



## EARTHQUAKE DAMAGE LEVEL OF GORONTALO AREA BASED ON SEISMICITY AND PEAK GROUND ACCELERATION

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### ABSTRACT

Gorontalo is located at the macro and micro plate boundary, therefore it is located in an active seismotectonic region. This study aims to analyze earthquake damage level in Gorontalo based on seismicity and peak ground acceleration. The data used is obtained from the USGS. Data is made into a database and plotted onto a geological map. Calculation of peak ground acceleration is obtained using the Kawashumi formula. The results of this study indicate that Gorontalo is included in the slight to moderate earthquake damage level because it is dominated by shallow to intermediate earthquake's depth, light to moderate earthquake magnitude, and have a peak ground acceleration 1,462 - 99,714 gal.

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### 1. Introduction

Indonesia's position on the boundary of three macro plates makes Indonesia an active seismotectonic region. The complex tectonic plate condition (Bird, 2003) caused Indonesia to be prone to earthquake disasters (Milsom et al., 1992).

The North Arm Sulawesi is located in the eastern part of Indonesia. The North Arm Sulawesi is formed by multiple subduction, namely the North Sulawesi subduction and the East Sangihe Subduction (Simandjuntak, 1992). North Sulawesi subduction is to the north of the North Arm of Sulawesi. East Sangihe subduction is in the southeast of the North Arm of Sulawesi. The research area is Gorontalo Province and its surroundings located in the coordinates between -0.258225 – 2.476234 N and 121.134444 – 123.535833 E.

The geological structures of the North Arm of Sulawesi are joint, folds and faults. Normal faults and strike slip faults are the main geological structures of the Gorontalo region. Gorontalo fault in the Gorontalo is major intracontinental strike-slip faults (Molnar & Dayem, 2010).

Geological conditions that are prone to earthquakes need to be considered. The progress of science and technology in the field of seismology has not been able to improve the ability to predict earthquakes, all that can be done is mitigation, namely the effort to minimize disasters that occur. This study aims to analyze the earthquake damage level of Gorontalo area based on seismicity and peak ground acceleration which is one of the important stages in mitigation efforts. Seismicity can be used to see patterns of earthquake spread. Peak ground acceleration can be used to determine the intensity value. Both of these factors are important for determining earthquake damage level.

## 2. Methodology

### 2.1 Seismicity

The seismicity of the Gorontalo region is made in the form of a seismicity map. Seismicity maps are created using QGIS software. Seismicity maps are divided into two maps, namely seismicity map based on earthquake depth and seismicity map based on earthquake magnitude. Classification of depth and magnitude based on the classification of UPSeis (2014) and Spence, et.al., (1989). Earthquake data from 1936 - 2018 is taken from the United States Geological Survey (USGS), consisting of dates, origin time, latitude, longitude, depth, and magnitude. Based map from Bachri, et.al., (1993) and Apandi and Bachri (1997).

### 2.2 Peak Ground Acceleration (PGA)

Peak ground acceleration is obtained by processing data using the Kawashumi formula (Soetadi et.al., 1974):

$$\log \alpha = M - 5,45 - 0,00084(\Delta - 100) + \left( \log \frac{100}{\Delta} \right) \times \frac{1}{0,43429} \quad (1)$$

The Kawashumi formula provides a relationship between ground acceleration ( $\alpha$ ), magnitude (M) and epicenter distance ( $\Delta$ ). The parameters of the magnitude and distance of the epicenter are entered to obtain the value of ground acceleration. Based on the results of peak ground acceleration calculations, one peak ground acceleration value is selected. Relationship between peak ground acceleration and Mercalli Modified Intensity (MMI) based on BMKG (2018).

### 2.3 Earthquake damage level

Earthquake damage level was analyzed based on seismicity and peak ground acceleration. Earthquake damage level was analyzed using qualitative descriptive methods using the relationship between earthquake damage level with magnitude and depth (seismicity map), intensity and peak ground acceleration (UPSeis, 2014; Spence, et.al., 1989; USGS, 2018; BMKG, 2018).

