The earthquake hazard level of Makassar

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Abstract. An earthquake is a natural disaster that is often found in Indonesia because its geological area is a meeting between three large tectonic plates. Earthquakes have a high level of danger due to unpredictable events. In the Sulawesi region, especially Makassar, in 2017, there was an earthquake measuring 3 SR-6 SR, with a shallow epicenter. Epicenter distance calculation is used to determine the value of peak ground acceleration (PGA), which can then affect the intensity value in the hypocenter. This study aims to analyze the level of earthquake hazard using the PGA value as the basis for the initial reference of earthquake disaster mitigation. Variables used include rock type (geology), slope and the value of peak ground acceleration (PGA). Data on rock types were obtained from the Makassar City BPBD, and slope variables were processed from the SRTM DEM. Next, an overlay analysis was conducted to determine the level of earthquake hazard using a GIS application. The results showed that Makassar City had a majority of 94% of its area has a low level of earthquake hazard, while 6% of the area that had an earthquake hazard level was quite high in the east of Makassar. The frequency of earthquakes that were felt to be influential by the community (scale III MMI) was only two times in the last three decades (1996 and 2018).

1. Introduction

Natural disasters are events that are difficult to predict when they occur. One of the natural disasters, which until now has not been able to predict its arrival, is an earthquake [1]. In Indonesia, earthquakes are often found because of their geological area, which is a meeting between three large tectonic plates [2]. One of the islands in Indonesia, which has a meeting between plates is Sulawesi Island.

The tectonic history of Sulawesi Island runs from the Tertiary era to the present. Sulawesi Island has a complex and complex geological phenomenon. Faults and volcanoes that are the result of tectonic manifestations can cause earthquakes [3]. Earthquakes occur when the surface of the earth shakes because the release of seismic energy follows the rapid movement of large blocks of crust along the fault [2]. On the island of Sulawesi, a meeting took place between the three plates in the eastern part of Sulawesi Island, namely the Pacific plate, the Asian plate, and the Indian-Australian plate. The third meeting of the plates is a major factor in the formation of the uniqueness of the island of Sulawesi, which resembles the letter "K" [4].

The movement of these three plates also have speeds between 3-7 cm/year. Pacific plate movement has a rate of about 6 cm/year from the east. Asian plate movements have a flow of about 3 cm/year and are relatively passive to the southeast [5]. The fastest movement occurs in the Indian-Australian plate with an average speed of 7 cm/year from the south. The third meeting of these plates is located in the eastern part of Sulawesi Island [5]. The meeting between the three plates led to the formation of the Walanae fault.
adjacent to Makassar City.

Based on earthquake data records conducted by Region IV BMKG, Makassar City experienced an earthquake [6]. Meanwhile, in the Sulawesi region, 1052 earthquake events were recorded with earthquake magnitudes from 3 SR to 6 SR. Some of these earthquakes can be felt by humans but are not destructive, and some are included as devastating earthquakes [6]. During 2016 871 earthquakes were occurring in the shallow earthquake epicenter distance category.

Calculation of epicenter distance is used to determine the value of peak ground acceleration (PGA), which can then affect the value of earthquake intensity in the hypocenter. The PGA value is used as a parameter of the damage caused by an earthquake; the PGA value is obtained from the earthquake magnitude, hypocenter distance, with a fixed value [7]. PGA value has a straight comparison with the level of danger; therefore, if the PGA has a higher value, the greater the risk of an earthquake hazard. [8].

In recent years, research in the field of earthquake hazard prevention and earthquake disaster response systems has used GIS to facilitate data processing [9]. In a previous study conducted by Bambang Sunardi, the study was conducted in Sukabumi, West Java. The method in this research uses the HVSR method by searching the assessment of soil movement or PGA using the Kannai Method. The SAW method is used to conduct multi Criteria decision analysis. So in the results of the study, it was found that there were five hazard classifications namely very low, low, medium, high, and very high, and data analysis found that earthquake vulnerability in Sukabumi had high to a very high vulnerability which was concentrated along the Cimandiri Fault [10].

