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Research Paper

Model of Peak Ground Acceleration (PGA) Used The Probabilistic Seismic Hazard Analysis (PSHA) Method In West Sulawesi, Indonesia

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ABSTRACT: *An earthquake hazard analysis in the province of West Sulawesi because some areas are close to the source of an active earthquake fault. Seismicity in West Sulawesi is classified as active, so it is necessary to make disaster mitigation efforts aimed at building and non-building construction references, reduce victims and the impact of earthquakes. The method used in the research with a probability approach is Probabilistic Seismic Hazard Analysis (PSHA) and the maximum likelihood method. From the PSHA method, a hazard map is obtained in the form of peak ground acceleration and spectral acceleration in bedrock. The maximum likelihood method is used to obtain seismic parameters of a and b values, the a value indicates the seismicity of the research area and the b value indicates the tectonics of the study area. Earthquake data sources used are from the BMKG, IRIS, ISC, and USGS earthquake catalogs. In this study, for 2% and 10% probability of exceedance in 50 years of the building's life. The results of the seismic parameter obtained a value is 4.91 and b value is 0.557, the result of 2% and 10% probability of exceedance in 50 years to get the respective peak ground acceleration values range from 0.15 g to 0.85 g, and 0.08 g to 0.6 g, for the spectra acceleration T=0.2 seconds with 2% and 10% probability of exceedance in 50 years with values is 1.4 g to 2.5 g and 0.4 g to 2.5 g, while for the spectra acceleration T=1.0 seconds with 2% and 10% probability of exceedance in 50 years with each value is 0.2 g to 1.0 g and 0.17 g to 0.7 g with the highest value dominant in part of the northern of Majene, Mamuju and North Mamuju Regencies. Based on the results of the research, the earthquake hazard level in West Sulawesi is strongly influenced by the Palu Koro fault, which moves actively to the northwest-north through sedimentary rocks, lava flows, and as a result causes the movement of the Majene-Mamuju local fault and there is also the Pasangkayu micro-fault which is a local subduction path of east. to the southeast in Mamuju.*

KEYWORDS: *probabilistic seismic hazard analysis, peak ground acceleration, spectra acceleration*

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I. INTRODUCTION

West Sulawesi is a province located in the Sulawesi island, astronomically located at coordinates $0^\circ 45' 59'' - 3^\circ 34' 01''$ LS and $118^\circ 43' 15'' - 119^\circ 54' 3''$. The Sulawesi area is located at the subduction of three plates, namely the Eurasian, Indo-Australian and Pacific. This island is composed of accretionary complexes, island arcs, bancuh complexes, ophiolites and microcontinental fragments as a result of a series of subduction, collision, and other tectonic processes. The regional geology of Sulawesi is divided into several mandalas, one of which is the Geological Mandala of West Sulawesi, which is referred to as a volcanic arc which is divided into the southern arm of Sulawesi, the middle part, the neck of Sulawesi, and the northern arm of Sulawesi. The Geological Mandala of West Sulawesi mostly contains volcanic rocks and Miocene plutonic rocks which form a Tertiary volcanic pathway which is also known as the West Sulawesi volcanic arc [1] .

Based on the geological and geographical conditions, West Sulawesi is classified as earthquake-prone because it is in the ring of fire route . Based on earthquake records in West Sulawesi, 15th January 2021 an earthquake with a magnitude of 6.2 occurred in Mamuju and Majene Regency without the potential for a tsunami, strong shocks were felt to Majene with MMI (Modified Mercalli Intensity) range scale is IV-V, the earthquake was affected by a Majene-Mamuju thurst fault. The earthquake in Mamuju and Majene Regency caused damage to facilities, infrastructure facilities, fatalities and injuries [2] . Areas that are close to faults need to more attention to the design of the seismic design category so that necessary an earthquake hazard map which is a Peak Ground Acceleration (PGA) map. PGA calculation can be done use Deterministic Seismic Hazard Analysis (DSHA) and Probabilistic Seismic Hazard Analysis (PSHA) methods.