## 3. Results and Discussion

### 3.1 Seismicity

The depth of the earthquake is classified by Spence, et. al., (1989) into three classes, namely shallow earthquakes (0 - 70 Km), intermediate earthquakes (70 - 300 Km) and deep earthquakes (300 - 700 Km). From seismicity maps based on earthquake depth (Fig. 2) it was found that shallow earthquakes (0 - 70 Km) were more common in the northern part of Gorontalo (Sulawesi Sea). The intermediate earthquake (70-300 Km) is dominant in the southern part of Gorontalo (Tomini Bay).

Seismicity in the Gorontalo area and its surroundings is influenced by the Sulawesi Sea subduction. The direction of Sulawesi Sea subduction is north-south. This can be seen in the seismicity map based on earthquake depth (Fig 2) and the cross section of the depth of the earthquake that shows the direction of the Sulawesi Sea subduction (Fig 3).

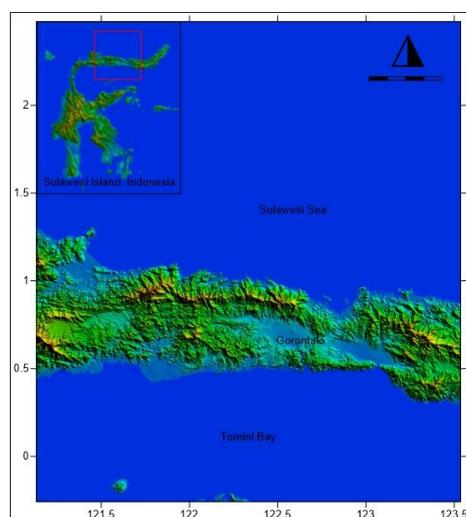


Figure 1. Map of the research location

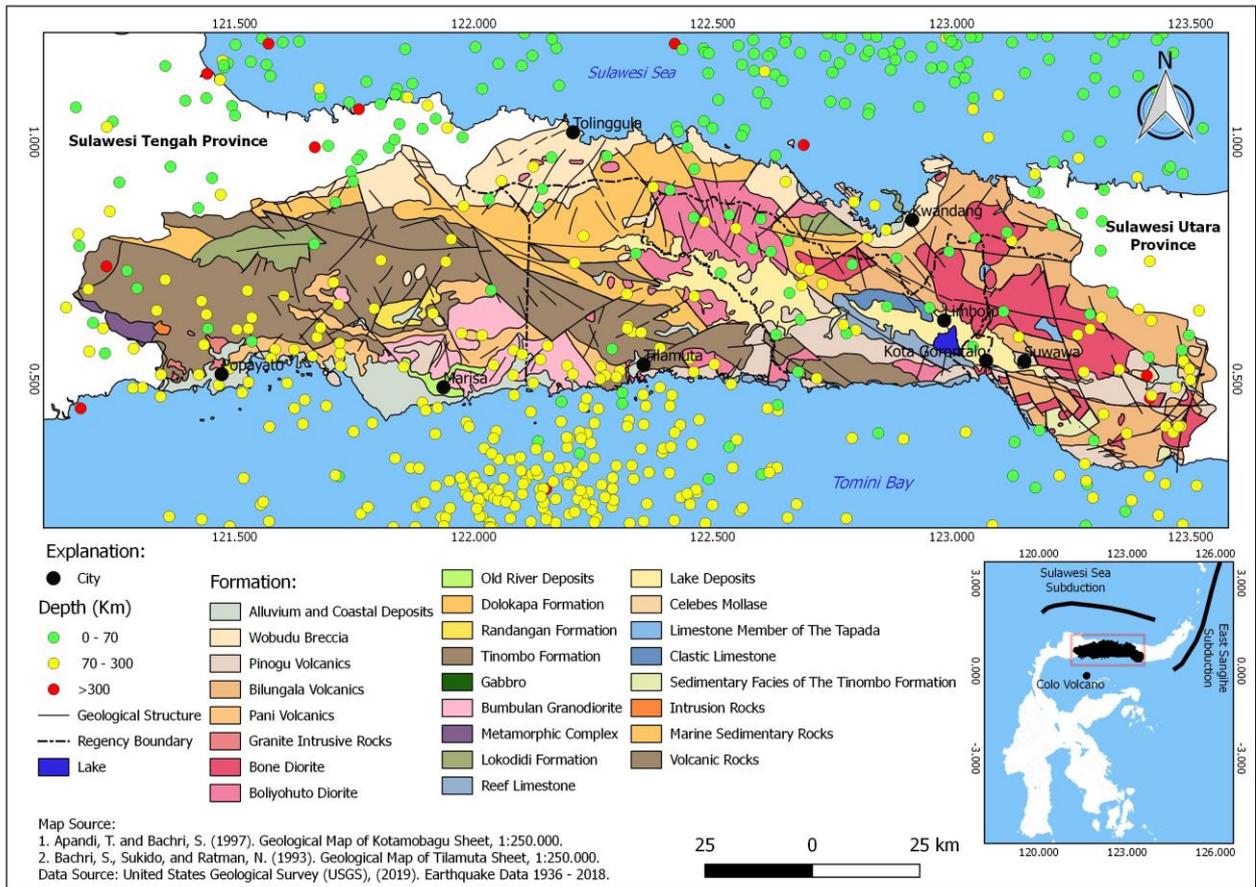


Figure 2. Seismicity map based on earthquake depth

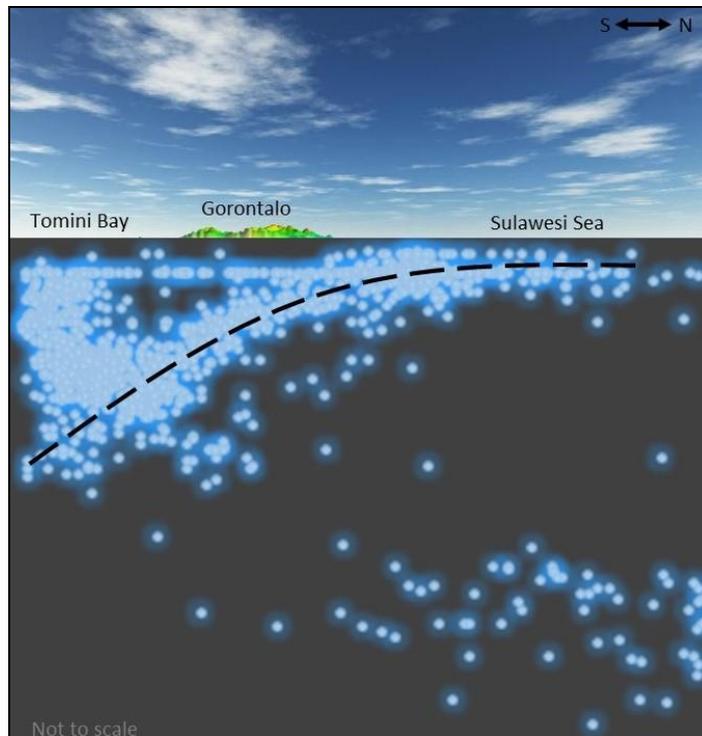
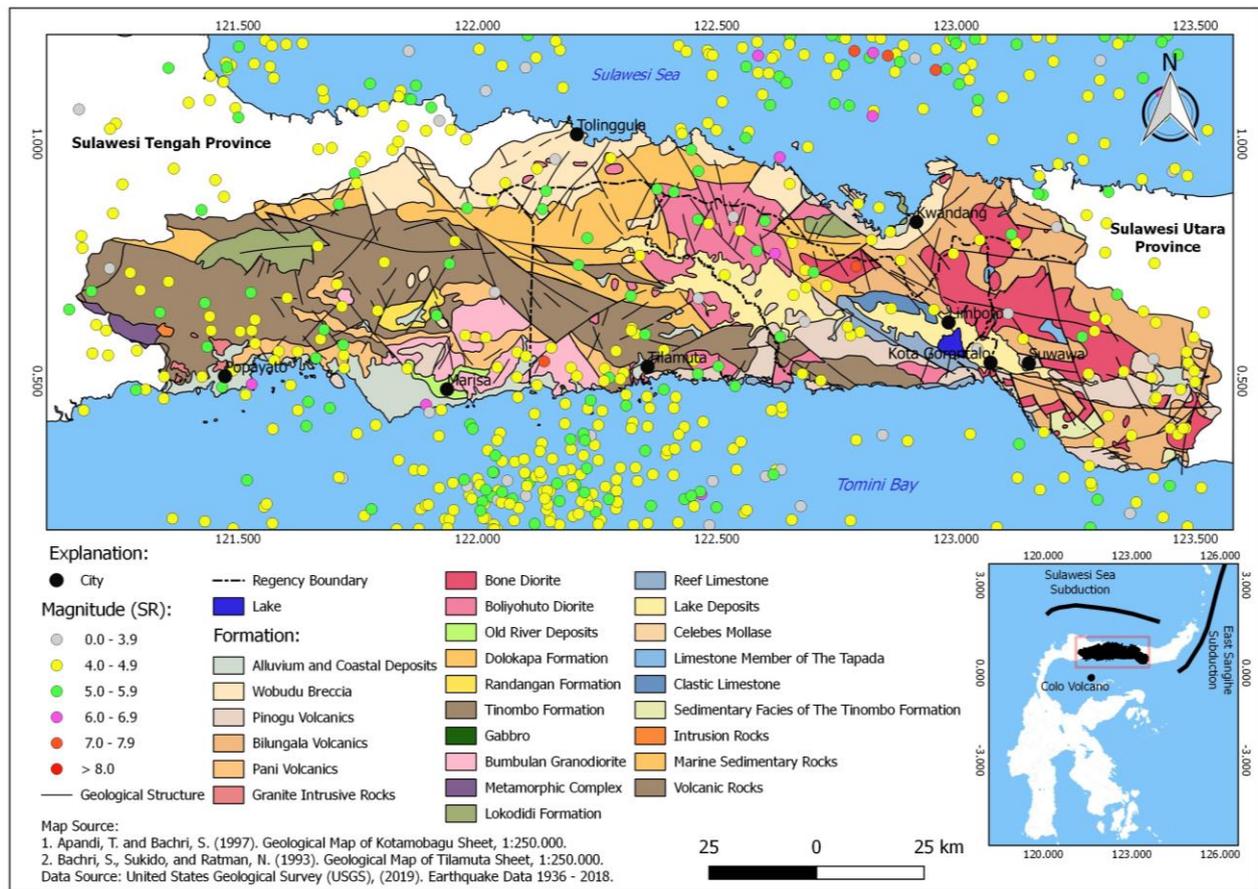