In another study conducted by Deliyanti Ganesha, the study used an overlay method to look for earthquake vulnerability, in the determination used scoring and weighting. The results of this study indicate that Pandeglang Regency has earthquake hazard vulnerability that spreads in 10 districts that have areas in the south of the Pandeglang Regency. [11] This study aims to determine the level of danger of tectonic earthquakes in Makassar City. The benefit of this research is to provide early information on earthquake-prone areas as an effort to mitigate earthquake hazards.

2. Methodology

2.1 Regional Descriptions

Makassar City is the Capital of South Sulawesi Province, with an area of 17,577 hectares. Makassar City Area is located in the coordinates of 119 ° 18 '30.18 " to 119 ° 32 '31.03 " East Longitude and 5 ° 00 '30.18 " to 5 ° 14 '6.49 " South Latitude. The boundaries of Makassar City are administratively directly adjacent to Maros Regency in the north and east, bordering Gowa Regency in the east and south, and in the west bordering the Makassar strait. The area of earthquake hazard obtained by referring to Ministry of Public Works Regulation No. 21 of 2007.

2.2 Materials and Method

The variables used to obtain earthquake hazard levels are geology (rock/lithology type and geological structure), slope, and Peak Ground Acceleration (PGA) values. The lithology and geological structure variables are closely related to the active geological and tectonic earthquake sub-disciplines, especially with the characteristics of seismic activity [7]. Data on rock types and geological structures were obtained from relevant agencies in the study area. Slope data is processed from SRTM DEM data collected from the U.S. Geological Survey (USGS).

The variable PGA value is obtained from the magnitude and the distance between the observation point and the hypocentre. PGA value has a straight comparison with the level of danger. PGA value is calculated based on earthquake event data, earthquake strength, epicenter point, and earthquake depth. The agency that became the reference for obtaining the data was the Meteorology Climatology and Geophysics Agency (BMKG). Rock data and geological structures are processed into a geological map. Meanwhile, the Makassar City slope value is the result of processing altitude data derived from SRTM DEM. Arc GIS 10.5 software presented the slope area map by activating the slope tools feature. Makassar City's PGA data processing method for finding mean values is to use the empirical formula [15]:

\[ a) \text{ Calculation of epicenter distance} \]
Cos Δ = \cos LE \cos Lx + \sin LE \sin Lx \cos (\lambda E + \lambda x) \tag{1}

Where:
- \( LE \) = Epicenter Latitude
- \( Lx \) = Geographic latitude point \( x \)
- \( \lambda E \) = Epicenter longitude
- \( \lambda x \) = Longitude point \( x \)
- \( \Delta \) = Distance between \( E \) and \( x \) in degrees (converted to km units times 111.11 km for 1 degree)

**b) Calculation of hypocenter intensity**

\[ Io = 1.5 \cdot (M - 0.5) \tag{2} \]

Where:
- \( Io \) = Intensity at source
- \( M \) = Magnitude

c) Calculate using the formula for the attenuation constant for the intensity at point \( X \)

\[ I = (Io \cdot \exp^{-b \cdot \Delta}) \tag{3} \]

Where:
- \( I \) = Surface intensity
- \( Io \) = intensity at source
- \( \Delta \) = Distance to earthquake source
- \( b \) = attenuation constant, worth 0.0021
- \( \exp \) = natural number, worth 2.786

d) Calculates the PGA value at point \( X \)

\[ \log \alpha = (I/3) - 0.5 \tag{4} \]

Where:
- \( \alpha \) = Peak Ground Acceleration
- \( I \) = Surface intensity on the MMI scale

e) Convert PGA values to acceleration values (\( A \))

\[ 1g = 9.8 \text{ m/s}^2 \]
\[ = 980 \text{ cm/s}^2 \tag{5} \]

| \( A \)   | \( \alpha \) |
|---------|-------------|
| < 0.05 g| < 49 gal    |
| 0.05 - 0.15 g | 49 gal - 147 gal |
| 0.15 - 0.30 g | 147 gal - 294 gal |
| > 0.30 g | > 294 gal   |