The DSHA method is a data processing that pays attention to assumptions about earthquake events at an estimated destructive earthquake strength, generally used in calculating earthquake acceleration for strategic vital buildings with dangerous considerations, the weakness is not considering the possibility of an earthquake and the influence of uncertainty [3]. The PSHA method is carried out by considering the uncertainty of several things, the magnitude, location, and time of the earthquake so that the results of the analysis are obtained in the form of estimates of earthquake parameters for the desired period [4]. Mitigation efforts due to earthquakes in the West Sulawesi region with PGA analysis, this study uses the PSHA method because this method considers all earthquake events along with the uncertainty factor. The PSHA method in PGA analysis is limited to 2% and 10% probability of exceedance in 50 years used RCRISIS software. Seismic parameters are needed to obtain the PGA value, , namely a-value, b-value and Mc (Magnitude of Completeness) using Maximum Likelihood Solution which is run on Zmap software. This study processes secondary data based on the sources earthquake catalogs of the BMKG, IRIS, ISC, and USGS with a minimum magnitude 3.5 Mw with a depth of > 300 Km.

II. THEORY

A Fault is the occurrence of cracks at the boundary between two rock blocks when rock blocks shift. The shift or movement occurs due to rocks that receive and store pressure by the activity of the lithospheric plate. the rock reaches the limit of rock flexibility and is able to shift rock along the fault line. The shift along the fault line occurs suddenly, resulting in waves in all directions reaching the earth's surface, which can be felt by humans or recorded on seismographs called earthquakes [5] . Types of faults that can be grouped based on the direction of movement of the fault plane, namely shifting in the direction of dip-slip faults and shifting in the direction of strike-slip faults . Dip-slip faults are divided into normal faults (downward fault) if the rock block above the fault plane moves downwards, and uplift fault if the rock block above the fault plane moves up [6].

Magnitude is an estimate of the relative or energy strength of an earthquake. Seismic waves that propagate as body waves and surface waves, then the magnitude scale used is the . scaleM_b and M_s. Every earthquake has a different magnitude. For example, large-magnitude earthquakes in broad fault planes result in the release of energy in long-period waves, so it is not possible to accurately use the scale M_b. Moment scale (M_0) is used to obtain the strength of magnitude accurately. The measure M_0 of the displacement in the fault plane path, withM_0 is the shear strength of the rock multiplied by the slip strength of the fault . Moment scale (M_0) is used to obtain an accurate magnitude strength [7] . Scale (M_0) is a measure of the amount of energy released in the fault plane area, the moment scale has been updated to the moment magnitude scale (Mw) [8] . The analysis for a - value and b - value parameters used to describe seismicity conditions, for uniformity of one type of the same magnitude unit which is a scale Mw or moment magnitude using references of several magnitudes for the Indonesian region is shown in Table 1 [9].

Table 1 Correlation of magnitudes for the territory of Indonesia

Correlation Conversion	***Magnitude Range***
Mw = 1.0107Mb + 0.0801	3.7 mb 8.2
Mw = 0.6016Ms + 2.476	2.8 Ms 6.1
Mw = 0.9239Ms + 0.5671	6.2≤ Ms 8.7

Tectonic faults can cause earthquakes of various sizes (magnitude). Gutenberg and Richter first studied the observation of earthquake magnitudes, and noted that the distribution of earthquake sizes in an area generally follows a certain distribution according to Equation (1) [10]:

