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An Estimation of Earthquake Impact to Population in Makassar by Probabilistic Approach

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Abstract. *Makassar is one of Indonesian big cities with rapid growth rate, but not totally save from earthquake hazard. This condition led study on affected population by earthquakes in this city are important to do. This paper estimated population of Makassar City treatened by the probabilistic earthquake hazard. In this current study, earthquake hazard in the forms of peak ground acceleration (PGA) and spectral acceleration, estimated by using Probabilistic Seismic Hazards Analysis (PSHA). The PSHA result then overlaid with administration map and population data to obtain distribution and percentage of population threatened by the probabilistic earthquake hazard. The results showed the smallest value of ground acceleration located in the southwest (Tamalate sub district), further north increased and reached the highest value in the northeast (Biring Kanaya sub district). Both Tamalate and Biringkanaya can be classified as rural area with low population density. The urban area of Makassar, which is the concentration of population, located in the center of Makassar, got the middle earthquake hazard.*

Keywords: *earthquake hazard, rural area, urban area, ground acceleration, PSHA.*

Abstrak. *Makassar merupakan salah satu kota di Indonesia dengan tingkat perkembangan yang pesat namun tidak terlepas sama sekali dari ancaman bahaya gempa. Keadaan ini menyebabkan penelitian tentang penduduk yang terancam bahaya gempa di kota ini penting untuk dilakukan. Makalah ini memperkirakan penduduk Kota Makassar yang terancam bahaya gempa secara probabilistik. Dalam penelitian ini, bahaya gempa dalam bentuk percepatan tanah maksimum (PGA) dan spektra percepatan ditentukan menggunakan Probabilistic Seismic Hazard Analysis (PSHA). Hasil PSHA selanjutnya di tumpangsusunkan dengan peta administrasi dan data kependudukan hingga diperoleh persebaran dan persentase jumlah penduduk yang terancam gempa. Hasil penelitian menunjukkan nilai percepatan tanah yang rendah terletak di arah barat daya (Kecamatan Tamalate), ke arah utara semakin meningkat dan mencapai nilai tertinggi di arah timur laut (Kecamatan Biringkanaya). Baik Kecamatan Tamalate dan Biringkanaya dapat diklasifikasikan sebagai daerah pedesaan dengan kepadatan penduduk rendah. Daerah perkotaan Makassar, yang merupakan pusat penduduk, terletak di tengah Makassar, mempunyai bahaya gempa menengah.*

Kata kunci: *bahaya gempa, daerah pedesaan, daerah perkotaan, percepatan tanah, PSHA.*

1. Introduction

Makassar is the capital city of South Sulawesi province and the largest city in eastern Indonesia. It is located on the southwestern coast of Sulawesi Island. Makassar is the fifth metropolitan in Indonesia, following Jakarta, Surabaya, Bandung and Medan. Makassar has a strategic position, because it is located at the crossroads of traffic from south and north in Sulawesi Island, also from western to eastern regions and from northern and southern regions of Indonesia. The total area of Makassar approximately 175.77 km^2, includes 11 islands in Makassar Strait plus sea area of approximately 100 km^2 (makassarkota.go.id).

In opposite with its strategic position, Makassar also cannot be separated from earthquake hazard. Makassar has a medium risk class on Earthquake Disaster Risk Index Regency / City, which is contained in Indeks Resiko Bencana Indonesia (IRBI) / Indonesian Disaster Risk Indexes 2013 issued by BNPB (Ruswandi et. al., 2014). Although its earthquake disaster risk class is moderate, Makassar has very decisive position in Indonesia development, especially in Eastern Indonesia. For this reason, study related to earthquake hazard and risk of Makassar need to be done. Various studies about earthquake in Indonesia has been done, but many of them only focused on the physical aspect of earthquake (Pandita *et al.*, 2016; Alif *et al.*, 2016).