**Table 1.** Classification of gravitational acceleration and PGA [7]

Geological data, slopes, and PGA values are given scores and weights to be used as material for analysis of earthquake hazard levels in Makassar City. The analytical method used in this way is called a weighted overlay that is by paying attention to the weight ratio of each variable [12]. The weighting of each variable is carried out using the reference from Minister of Public Works Regulation no. 21 of 2007 [12]. Then scoring is done by converting the weighting matrix (Table 1).
Scoring is formed with a weight value of 4 for the PGA value, a weight value of 3 for geology, a weight value of 3 for the slope (Table 2). Rock type and slope variables were assessed with reference from PU PERMEN Number 21 / PRT / M / 2007 [12]. Based on a 1: 250,000 scale geological map, Makassar City only has three types of rocks. The three types of rocks are included in score 1 to score 3. Scoring for slope variables refers to PU PERMEN Number 21 / PRT / M / 2007, also with classification reaching five scores. Finally, to determine the classification of earthquake hazard levels based on BNPB Head Regulation number 2 of 2012 concerning General Guidelines for Disaster Assessment [12].

Table 2. Rock type, Slope, and PGA Assessment Parameters [12]

| Variable               | Score of Parameters | Classification                  | Richter |
|------------------------|---------------------|----------------------------------|---------|
| **Rock type assessment parameters** |                     |                                  |         |
| Rock Type              |                     |                                  |         |
| Score 1                | Andesite, Granite, Metamorphic, and Volcanic Breccia |                     |         |
| Score 2                | Agglomerates, Sediment Breccias and Conglomerates |                     |         |
| Score 3                | Sandstone, Limestone, Rough Tuff, and Silt Stone |                     |         |
| Score 4                | Sand, Silt, Fine Tuff, and Flakes |                     |         |
| Score 5                | Clay, Peat, and Mud |                     |         |
| **Slope assessment parameters** |                     |                                  |         |
| Slope                  |                     |                                  |         |
| Score 1                | 0-8 °               |                                  | <5      |
| Score 2                | 8-15 °              |                                  | 5-6     |
| Score 3                | 15-25 °             |                                  | 6-6,5   |
| Score 4                | 25-45 °             |                                  |         |
| Score 5                | >45 °               |                                  | >6,5    |
| **PGA assessment parameters** |                     |                                  |         |
| PGA                    |                     |                                  |         |
| Score 1                | <0,05g              |                                  | <5      |
| Score 2                | 0,05-0,15g          |                                  | 5-6     |
| Score 3                | 0,15-0,30g          |                                  | 6-6,5   |
| Score 4                | >0,30g              |                                  | >6,5    |

Table 3. Earthquake hazard weighting matrix [12]

| Variables | Parameters | Weight | Scores |
|-----------|------------|--------|--------|
| Geology   | Score 1    | 3      |        |
|           | Score 2    | 6      |        |
|           | Score 3    | 9      |        |
|           | Score 4    | 12     |        |
|           | Score 1    | 3      |        |
|           | Score 2    | 6      |        |
|           | Score 3    | 9      |        |
|           | Score 4    | 12     |        |
|           | Score 1    | 5      |        |
| Slope     | Score 2    | 10     |        |
|           | Score 3    | 15     |        |
|           | Score 4    | 20     |        |

The level of earthquake hazard is an area that is physically based on the influence of variable characteristics that can support the formation of an area prone to earthquake disasters. Physical conditions that can be attributed are slope, geological conditions specified in rock types, and PGA distribution. In this determination, the researcher divides the determination of the area into three classes, namely vulnerable, not vulnerable, and very vulnerable.
3. Result and Discussion

The geology of Makassar City has a slight variation, but it has a significant age difference. Where young rocks such as rocks resulting from alluvium deposition (Qac) meet with volcanic rock formation (Tmc). Makassar City geologically stands on alluvium deposited rocks (Qac) in Makassar, namely the Jeneberang River and Tallo River, and also coastal alluvial deposits (Qac). Other rock types in Makassar City are breccias and conglomerates (Figure 1).

