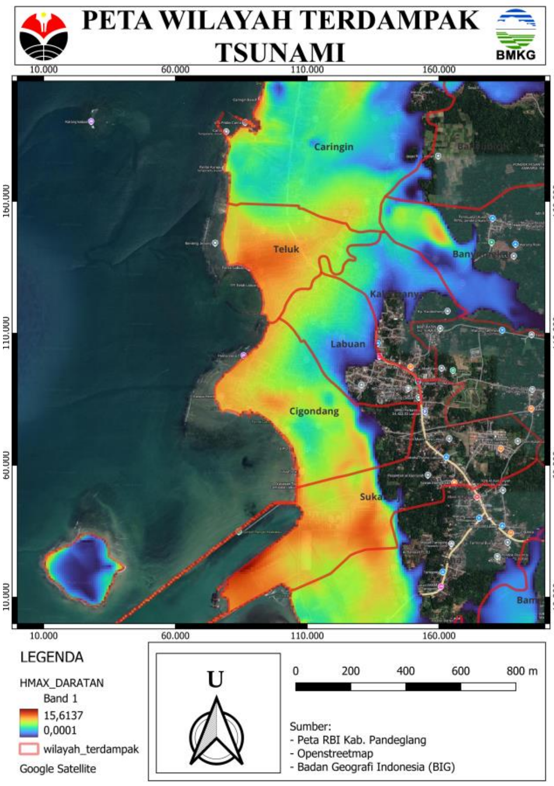

Figure 5. Affected Region

In accordance with Figure 4 from this modeling, the results show the tsunami height pattern on the coast of Pandeglang Regency *layer* Finally, with a resolution of 20m, a maximum height of 15 m was obtained. In the depiction of the modeling results, areas that have high levels of inundation are colored red and areas that are colored blue have lower inundation height values. From the results of the distribution *layer* 4 found 11 villages in the district. Pandeglang was affected by the tsunami, 8 of which were in Labuan sub-district. according to Figure 5. Three of the villages have quite high wave heights measured from the tsunami waves on the coastline, Sukamaju reached 15m, Cigondang reached 10m while in the Gulf the maximum wave height when it reached the coastline reached 12m.
The results of this modeling become a reference in the process of evacuating surrounding communities, especially several villages that are densely populated. The spread of water whose reach can be said to be as far as puddles of water reaching Banyumekar village, although the puddles are not very high, this can be an anticipation for residents in Banyumekar to protect themselves or their property. This is different from the 3 villages which are actually located on the coast, Cigondang, Teluk and Sukamaju. The people in these 3 villages must be ready for a fast and maximum evacuation process because the impact of this incident will be severe for local residents.
The arrival time of the tsunami is known by looking at the results of the TTT (*Tsunami Time Travel*) when the wave arrives at the coastline it takes approximately 66 minutes. The maximum period of one hour is for the community to evacuate themselves to avoid being affected by the tsunami event. During the evacuation process of 1.2 km, it took around 12 minutes for densely populated communities around the coast to move to a safe place [1]. In determining the TES, you must also look at the distance that allows people to reach it quickly.
Determination of temporary evacuation spots (TES) refers to the criteria determined by BNPB. According to the 2012 BNPB provisions, the criteria for buildings that can be used as evacuation spots are places that are public facilities, multi-storey buildings and open land [12]. The TES used in this research mostly uses public

facilities such as places of worship, tall buildings and open land. Determining the evacuation point is determined by considering the function of the building, number of floors of the building, height of the area, distance from the coastline, location from the road, and outside the tsunami inundation, also looking at how high the land is around the determined point based on topographic data which was also used previously in the tsunami modeling process. There are 12 spots that are TES locations that can be used as evacuation places in the event of a tsunami with wave heights of up to 15 m in 8 villages that fall within the Labuan sub-district and are affected by the tsunami. The author's determination of these 12 spots refers to the function of the building, number of floors of the building, height of the area, distance from the shoreline, location from the road, and outside the tsunami inundation. Table 2 shows a list of Temporary Evacuation Spots (TES) that can be used if a tsunami occurs around the coast of Labuan District.

Table 2. TEST

No.	Evacuation place	Type	Ground Surface Height (m)	Flood Height	Jarak (m)
1	Islamic boarding school	School	13	0	1.156
2	Trogong Mosque	Mosque	24	0	1.442
3	Margasana prayer room	Prayer room	20	0	1.345
4	Radio Krakatoa 93.7 FM	Office	12	0	1.186
5	Al-Barokah Mosque Daya Mekar	Mosque	16	0	1.169
6	Margasana	Open land	12	0	1.195
7	Labuan tsunami shelter building	3 Floor Building	5	6	421
8	GOR & futsal H. Margono	Building	20	0	1.895
9	Cigondang Village Office	Office	2	7	774
10	Banyumekar Volleyball Court	Open Land	21	0	2.432
11	Banyu Mekar Village Hall	village meeting hall	29	0	2.711
12	Kalanganyar	Open Land	14,8	0	1.138