Figure 3. Earthquake depth of Gorontalo and surrounding area in cross section

The Gorontalo Province is a transition from shallow earthquakes and intermediate earthquakes. Earthquakes with depths above 300 Km (deep earthquakes) are rare in Gorontalo Province. Intermediate earthquakes are more distributed in Pohuwato Regency and Boalemo Regency. Shallow earthquakes are more distributed in North Gorontalo Regency, Gorontalo Regency, and the northern



**Figure 4.** Seismicity map based on earthquake magnitude

part of Bone Bolango Regency. Shallow earthquakes (1 - 70 Km) cause more damage than intermediate earthquakes and deep earthquakes because of their proximity to the surface of the earth.

Magnitude of earthquakes is classified by UPSeis (2014) into six classes, namely minor (3-3.9), light (4 - 4.9), moderate (5 - 5.9), strong (6 - 6.9), major (7 - 7.9), and great (8 or more). From a seismicity map based on earthquake magnitude (Fig. 4) it is found that the Gorontalo area and its surroundings are dominated by light earthquakes (4 - 4.9 SR) and moderate earthquakes (5 - 5.9 SR). Strong earthquakes (6 - 6.9 SR) and major earthquakes (7 - 7.9 SR) generally occur in the Sulawesi Sea and Tomini Bay. Some have been recorded in Gorontalo Regency, Boalemo Regency and Pohuwato Regency.