$$Log\ N = a - bM \qquad (1)$$

Where N is the number of earthquakes with a magnitude of M > m per unit time, which decreases exponentially as the magnitude of the earthquake increases and a and b are constants. The above equation is called the Gutenberg-Richter loop law. The constants a and b are estimated using the maximum likelihood solution , the value of a indicates the overall earthquake level being observed, and the value of b indicates the relative ratio of small and large magnitudes. The results of data processing to obtain the values of a and b also obtained the magnitude of completeness (Mc) which is the lowest magnitude of the main earthquake data from all events. The input earthquake data is fully detected which is estimated using the Maximum Curvature in the Zmap software [11] . PGA is the highest ground acceleration value that has occurred in a research location. PGA calculation on a location event that allows it to occur at earthquake sources that have different magnitude variations by using the attenuation function and taking into account uncertainty. Determination of earthquake uncertainty as well as the possibility of PGA at a certain location to obtain the probability of exceeding the acceleration which is at a certain return period [9] . In this study, to estimate the maximum cooking acceleration with probability, it is solved based on one of the available attenuation functions, namely because Indonesia does not yet have an attenuation function.

The PSHA method is one of the methods used in analyzing the probability of earthquake risk which is influenced by the uncertainty of the magnitude, location, and time of the earthquake, so it is taken into account in this method. The result of the analysis using this method is the probability for a certain desired return period. The PSHA method does not only take into account certain cases of earthquakes that are only destructive, but also various levels and possibilities and all possible sources of earthquakes that may occur in the research location. The concept of probability considers the size, location and return period of an earthquake to evaluate the seismic hazard level. In the PSHA method, these uncertainties are identified, quantified and combined to obtain a more complete picture or map of the level of seismic hazard risk. The basic things that need to be done in the PSHA Method based on Figure 1 are (1) Identifying all earthquake sources that have the potential to make ground motion possible, (2) Characterizing the distribution of the magnitude of the earthquake, (3) Characterizing the distribution of distance from the source to the site that has the potential for an earthquake, (4) Predicting the distribution of the resulting intensity to be used as an earthquake function. Earth's magnitude, depth and distance, and (5) Combining the uncertainty of the earthquake size, location, and ground motion strength under study using the concept of probability. Calculating the total probability in general can be expressed in Equation 2 [4] :

$$P[I \geq \text{ i}] = \iint_{r\ m} P[\, I \geq \text{i}|\, m \text{ dan } r]\ f_M(m).\, f_R(r)\, dm\, dr \qquad (2)$$

Where f_(M)is the density density function for, f_Ris the density function of the hypocenter distance, while P[I≥ i]|m dan r] is the conditional random probability at the intensity (I) with exceeding the smallest intensity limit (i) at a certain location of the influence of the magnitude (M) and is the hypocenter distance (R).