In accordance with the results of the TES determination in table 2. The TES determined to have a building function that is accessible to the public, there are several buildings consisting of several floors, varying heights at each evacuation point, and the furthest distance of the TES measured from the shoreline is no more than 3000 m. Of the 12 existing TES, there are several TES that have been determined by the District BPBD. Pandeglang is like TES 4, 7, 8 and 9. In the tsunami disaster evacuation route document, Kab. Pandenglang, TES 3 is one of the recommendations from the District tsunami evacuation route document. Pandeglang in Sector B with evacuation route coverage Jl. Margasana Village, Pagelaran District

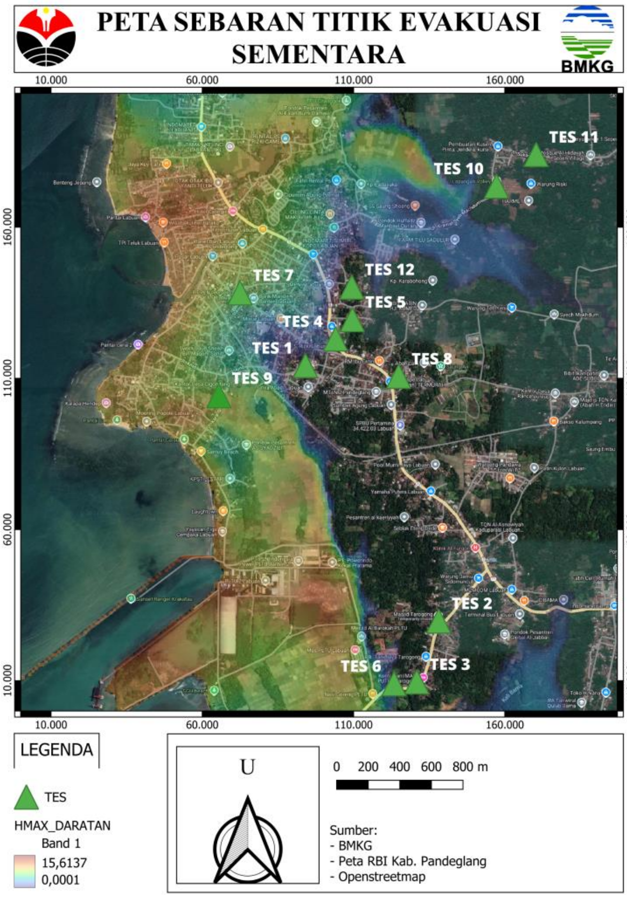

Figure 6. TEST

In accordance with Figure 6, there are 2 evacuation spots which are in quite high puddles, it can be seen from these three spots that they are still in a slightly orange to green color, which is likened to a high puddle height, rather than the distribution of water in light blue to dark blue which falls into the category of low puddles.

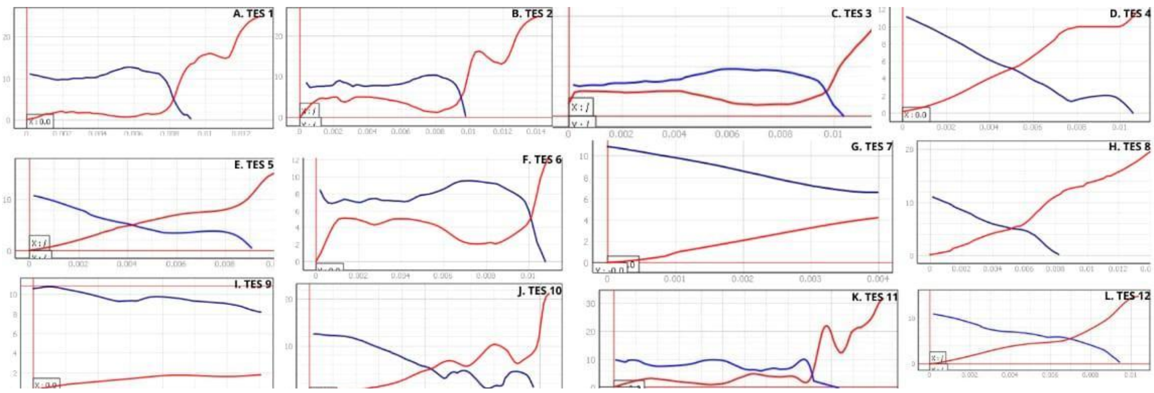

Figure 7. TES Comparison Curve

Description: = Inundation Height
= Ground Surface Height
X = Altitude (m)
Y = Distance (m)