Various studies linking earthquake hazard and population have been conducted. Dell' Acqua et al. (2013) conducted a study using remote sensing method to obtain spatial data of buildings and population to be used in the global exposure database for the modeling of global earthquakes. Wang et al. (2012) connected the physical condition of the environment, social conditions and human expectations to calculate the capacity of the population (population carrying capacity / PCC) in facing earthquake. Allen et al. (2009) created a shakemap atlas (in PGA form) and population exposure catalog, which the data can be used to find the degree of vulnerability of a country to earthquake hazard.

Liu and Wang (2015) studied the differences in human vulnerability to earthquake hazard between rural and urban areas. Rahman et al. (2015) combines physical and social factors in calculating the vulnerability of society to earthquakes and fires. Ara (2014) assessed the risk of earthquake hazard for the population temporally. He divided into working days, holidays, Ramadhan, and busy days, also distinguished between day and night. This study is most similar to Gupta et al. (2006), which connected the population and PGA values. This study is a first step in determining seismic vulnerability, human exposure, population carrying capacity and the determination of seismic risk.

This study aims to determine the population of Makassar City threatened by the probabilistic earthquake hazard. The earthquake hazards will be calculated at peak ground acceleration (PGA) and spectral acceleration at two specific periods T=0.2 and T=1 second. Generally, this study combines two types of data, probabilistic earthquake hazard and population of Makassar.

2. Research Method

The area of study bounded by Makassar Strait in the west, Kepulauan Pangkajene in the north, Maros in the east and Gowa in the south. It is geographically located between 119°15′41.728″ - 119°32′34.579″ East and 5°01′42.08″ - 5°14′ 0.09″ South. The area of study was shown in Figure 1.

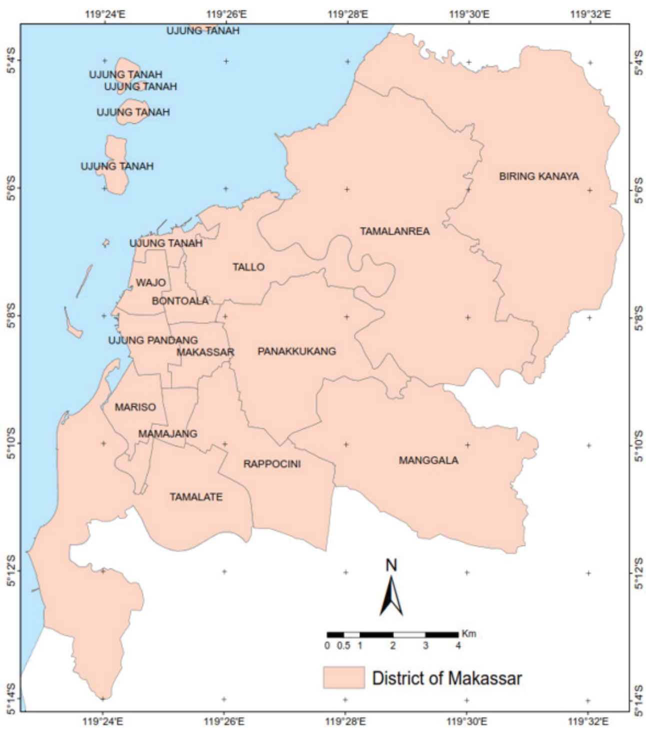

Figure 1. *The area of study*

Makassar City is part of Sulawesi Island. Based on their formation, this island can be divided into four zones, i.e. West Sulawesi, East Sulawesi, Banggai-Sula and Central Sulawesi. They were united in Miocene-Pliocene era caused by interaction between Pacific and Australian plates to Asian plate (Kaharudin et al., 2011). The interaction of the three plates could be the cause of the geological disaster in Sulawesi, such as earthquakes, tsunamis, volcanic eruptions and ground movements. There are at least 12 tectonic and structural elements that can trigger earthquake at Sulawesi, i.e Walanae fault, Makassar thrust, Lawanopo fault, Tolo thrust, Matano fault, Poso fault, Sula fault, Batui thrust, Palu Koro fault, Gorontalo fault, Sulawesi Sea subduction plate and Maluku subduction plate (Irsyam et al., 2010).