Light Earthquake often occurs, but only causes a small danger. Generally a light earthquake can occur 30,000 times in one year. Moderate earthquake is rather dangerous for buildings, generally occurs 500 times in one year. Strong earthquakes can cause many hazards in areas with high population. A strong earthquake can occur 100 times in one year. Major earthquakes can cause serious hazards, generally occurring 20 times a year (UPSeis, 2014).

Gorontalo area dominated by light earthquakes and moderate earthquakes which can cause small danger and dangerous for buildings. Some areas are like Gorontalo Regency, Boalemo Regency, Pohuwato Regency, Sulawesi Sea, Tomini Bay, have strong earthquakes and major earthquakes that can cause many hazards and serious hazards.

North Sulawesi subduction which was suspected to have been active since the Tertiary era (Apandi & Bachri, 1997) produced a number of faults in Gorontalo. North Sulawesi subduction and faults in Gorontalo, which have implications for seismicity in Gorontalo. The earthquake that occurred in Gorontalo as seen in the seismicity map generally occurs in fault zones.

The position of North Gorontalo Regency facing the Sulawesi Sea makes the North Gorontalo Regency potential for a tsunami hazard. South coast of Bone Bolango Regency, Gorontalo City, Gorontalo Regency, Boalemo Regency, and Pohuwato Regency also need to be vigilant from the tsunami because it faces Tomini Bay, where in the south there is a Colo volcano and in the southeast there is an East Sangihe Subduction.

### 3.2 Peak Ground Acceleration (PGA)

Ground acceleration values are obtained by using the Kawashumi formula, by entering earthquake parameters such as earthquake magnitude and earthquake epicenter distance. From the results of the calculation of ground acceleration, one maximum value of ground acceleration is selected. The value of ground acceleration is calculated for 8 (eight) cities in Gorontalo Province. The city that has a peak ground acceleration value is Tolinggula, with a peak ground acceleration value of 99,715 gal. The graph of peak ground acceleration can be seen in Figure 5.

Peak ground acceleration of 8 (eight) cities in Gorontalo Province shows that Tolinggula has a higher peak ground acceleration than 7 (seven) other cities in the Gorontalo Province. Peak ground acceleration towards Gorontalo City is 21,780 gal, Marisa is 21,589 gal, Limboto is 20,321 gal. Peak ground acceleration for Kwandang is 18,619 gal, Tilamuta is 13,389 gal, Popayato is 7,718 gal, and Suwawa is 1,462 gal.

The graph of the peak ground acceleration of 8 (eight) cities in Gorontalo Province shows that the earthquake that caused peak ground acceleration was an earthquake that occurred on November 25, 1997 and on July 19, 2002. Peak ground acceleration towards Gorontalo City, Limboto, Kwandang, Popayato, and Suwawa originated from the earthquake that occurred on November 25, 1997 while the peak ground acceleration towards the city of Tolinggula and Marisa originated from the earthquake that occurred on July 19, 2002.

The earthquake that occurred on November 25, 1997 was at a depth of 40 Km with a magnitude of 6.8 SR while the earthquake that occurred on July 19, 2002 was at a depth of 33 Km with a magnitude of 6.7 SR. The earthquake that produced a peak ground acceleration of 8 (eight) cities in Gorontalo Province was located in the Sulawesi Sea. The results of the analysis of peak ground acceleration indicate that the peak ground acceleration of a city is influenced by the depth and magnitude of the earthquake, the distance between the city and the epicenter, and the geological conditions.

The relationship between peak ground acceleration and intensity shows that Tolinggula with peak ground acceleration 99,714 gal is on intensity VI MMI. Gorontalo City with a peak ground acceleration of 21,780 gal is on the V intensity of MMI. Marisa with a peak ground acceleration of 21,589 gal is on the intensity of V MMI. Limboto with a peak ground acceleration of 20,321 gal is on the intensity of V MMI.

Kwandang with peak ground acceleration of 18,619 gal is on the intensity of V MMI. Tilamuta in the Boalemo Regency region with a peak ground acceleration of 13,389 gal is on the intensity of the V MMI. Popayato with a peak ground acceleration of 7.718 gal is on the intensity of the V MMI. Suwawa with a peak ground acceleration of 1,462 gal is on the intensity of the II MMI.