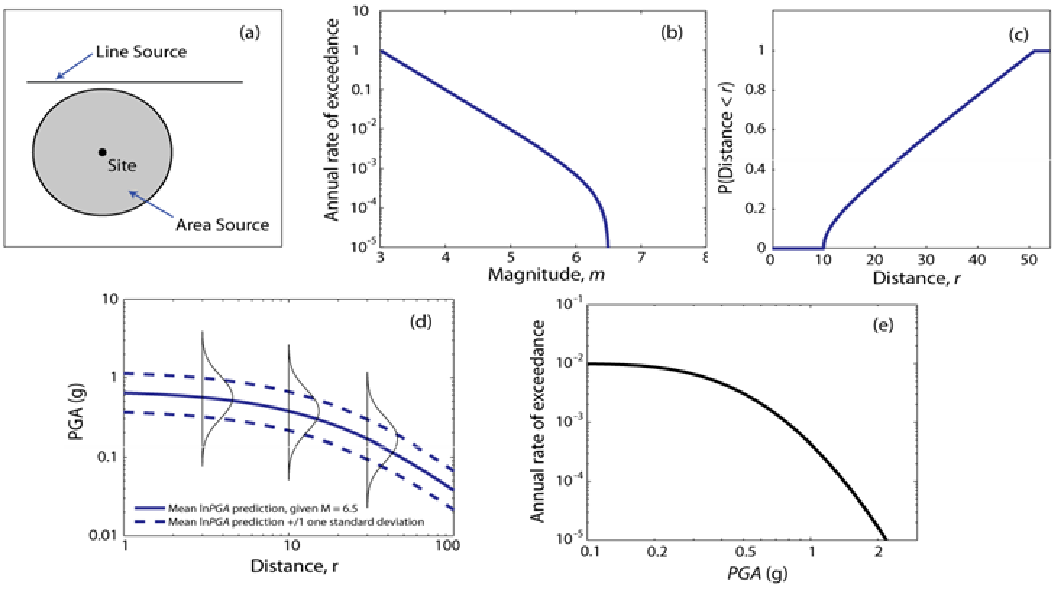


Figure1 Schematic illustration of seismic hazard probability analysis (PSHA). (a) identification of earthquake sources (b) characterization of earthquake magnitude distribution (c) characterization of distance distribution from source to site (d) prediction of ground motion intensity distribution (e) combined information from ad section (Baker, 2008)

III. METHODS

The data used in this study were sourced from the BMKG, IRIS, ISC, and USGS earthquake catalogs according to the location of the research coordinates, magnitude and depth. The data that has been collected from the earthquake catalog needs to be homogenized into one type of scale, namely Mw before moving on to the next data processing stage. Uniformity of magnitude based on the provisions of Table 1 , after the uniformity of magnitude, earthquake data with a magnitude of > 3.5 Mw was taken. Furthermore, making the earthquake data format according to the provisions of the Zmap software , changing the data file format into txt using the Notepad++ software. Earthquake data that has been created in txt format is input into the Zmap software , then decluster is carried out to separate the main earthquake data from aftershocks using Gardner and Knopoff. The main earthquake data that has been obtained then performs the processing of seismic parameters, namely a and b values and Mc . With the acquisition of these seismic parameters, it can be continued for the calculation of PGA values and hazard maps.

The calculation of the PGA value using the PSHA method in this study for 2% and 10% in 50 years based on the RCRISIS software. The input data in the RCRISIS software are seismic parameters resulting from the Zmap software, the shapefile of the research location to obtain a hazard map , Geometry sources using the main earthquake data, the selection of the attenuation function according to geological conditions, this study using Sadiegh et al (1999) which is already available in the RCRISI software and spectral ordinates , this study used a period of T=0 seconds for PGA and T=0.2 seconds and T=1.0 seconds for Spectral Acceleration (SA). The data input process is carried out carefully, especially for geometric sources and very important seismic parameters. The input data that has been completed is validated and run and the data is error or correct, if it is true, then save the file and run after it is finished, a map of the distribution of PGA and SA values is seen in the form of a hazard map for the period T=0 seconds or PGA and T=0, 2 seconds and T=1.0 seconds or Spectral Acceleration (SA). The completeness of the West Sulawesi Hazard Map was carried out with the help of QGIS software.

IV. RESULTS AND DISCUSSION

The seismic parameters shown in Figure 2 are plots of the moment magnitude Mw (X axis) for the total cumulative earthquake occurrence N (Y axis) and the logarithm of the total earthquake event log N (straight line). The figure shows the estimated b - value of 0.557 (with measurement uncertainty + 0.01), the estimated a - value of 4.91 and the Magnitude of Completeness (Mc) of 3.6.