To calculate probabilistic earthquake hazard, first step is identify earthquake sources which influence in Makassar, either subduction, faults and background sources. The next step is collecting earthquake data having these criteria, magnitude Mw ≥ 5 and a maximum radius of 500 km from Makassar. It was under assumption that earthquakes with magnitude Mw < 5 and a radius of over 500 km will not give a significant impact or less likely to cause damage.

The data processing includes creating a homogeneous magnitude earthquake data, separating the mainshock from its foreshocks and aftershocks, also analyzing the completeness of earthquake data. The next stage is earthquake source modeling based on geological and tectonic conditions and characterizing earthquake source. Probabilistic earthquake hazard analysis required appropriate attenuation functions for earthquake hazards analysis and managing uncertainty elements with logic-tree. By using a logic-tree, earthquake source parameters and attenuation models can be accommodated with appropriate weights.

Earthquake hazard analysis was conducted using Probabilistic Seismic Hazards Analysis (PSHA), by using total probability concept (Cornell, 1968) as defined in equation 1.

$$P[I \geq i] = \iint_{r\,m} P[I \geq i|m \; and \; r]\, f_M(m) f_R(r)\, dm\, dr \quad (1)$$

with f_m is magnitude distribution function, f_r is distance to hypocenter distribution function, $P\ [I \geq i\,|\,m\ and\ r]$ is the conditional probability of intensity I that exceed the value of i at a reviewed location of an earthquake event with a magnitude M and distance to hypocenter R, and $P\ [I \geq i]$ is the probability of intensity I that exceed the value of i. In this study, PSHA was analysis for 2% exceeded probability in 50 years or equivalent with 2,500 years earthquake return period, adjust to modern seismic regulations as well as NEHRP 1997, ASCE 7-98, IBC 2000 and SNI 1726:2012 which refers to ASCE 7 -10 (Imran, 2010).

An overview of Makassar population in 2013 can be seen in Figure 2. We could see that the Makassar, Mariso and Mamajang sub districts got highest population density, while Biringkanaya, Tamalanrea and Manggala sub districts got the lowest density. According to these, Makassar, Mariso, and Mamajang can be classified as urban areas, while Biring Kanaya, Tamalanrea, and Manggala as rural areas. Other sub districts, can be classified sub urban areas, those are between urban and rural areas.

Earthquake hazard for Makassar was determined by combining probabilistic earthquake hazard map with administrative map of Makassar. Administrative map derived from RBI map of Makassar 1: 25,000 Scale. This probabilistic earthquake hazard map is based on peak ground acceleration (PGA) and spectral acceleration at two specific periods T=0.2 and T=1 second respectively. Each earthquake hazard map generated will split Makassar City into several areas with different acceleration values, expressed in g (gravitational force of the earth).

Estimation number of people threatened by the probabilistic earthquake hazard in Makassar is conducted by overlaying earthquake hazard map with population data. Population data used in calculation was obtained from Central Board of Statistic of Makassar, Makassar in Figures, 2013. The reason for the use of Makassar in Figures 2013 and not Makassar in Figures for 2014 was due to population data can be obtained up to the village level. Makassar in Figures 2013 contains demographic data for the city of Makassar in 2012, while the current year at this time was in 2015. The assumption used here is the population growth rate for the city of Makassar almost the same for all regions of Makassar, so even if calculations using population data in 2013, but it still can be applied for 2015.

Estimation number of people threatened by earthquakes was calculated for every village in Makassar. It is assumed that the population of each village distributed homogeneously, so to find the number of inhabitants of the village with different acceleration value used the comparison of area. For example, to search how many endangered populations of 0.1 g for village *D*, the formula used is as follows.

$$P(0.1\,g) = \frac{A(0.1\,g)}{AD} \quad (2)$$

With *P* (0.1 *g*) is the estimated number of people in Village *D* threatened by 0.1 g earthquake hazard, *A* (0.1 *g*) is the area of Village *D* threteaned by 0.1 g earthquake hazard, and *AD* is total area of Village *D*.