### 3.3 Earthquake Damage Level

Based on (UPSeis, 2014; Spence, et.al., 1989; USGS, 2018; BMKG, 2018) earthquake damage level is divided into four levels. The four levels are minus damage (I - IV MMI, minor to light earthquake magnitude, deep earthquake), slight damage (V - VI MMI, light to moderate earthquake magnitude, deep to intermediate earthquake), moderate damage (VII - VIII MMI, moderate to strong earthquake magnitude, intermediate earthquake), and heavy damage (IX - MMI XII, strong to great earthquake magnitude, shallow earthquake).

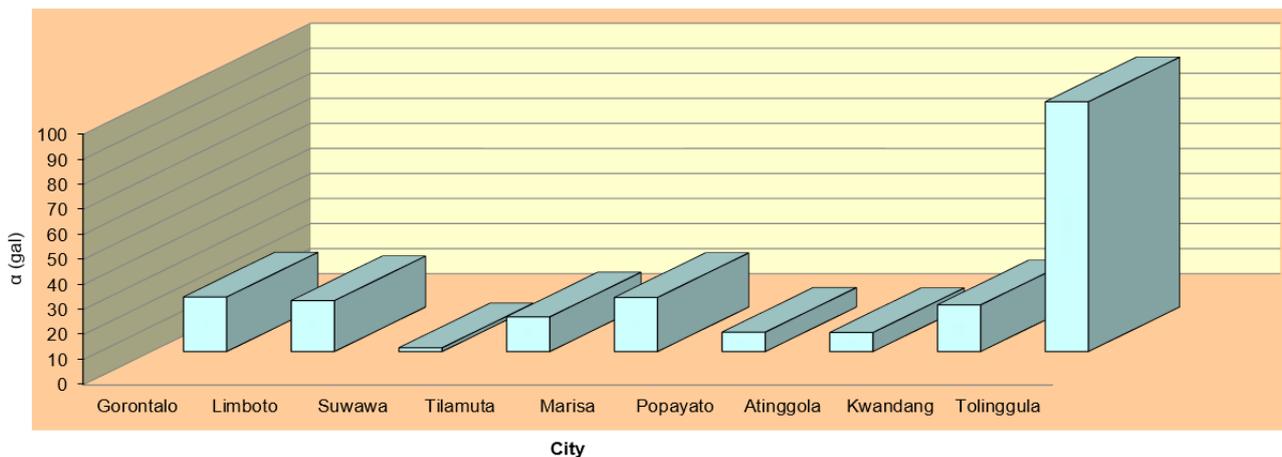


Figure 5. Peak Ground Acceleration of city in Gorontalo Province.

The earthquake magnitude that generally occurs in Gorontalo is light to moderate earthquake. The depth of earthquakes that generally occur is shallow to intermediate earthquake. Based on seismicity, damage level is in the category of slight to heavy damage and generally is at slight to moderate damage. Eight cities in Gorontalo have a scale of II, V, and VI MMI with peak ground acceleration 1,462 - 99,714 gal where the northern part of Gorontalo has a large peak ground acceleration compared to the southern part. Based on the intensity and peak ground acceleration, generally the damage level is in the slight damage.

#### 4. Conclusions

Shallow to intermediate earthquake's depth, and light to moderate earthquake magnitude are distributed throughout the Province of Gorontalo. From the peak ground acceleration and the relationship between the peak ground acceleration and the intensity obtained that eight cities in Gorontalo were in II - VI MMI scale with the value of peak ground acceleration 1,462 - 99,714 gal. This causes Gorontalo Province to be categorized in slight to moderate earthquake damage level. The earthquake in Gorontalo occurred because of Sulawesi Sea subduction and active faults in Gorontalo. In order for more earthquake damage level to be further refined, it is recommended to make earthquake depth zone maps, earthquake magnitude zone maps, peak ground acceleration zone maps and earthquake intensity zone maps.

#### 5. Acknowledgments

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