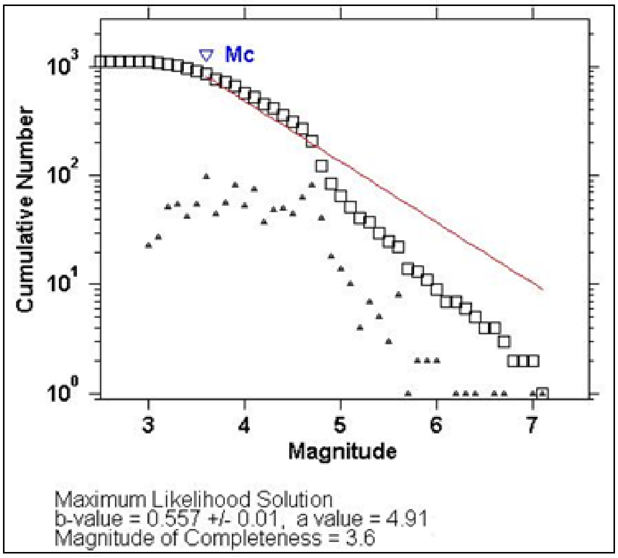


Figure2: Plot of Mw against the frequency distribution of magnitude (FMD), Mc,and the seismic parameters a and b values are determined based on *maximum likelihood solution*

The results of the earthquake hazard analysis with a probability of 2% in 50 years, Figure 3 the Peak Ground Acceleration (PGA) value in the bedrock T = 0 seconds, the results show that the Province of West Sulawesi from the influence of all earthquake sources has a PGA value ranging from 0.15 g - 0.85 g . Seismic hazard analysis results show that the highest PGA values in red are in the northern part of Majene Regency ranging from 0.7 g - 0.85 g, followed by PGA values in Mamuju City, North Mamuju Regency and Polewali

Mandar Regency ranging from 0.3 g - 0, 7 g, while for the lowest value in Central Mamuju Regency, Mamuju Regency and parts of Mamasa Regency it ranges from 0.15 g – 0.3 g. In Figure 4 shows the hazard map Spectral Acceleration (SA) the highest values in the north of Majene Regency, Mamuju City, and North Mamuju Regency ranged from 1.4 g - 2.5 g and the lowest values indicated in blue and green were in Central Mamuju Regency, Mamuju Regency, Mamasa Regency and Polewali Mandar Regency with SA values ranged from 0.4 g – 1.4 g.