The last step is to state the estimated number of Makassar people threatened by earthquake hazard in a percentage. For example, to state the percentage of estimated population threatened by earthquake hazard of 0.1 g, the formula used is as follow.

$$E(0.1\,g) = \frac{\sum P(0.1\,g)}{\sum P} \times 100 \quad (3)$$

With *E* (0.1 *g*) is the estimated percentage of estimated population threatened by earthquake hazard of 0.1 g, $\sum P$ (0.1 *g*) is the total of estimated number of people threatened by earthquake hazard of 0.1 g, and $\sum P$ is the total population.

3. Results and Discussions

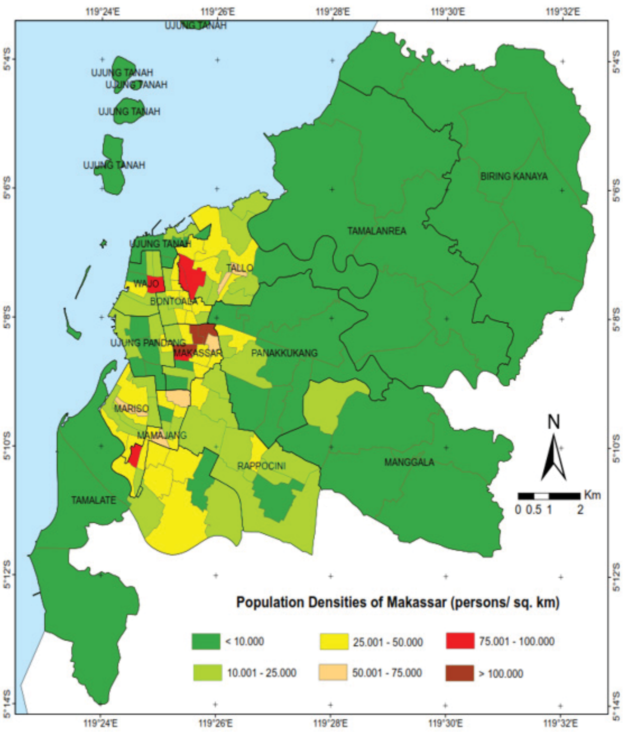

Figure 2. *Population densities of Makassar City*

Based on Makassar in Figures 2013, the population of Makassar is 1,369,606 people. The population density per village of Makassar varies widely, ranging from 752 persons/ km^2 to 258,000 persons/km^2. The highest population density is in Makassar sub district and the lowest population density is in Biringkanaya sub district (northernmost). Population density of Makassar City was shown in Figure 2.

As stated before, the probabilistic earthquake hazard of Makassar City was made at three conditions, peak ground acceleration (PGA) and spectral acceleration at two specific periods T=0.2 and T=1 second respectively. The estimated number of people affected by probabilistic earthquake hazard will be discussed at these conditions.

Spectral acceleration value at T = 0.2 seconds ranged from 0. 29 to 0.36 g. The study area was divided into three classes, i.e. area acceleration between 0.29 to 0.31 g, between 0.31 to 0.33 g, and between 0.33 to 0.36 g respectively. Spectral acceleration value at T = 0.2 seconds is the highest acceleration among all periods. Estimation of population threatened by earthquake hazard at these conditions have a similar pattern to PGA result, but differ in percentage of the area and the percentage of population, as shown in Figure 4. Around 18.37% of area with relatively low acceleration spectra between 0.29 to 0.31 g, covered Tamalate, southern parts of Mariso, Mamajang, and Rappocini respectively. The percentage of population affected by earthquake hazard at acceleration between 0.29 to 0.31 g approximately 19.73% of total population. Area with acceleration between 0.31 to 0.33 g reached 44.01%, included Ujung Tanah, Tallo, Wajo, Bontoala, Ujung Pandang, Makassar, Panakkukang, southwest of Tamalanrea, most of Manggala, Rappocini, Mamajang and Mariso. The percentage of population affected by earthquake hazard with acceleration between 0.31 to 0.33 g was approximately 61.42% of total population. Area with acceleration between 0.33 to 0.36 g reached 37.62%, covering Biring Kanaya and northern of Tamalanrea. The percentage of population affected by earthquake hazard with acceleration between 0.33 to 0.36 g approximately 18.85% of total population.

