MAPPING OF POTENTIAL AREAS TSUNAMI PRONE IN BENGKULU CITY

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ABSTRACT
Bengkulu city including tsunami-prone areas. This study aims to calculate the level of tsunami hazard in the Bengkulu city. The risk level is calculated based on the height from sea level (h), the distance from the shoreline (x), distance from the nearest river (s), the condition of geomorphology (k), the number of buildings per square kilometer (p), and the value of the peak ground acceleration (α). All variables are measured with the rules of research. Tsunami will continue to be a threat in earthquake prone areas. Threats region more concentrated along the coast and moves upstream as far as 10 kilometers. Tsunami threat is more factual determined by height, distance from the shoreline, distance from the nearest river, and peak ground acceleration. The correlation between tsunami potential score with each variable tends to be linear.

Keywords: bengkulu city, earthquake, peak ground acceleration, tsunami.

INTRODUCTION
The worst impact of the earthquake is a tsunami. Aceh earthquake 2004 resulting tsunami and deadly more than 100 thousand inhabitants. The tsunami also caused damage to the network infrastructure, public facilities, education buildings and settlements [1].

In general, the tsunami will threaten human life. Thanh and Xuyen (2008) conduct studies about the chances of a tsunami on the coast of Vietnam. Results of the study indicate where very small chance of a tsunami on the coast of Vietnam, but still carried mitigation to secure the social and economic system in the country [2].

Briggs et al (2005) modeling about level of tsunami inundation in Southern California, Modeling results provide information about the losses that will be suffered by the state. Losses could reach US $ 4.5 Billion which would result in damage and disruption of port operations, so can have a significant impact on the national and global economy [3].

Hoechner et al (2013) suggested that the Sumatra earthquake of 2004 has been impacted by the tsunami, with inundation length 1600 km in 10 minutes. Very long puddle scope and duration of only 10 minutes after an earthquake has similarities with Tohoku earthquake [4].

Bird and Dominey (2006) expressed the need for tsunami hazard mitigation which must be done by the Australian government after the Aceh tsunami in 2004. Sydney City Council stresses the importance of government preparedness to face the hazard of tsunami due to the earthquake that comes from subduction the Indo-Australian and the Pacific plate [5].

Breaker et al (2011) suggested that the tsunami which occurred as a result of the Tohoku earthquake have made huge losses in terms of damage in the Gulf of Santa Cruz Harbor. [6].

Figure-1. Bengkulu city map.
at around 75%. The intensity of a tsunami wave can be connected with the water level (Suppasri et al., 2013) [7], which is defined in equation (1).

\[ I = \frac{1}{2} + \log_2 H_{av} \] 

(1)

Figure-2. The relationship between the intensity with the average height of the waves.

Nakamura (1979) suggests a relationship between the intensity of a tsunami with a moment magnitude of earthquakes [8]. Its relationship as shown in equation (2).

\[ I = 3.55M_w - 27.1 \] 

(2)

Where \( M_w \) is the moment magnitude.

The equations are necessary to be as a reference in the reducing the tsunami effect hazard. Tsunami hazard can be reduced by two approaches, namely structural and nonstructural [9]. Structural approach taken to control the height of the tsunami wave by several types of structures such as sea walls or embankments, dams, thick vegetation, [10].

This structural approach will fail if tsunami high very large and outside the selected design criteria, [11]. Non-structural approach was done by planted trees against waves and mapping before the disaster.

Maeda et al., Propose to reduce the speed of tsunami waves must be made the forest control along 0 to 30 [12]. Timber stronger withstand tsunami waves compared to the building of concrete [13]. Paper is made to reduce the risk of tsunami with non-structural approach.

METHODOLOGY

Measurement of the variables that will determine the speed of a puddle by the tsunami is done by direct measurement at each point of interest.

Measurement of height (h) is done directly using altimeter. Measuring the distance from the shoreline to the point of being reviewed (x) is done by measuring directly on a map of the city of Bengkulu using software ArkGis. By using this software a distance on the map can be measured. The map which be used is a map on Google Earth. Measuring the distance from the point in terms of the river (s) do the same as measuring the distance to the shoreline. Calculation of Peak Ground Acceleration (\( a \)) was performed using the Kanai attenuation equations.

\[ a = \frac{5}{\sqrt{T_g}} 10^{-0.6M_w - (0.66 - 3.5 \log R) + (0.6 \gamma - 1.85) \frac{R}{R}} \] 

(3)

In the equation is required determinant variable, that is dominant ground period (\( T_g \)), the moment magnitude (\( M \)) and the distance from hipocentrum (\( R \)) to a point of interest. The next measurement is geomorphologi condition (G), and a number of buildings (\( \rho_b \)) in the square kilometer. Geomorphologi condition of choice is only 2 kinds, that is flat or hilly. All quantities are then quantized. Quantization for altitude is done as follows:

- \( \text{altitude } 0 - 10 \text{ meter were scored 6} \)
- \( \text{altitude } 10 - 20 \text{ meter were scored 5} \)
- \( \text{altitude } 20 - 30 \text{ meter were scored 4} \)
- \( \text{altitude } 30 - 40 \text{ meter were scored 3} \)
- \( \text{altitude } > 40 \text{ meter were scored 2} \)