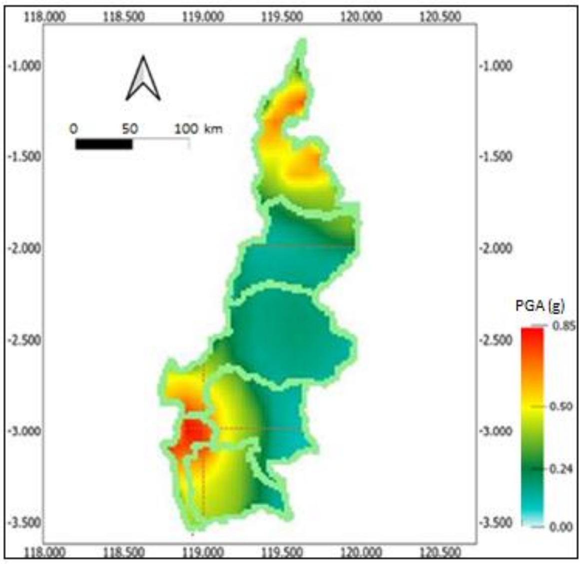


Figure 3 PGA hazard map T=0 second condition 2% in 50 years

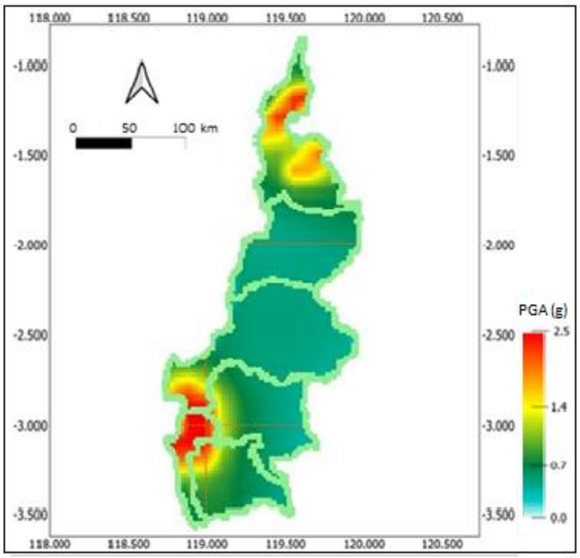


Figure 4 SA hazard map T=0.2 second condition 2% in 50 years

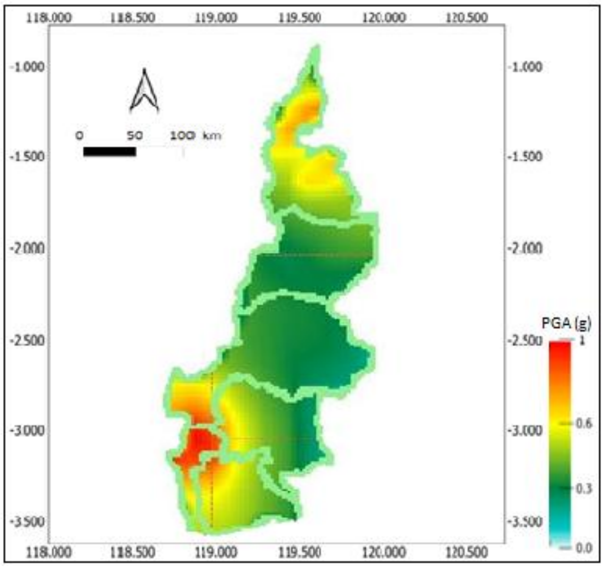
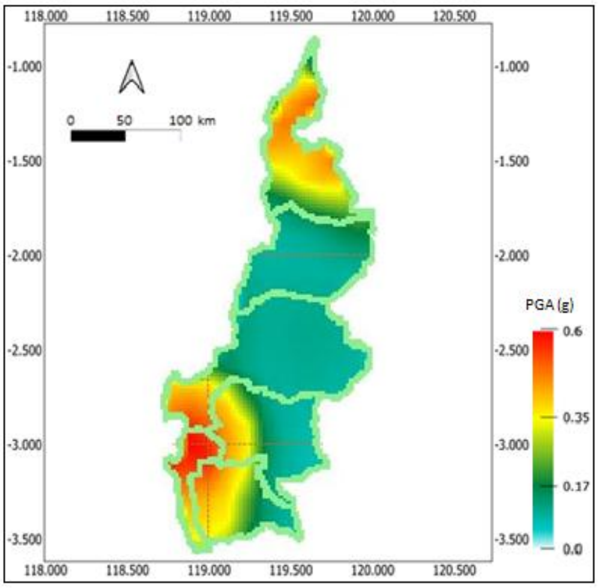


Figure 5 SA hazard map T=1.0 second condition 2% in 50 years

Figure 5 shows the SA hazard map T = 1.0 seconds, it can be seen that the SA value is in the range of 0.2g –1.0g. The highest SA value is in the northern part of Majene Regency with a red gradation which means the area has the highest SA value ranging from 0.8 g - 1.0 g, then with a yellow gradation in Mamuju City and North Mamuju Regency the SA value ranges between 0.6 g – 0.8 g, while the lowest values were in Central Mamuju District, Mamuju District, Mamasa District and parts of Polewali Mandar District with SA values ranging from 0.2 g – 0.6 g. Based on an earthquake hazard analysis with a probability of 10% in 50 years, Figure 6 shows the PGA values ranging from 0.08 g – 0.6 g, the highest PGA values are mostly located in Majene Regency, Mamuju City, North Mamuju Regency and parts of Polewali Mandar Regency. ranged from 0.35 g – 0.6 g, then the lowest values were in Central Mamuju District, Mamuju and Mamasa Districts ranging from 0.08 g – 0.35 g. Figure 7 shows the SA values (T=0.2 seconds) ranging from 0.4 g – 2.5 g, the highest SA values ranged from 1.2 g – 2.5 g in the northern part of Majene Regency, the lowest SA values ranged from 0, 4 g – 1.2 g in Mamuju, Mamasa, Polewali Mandar, Central Mamuju and North Mamuju Districts.