Looking at the results of the comparison of land surface height and puddle height in Figure 7, which are sequential, the surface conditions at TES 1 are marked with the letter A, where the puddle height shows a decrease before reaching the evacuation point and the surface height from the coastline to TES 1 has

increased quite significantly, up to 13 m. In image B which shows TES 2, it is found that the condition of the land surface as measured from the coastline experiences ups and downs until the TES 2 point is at a height of 24 m. In the curve image, the height of the land surface increases from the coastline to TES 3. Curve D in Figure 4.4 shows that the water pool is decreasing and the land surface is increasing, indicating that TES 4 is the optimal point as an evacuation point because there is minimal inundation. The next curve result, namely curve E, shows a comparison of TES 5 conditions where the initial height of the water pool was 11 meters which spread perpendicularly to the east, sweeping across the land with the height of the land pool decreasing over a distance of around 800 m towards the east. TES 6 with a comparison of the F curve which shows the water pool decreasing and the ground surface increasing to a height of approximately 12 m.
The G curve shows the comparison in TES 7, being the first TES which was not optimal in determining a temporary evacuation point because of the condition of the ground surface and the height of the puddle, the higher the puddle of water that swept over the land. In contrast to TES 8 on the H curve where the puddle of water does not spread too far around the evacuation site, looking at the curve results shows that the surface height is increasing and the puddle of water only reaches the midpoint of the land surface. The results of curve I in Figure 4.4 show that the ratio is very suboptimal in making TES 9 a temporary evacuation point, because the height of the inundation is higher than the height of the ground surface. In curve J, there is a comparison curve in TES 10, where the description of the height of the pool and the surface is not much different, but the surface height towards that point increases and the water level also decreases. TES 11 is a point that experiences increases and decreases in height between the two because seen from the results of the K curve, the pool of water has risen again above the height of the ground surface. The last curve, namely L, which is a comparison in TES 12 shows a comparison, where the height of the ground surface increases and the water pool increases from 11 m to 0 and it is stated that the TES is outside the pool.
Comparing the 12 curves in each TES, the results obtained were the differences between each other, to obtain a safe point in the community evacuation process by looking at the results of the tsunami modeling that had previously been made. Of the 12 TES, 9 of them fall into the safe point for evacuation because the water inundation curve is decreasing and at that point the ground surface is above the water inundation curve, so it is very likely that the point will not be submerged with water originating from the tsunami that occurred. The remaining 2 TES are not included in the safe TES because looking at the results of the existing curve it shows that puddles of water still cover the land surface around the TES. The TES that has been determined in this study is at a distance of 400 m-3000 m and is on the main road for the reason that this makes it easier to find the TES directly [24].
In the process of evacuating the people in these 8 villages, the author suggests that the people of Caringin can evacuate themselves to TES 12 and 10, with a distance of 2 km calculated from the coastline, for Teluk Village the writer suggests going to TES 11, TES 10, TES 12 or TES 7, by accessing the TPI Labuan bridge, then for Banyumekar and Banyubiru villages they can evacuate the surrounding community to TES 10 or TES 11, but seen from the tsunami modeling results, the water spread did not reach densely populated areas in the village. Labuan Village is a village that has several places to use such as TES 1, TES 4, TES 12, TES 5 and TES 7. The tests that can be used in Cigondang village are TES 1, TES 4, TES 5, TES 8 or 7, but note that in TES 7, refugees must be on the 2/3 floor to be safer. Meanwhile, the TES that can be used to evacuate Kalanganyar village are TES 12, TES 5 or TES 4 or TES 8. Finally, the people of Sukamaju village can evacuate themselves to TES 3, TES 2 and TES 6.
Evacuation spots that are unsafe can be updated again according to the results of the analysis. In this study, the 2 TES that are not suitable are recommended to be kept away from the previous TES as far as 600-800 m to the east to avoid inundation from the tsunami modeling results.

4. CONCLUSION

The potential danger of a tsunami on the coast of Labuan can be said to be quite dangerous, with an earthquake measuring 8.9 magnitude occurring and causing a tsunami that impacted the Labuan coastal area with the maximum wave height reaching the Labuan coastline reaching 15 m with the furthest spread inland up to 3 meters.
Temporary Evacuation Spots are determined by considering the function of the building, number of floors of the building, height of the area, distance from the shoreline, location from the road, and outside the tsunami inundation, also looking at how high the land is around the determined point based on topographic data which was also used previously in the tsunami modeling process.

The community evacuation process in the 8 affected villages suggests that the Caringin community can evacuate themselves to TES 12 and TES 10, Teluk Village is advised to go to TES 11, TES 10, TES 12, and TES. Banyumekar and Banyubiru villages can evacuate local communities to TES 10 or TES 11, Cigondang Village is TES 1, TES 4, TES 5, TES 8 and TES 7, Labuan Village has several TES that can be used such as TES 1, TES 12 TES 4, TES 7 and TES 5, Kalanganyar Village is TES 12, TES 5, TES 4 or TES 8. Sukamaju Village can evacuate themselves to TES 2, TES 3 and TES 6. It is hoped that this research can be a reference in carrying out mitigation measures for tsunami disasters, especially in coastal areas of Labuan sub-district which is close to the Sunda Strait sea. With the spread of news *megathrust* also make this research an anticipatory event for the residents there and tourists who are on holiday in the coastal area of Labuan District.

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