The Qac rock formation (alluvial sedimentary rock) is the widest (12188 ha). Makassar City is a coastal area that has young rock formations. In Makassar City, there is also basalt rock (Ba) with a narrow space with a square (141 ha) due to intrusion of ophiolites. Intrusion itself is the igneous rock which has become a crystal from a magma that melts underground before they reach the surface of the earth, while ophiolites occur due to removal and displacement of fragments of the upper mantle layer and an oceanic crust which then are exposed at the edges of the continental crust [14].

Makassar City's topography is relatively flat to bumpy and hilly. The height ranges from 0-25 m above sea level with a slope of 0-15%. Morphologically, the landforms of Makassar City are grouped into two, namely morphological units of coastal alluvial plains and corrugated hill morphological units. The slope of Makassar City is dominated by a gentle slope (0-2%), with an area (13066 ha or 74.4%). Because of its location on the coast of the Makassar Strait (Figure 2).

Based on the results of calculations and data processing spatially, it is known that the entire area of Makassar City has a Peak Ground Acceleration value of 0 - 0.1 gals. The PGA value, according to the parameters made by BNPB is included in the low-risk level (Figure 3).
Of the three variables used in this study, it was shown that the most influential variable on the level of earthquake hazard was the slope variable and geological conditions. The variables are due to the PGA variable not having a value variation in Makassar City. PGA value does not have a significant effect because the PGA value obtained has a small value of only 0 - 0.1 gals. The value is since Makassar City has an area that is quite far from the plate line. That way, Makassar City has a low level of danger with an earthquake if seen from its PGA Value variable. In the data analysis conducted, it was found that Makassar City is dominated by areas that are not prone to earthquakes. The area is spread in the southern and western parts of Makassar City, while areas that have a vulnerable level are found in the eastern part of Makassar City.
Table 4. Classification of vulnerability

| Hazard      | Area (Ha) | %     |
|-------------|-----------|-------|
| Prone       | 946.11    | 5.41  |
| Not prone   | 16454.71  | 94.13 |
| Very not prone | 80.59    | 0.46  |
| Total       | 17481.41  | 100   |

The results of interviews about understanding the earthquake community are summarized in Table 5. Shows that respondents who had settled in Makassar before 1996 felt the most influential earthquake in 1996. While those who lived in 1997 and above would say 2018 was the most influential earthquake for Makassar. Descriptive interviews on table 5 also explained that people who settled in the city of Makassar tend not to have an excessive fear of the potential hazards that occur due to earthquakes. Interesting things that can be concluded in observations made in the study area that areas that have basalt rock types are not never once felt the slightest shake caused by the earthquake, according to residents of the Biringkanaya sub-district whose house is just above the basalt.

Table 5. Results of community interviews

| Sub-district | Feel the Earthquake | The Most Affected Earthquake |
|--------------|----------------------|-------------------------------|
| Rappocini    | 4 times              | 1996                          |
| Manggala     | 4 times              | 1996                          |
| Panakkukang  | 2 times              | 2018                          |
| Biringkanaya | Never                | -                             |
| Tamalanrea   | 1 time               | 1996                          |
| Ujung Pandang| 1 time               | 2018                          |

4. Conclusions

Makassar City has a low level of earthquake hazard with no hazard classification. The area of the area is not prone to reach 94.13% of all the regions in Makassar City. The most influential variable in determining the level of danger in Makassar City is the geological variable. Geological variables have significant rock age differences so that they can affect earthquake-prone areas. In the interview data analysis, it is known that the most influential earthquake in Makassar City was in 1996.

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