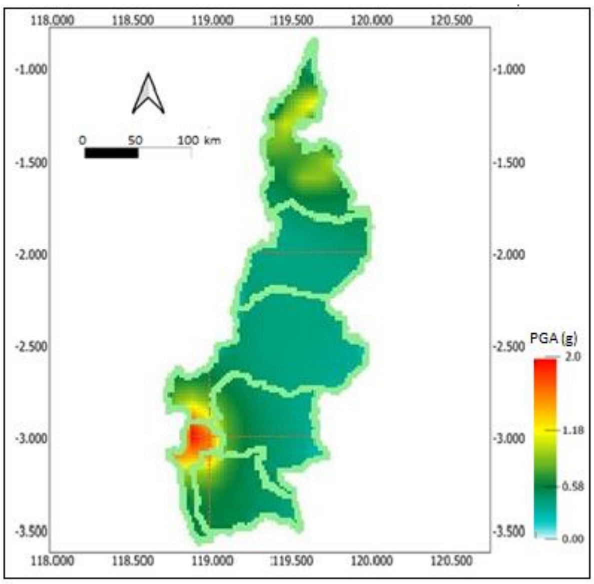


Figure 6 PGA hazard map T=0 seconds condition 10% in 50 years

Figure 7 SA hazard map T=0.2 seconds condition 10% in 50 years

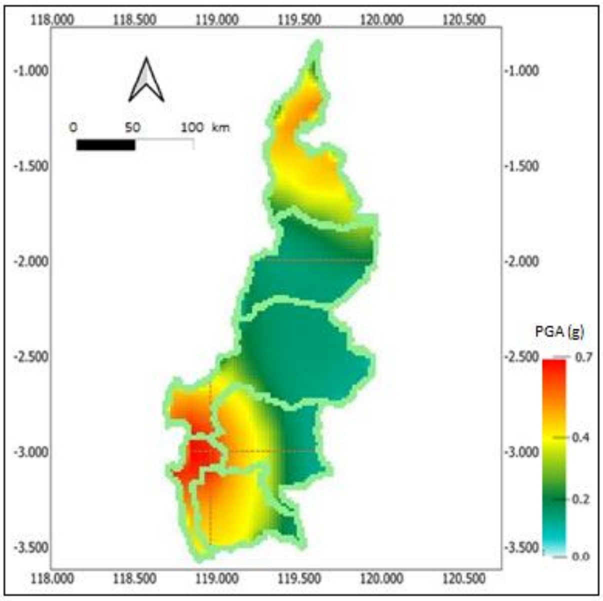


Figure 8 SA hazard map T=1.0 second condition 10% in 50 years

Figure 8 shows the SA value (T=0.0 seconds) in the range of 0.17 g – 0.7 g, the highest SA value is in the northern part of Majene Regency with red gradations with SA values ranging from 0.5 g – 0.7 g. , then in North Mamuju Regency, Mamuju City, Polewali Mandar Regency and parts of Mamasa Regency are yellow with SA values ranging from 0.3 g - 0.5 g while for the lowest SA values in and parts of Mamasa Regency, Mamuju Regency and Central Mamuju Regency it ranges 0.17 g – 0.3 g.

Earthquake hazard map is carried out by processing data for West Sulawesi seismic parameters, namely parameters a- value, b -value and Mc, to obtain these values, data processing is carried out in separating the main earthquake data from aftershocks data based on recorded data that is affected by time and distance. (declustering) based on Gardner and Knopoof. The estimated b - value is around 0.557, a - value is around 4.91 and M_cabout 3.6, West Sulawesi has a relatively low seismicity level, while the parameter value b describes a high local stress condition and has the potential to cause a large, destructive earthquake.