Spectral acceleration value at T = 1 second of Makassar ranged between 0.13 to 0.16 g. The study area also divided into three, i.e. area acceleration between 0.13 to 0.14 g, between 0.14 to 0.15 g, and between 0.15 to 0.16 g respectively, as shown in Figure 5. At T = 1 second period, about three-quarters of the area and three quarters of the population is threatened by earthquake hazard between 0.14 to 0.15 g, and the rest in danger of earthquake hazard between 0.13 to 0.14 g in the south, and between 0.15 to 0.16 g in the north. Around 77.25% of the population affected by the earthquake hazard with acceleration between 0.14 to 0.15 g, covered Ujung Tanah, Wajo, Bontoala, Tallo, Tamalanrea, Panakkukang, Makassar, Ujung Pandang, mostly of Biring Kanaya, western of Manggala, northern parts of Rappocini, Mamajang and Mariso respectively. While 20.25% of population affected by earthquake hazard with acceleration between 0.13 to 0.14 g covered Tamalate, southern of Rappocini and northeast of Manggala. The remaining 2.5% of the population affected by earthquake hazard acceleration spectra of 0.15 to 0.16 g covered a small area of Biring Kanaya.

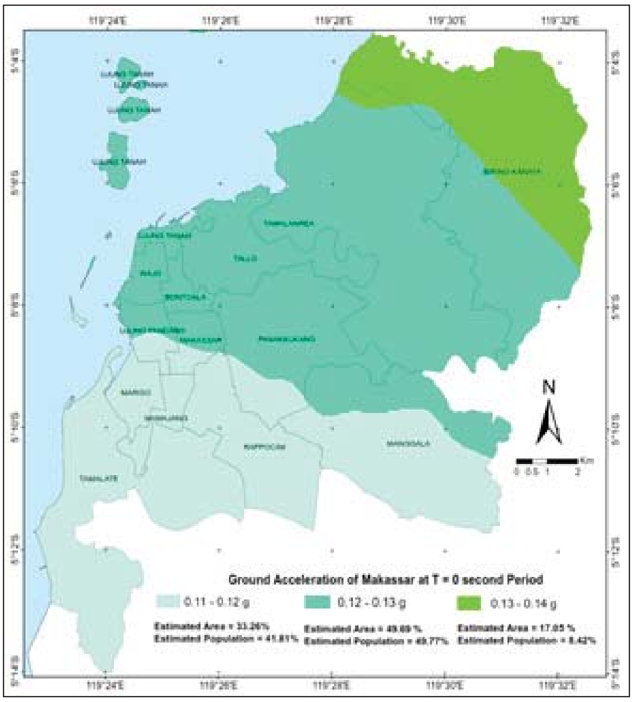

Figure 3. *Peak ground acceleration (PGA), estimated area and affected population*

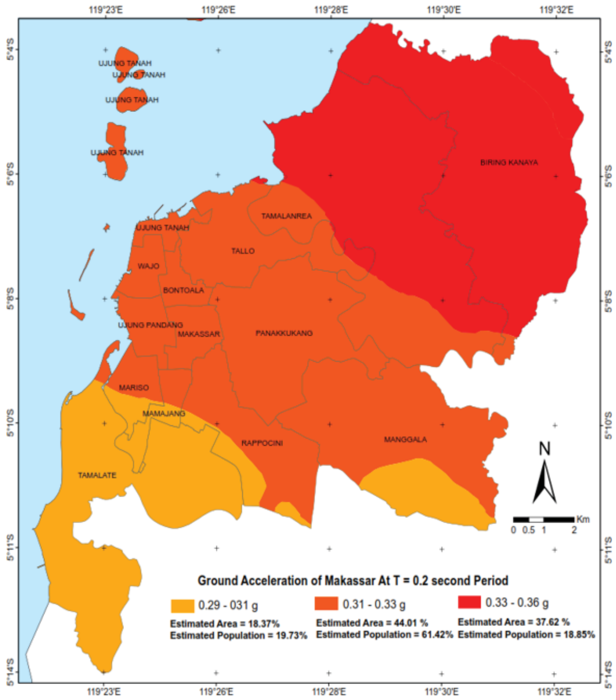

Figure 4. *Spectral acceleration at T=0.2 seconds, estimated area and affected population*