The smaller the score of altitude, the smaller the risk of a tsunami. Quantization to the distance from the shoreline is done as follows:

- \( \text{< 500 meter is given score 6} \)
- \( \text{500 - 1500 meter is given score 5} \)
- \( \text{1500 - 2500 meter is given score 4} \)
- \( \text{2500 - 3500 meter is given score 3} \)
- \( \text{> 3500 meter is given score 2} \)

The smaller the scores of the coastline will be less risk of a tsunami. Quantization to the distance from the river carried out as follows:

- \( \text{< 500 meter from the river is given score 6} \)
- \( \text{500 - 1000 meter from the river is given score 5} \)
- \( \text{1001 - 1500 meter from the river is given score 4} \)
- \( \text{1501 - 2000 meter from the river is given score 3} \)
- \( \text{> 2000 meter from the river is given score 2} \)

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- \( \text{1501 - 2000 meter from the river is given score 3} \)
- \( \text{> 2000 meter from the river is given score 2} \)

The smaller the scores of the coastline will be less risk of a tsunami. Quantization to the distance from the river carried out as follows:
The number of buildings between 1.500-2.000 is given score 3
The number of buildings between 1.000 -1.500 is given score 4
The number of buildings between 500-1.000 is given score 5
The number of buildings between < 500 is given score 6

The greater the number of building will impede the flow of water, so that the less exposed to the risk of a tsunami.

From this score, then each point being reviewed have a risk of tsunami different from one another.

With this score, it can be made Map of Tsunami Potential Risk in every region of the Bengkulu city.

RESULTS AND DISCUSSION

Results of the study appear in Table-1 as follows:

Table-1. Tsunami potential score in each region.

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If displayed in the map can be seen in Figure-3.

Figure-3. Tsunami potential map Bengkulu city.

The red area is the area which potentially affected by the tsunami. The reach of the tsunami with altitude 30 meters could reach 10 km, this is in accordance with simulation 30-meter high tsunami inundation by Yulian [14] as Shown in Figure-4.

Figure-4. Tsunami flood areas with a height of 30 meters (Yulian, 2013).

With a range so far predictable amount of assets that were heavily damaged buildings can reach 40,000 units, including residential buildings, offices, hotels, hospitals, and houses of worship.

The number of people affected by the tsunami could reach 100,000. Losses incurred by the government of the city of Bengkulu is not only the soul but also the property.

Map of potential tsunami in Figure-3 is not the same as the map puddle in Figure-4. In Figure-3, a map of the potential tsunami of red color has not stated complete. For the most northern areas of the city not depict the actual conditions. In this area has not surveyed its maximum, ie there is no data in the region, so that the northern part of Bengkulu city still appeared yellow.
In coastal areas of Bengkulu City has a flat geomorphology that will further facilitate the movement of water entering the mainland. City areas being brought upstream more undulating and has a height which varies greatly, so it will be easier to inhibit the movement of water.

Of all the variables that predicted in determining the level of a potential tsunami, would only altitude (h), distance from shoreline (x) and distance from the river (s) are significantly become major variables in determining the level of potential tsunami disaster, as shown in Figure-5, Figure-6 and Figure-7.

![Figure-5](image)

**Figure-5.** The correlation between Tsunami potential score with region altitude.

The correlation between the tsunami potential score with altitude region tend to linear correlation with a regression coefficient of 0.606. Regression coefficient for 0606 is enough to justify that the correlation between the tsunami potential scores with altitude region is a linear correlation.

The correlation between the tsunami potential score with a distance of shoreline also provide clear information. The distribution of the dots give a tendency to a linear function as shown in Figure-6.

![Figure-6](image)

**Figure-6.** The correlation between Tsunami potential score with distance from the shoreline.

Regression coefficient for 0708 is very strong to justify that the correlation between the tsunami potential scores with the distance from the shoreline is a linear correlation.

The correlation between the tsunami potential score with the distance from the river also provide clear information. The distribution of the dots give a tendency to a linear function as shown in Figure-6.

![Figure-7](image)

**Figure-7.** The correlation between Tsunami potential score with distance from the river.

Regression coefficient for 0607 is enough to justify that the correlation between the tsunami potential scores with the distance from the river provide a linear correlation.

The correlation between the tsunami potential score with Peak ground acceleration also tend to be a linear correlation, with a regression coefficient of 0522 as shown in Figure-8.

![Figure-8](image)

**Figure-8.** The correlation between Tsunami potential score with peak ground acceleration.

Regression coefficient for 0522 provide information that is optimistic about the linear correlation between the tsunami potential scores with the Peak Ground Acceleration. For densely populated areas does not determine the level of tsunami danger, ut give a greater risk, especially during the day, because human ativitas.
CONCLUSIONS

Tsunami will continue to be a threat in earthquake prone areas. Threats region more concentrated along the coast and moves upstream as far as 10 kilometers. Tsunami threat more strongly determined by the altitude, distance from the shoreline, distance from the nearest river, and peak ground acceleration. The correlation between tsunami potential score with each variable tends to be linear. The correlation between the tsunami potential score with a geomorphological conditions, the number of buildings per square kilometers, and the number of people do not give clear information.

REFERENCES