Earthquake hazard map performed using the PSHA method at a probability of 2% in 50 years or equal to a return period of 2475 years, meaning that there is a 2% chance that the acceleration of an earthquake will be higher than what is stated on the map in 50 years of the building's life. The PGA value on the probability ranges from 0.15 g - 0.85 g, the highest PGA value is in the northern part of Majene Regency. and the Palu Koro fault which is actively moving in a northwest-north direction through sedimentary rocks, lava flows, and tuff that causes movement in the local Majene-Mamuju fault. SA values (T=0.2 seconds) ranged from 1.4 g – 2.5 g with the highest values in the north of Majene Regency, Mamuju City, and North Mamuju Regency and SA (T=1.0 seconds) in the 0.2 range. g – 1.0 g with the highest value in the northern part of Majene Regency. The SA value is also suspected to be the influence of the local majene fault and is also thought to be due to the Walane fault which stretches from Mamuju relative to the southeast. If the source of the earthquake is farther away, the period will be longer which can affect buildings with a long period as well, which are taller buildings. The long period or T=1.0 seconds has an effect on taller buildings compared to the short period or T=0.2 seconds and PGA or T=0 seconds.

An earthquake hazard map with a probability of 10% in 50 years or equal to a return period of 475 years means that there is a 10% chance that the acceleration of an earthquake will be higher than that shown on the map in 50 years of the life of the building. The PGA value in the probability ranges from 0.08 g – 0.6 g, the highest PGA value is mostly located in Majene Regency, Mamuju City, North Mamuju Regency and part of Polewali Mandar Regency. SA values (T=0.2 seconds) ranged from 0.4 g – 2.5 g, with the highest value in the northern part of Majene Regency. SA value (T=1.0 sec) is in the range of 0.17 g – 0.7 g, the highest value is in the northern part of Majene Regency. Based on the map the tectonic setting is caused by seismic hazard, presumably dominated by the presence of the Majene fault line and the Palu Koro fault moving actively to the northwest-north through sedimentary rocks, lava flows that cause movement in the local Majene-Mamuju fault and then the presence of micro-faults in Pasangkayu. is a local subduction line in Mamuju that moves east to southeast.

Calculation of the value of PGA and SA conditions of 2% and 10% in 50 years of age of the building based on SNI. The probability condition is 10% in 50 years based on SNI 1726:2012 which only takes into account the PGA value while for SA it is considered the same for all regions. The probability condition is 2% in 50 years based on SNI 1726:2019 by taking into account the PGA and SA values, that each area has a different SA value because the subsurface layers of each area are not the same, so it is necessary to calculate the SA value at the research site. The areas mentioned with the highest or dominant values have the potential for earthquake hazards to pay more attention to earthquake-resistant development based on standards so as to reduce casualties due to building collapses, large losses and damage to buildings and infrastructure.

V. CONCLUSION

The results of the research that have been carried out have obtained the Peak Ground Acceleration (PGA) and Spectral Values Acceleration (SA) in bedrock for a probability of exceeding 2% in 50 years or equivalent to an earthquake return period of 2475 years for the Province of West Sulawesi, obtained a range of values for PGA (T=0 seconds) 0.15 g - 0.85 g, for SA (T=0.2 sec) ranged from 1.4 g – 2.5 g, and for SA (T=1.0 sec) it ranged from 0.2 g – 1.0 g. PGA and SA values in bedrock for a probability of exceeding 10% in 50 years or equivalent to an earthquake return period of 475 years for the Province of West Sulawesi, the values range for PGA (T=0 seconds) 0.08 g – 0.6 g, for SA (T=0.2 sec) ranged from 0.4 g – 2.5 g, and for SA (T=1.0 sec) ranged from 0.17 g – 0.7 g. Hazard Map of West Sulawesi as an effort to reduce the risk of earthquakes, the dominant area with the potential for a large and destructive earthquake is in the northern part of Majene, Mamuju, and North Mamuju Regencies. The dominant area with the potential for earthquakes pays more attention to the development of earthquake resistance based on standards so that it can provide much better security against the risk of earthquakes..

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