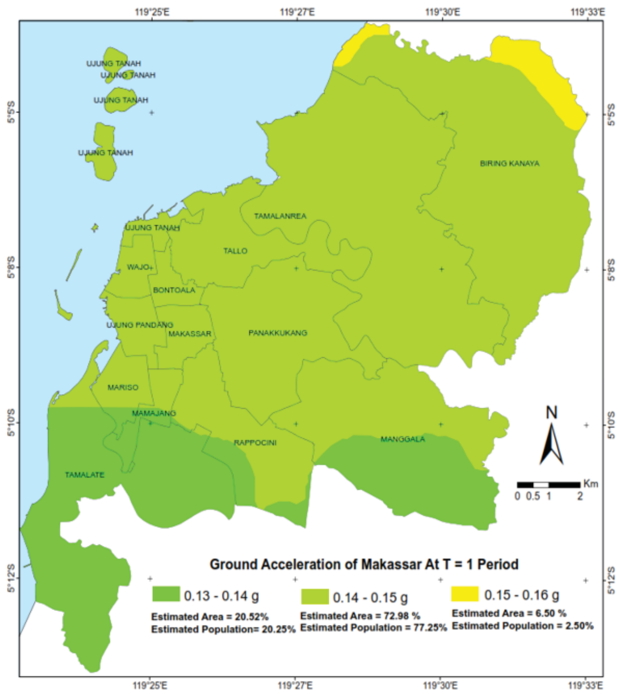

Figure 5. *Spectral acceleration at T=1 second, estimated area and affected population*

The pattern of probabilistic earthquake hazard as shown in Figure 3, Figure 4 and Figure 5 showed low ground accelerations values in the south, especially in Tamalate sub district. Further north increased and reached the highest value in the north, in Biringkanaya sub district. The existence of Walanae fault in northeast Makassar is the reason why PGA values relatively tend to rise toward northeast. Walanae fault is an active fault located approximately 89.6 km from Makassar City (Rante, 2015). The calculation result of maximum ground acceleration based on historical seismicity indicated that Walanae fault gave the highest impact to earthquake hazard compared to other seismic sources around Makassar City (Makassar thrust, Lawanopo fault, Matano fault, Poso fault, Palu-Koro fault).

Both Tamalate and Biring Kanaya sub districts are rural areas, but the Tamalate got the lowest and Biringkanaya got the highest seismic ground acceleration. The concequency is that the Biringkanaya people should build the more resistant building to earthquake, if they want to minimize the earthquake impacts. The education about earthquake hazard, its impacts, and how to minimalize the effects should be given, especially to people in Biringkanaya.

The urban areas which are located next to the central of Makassar got the medium earthquake hazard, when compared with other areas in Makassar. For a growing city like Makassar, it needs spaces for the regional development. To minimize the the cost of buildings and other facilities, the city development should expand to Tamalate. If there is another consideration about the city developmet, in another words if the city development move to Biringkanaya, more costs are needed to make a more resistant building.

4. Conclusion

Study on estimation of Makassar City population threatened by probabilistic earthquake hazard overlay method of probabilistic earthquake hazards map and population data successfully performed on peak ground acceleration (PGA), spectral acceleration at period T=0.2 seconds and T=1 second respectively. Each result gave different acceleration values, but have a similar pattern, i.e. a low acceleration values lies in the south, especially in Tamalate sub district. Further north increased and reached the highest value in the sub district Biringkanaya. Other conclusions is urban area of Makassar which is the concentration of the population, received the medium earthquake hazard, when compared with other areas in Makassar City.

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