Earthquake Macro-zonation Based Peak Ground Acceleration, Modified Mercalli Intensity, And Type of Rocks around Matano Fault

Muh Karnaen, D A Suriamihardja, A Maulana, A Jaya
Hasanuddin University, Makassar, Indonesia

Email: muh.karnaen@gmail.com

Abstract. This study aims to determine earthquake vulnerable zones. We conducted research on earthquake macro-zonation based on PGA, Modified Mercalli Intensity (MMI), and type of rocks around Matano Fault in the area of 1.60 S to 2.990 S and 120.50 E to 122.470 E. We have acquired Maximum PGA and Modified Mercalli Intensity (MMI) for each observation point on the ground from the four major earthquake events. The empirical model is used due to lack of acceleration data recorded. We tried some empirical methods, but the McGuire method is found to be acceptable for this area. The result gives the maximum variation of PGA which is ranged between 18.40 - 363.54 gals. While the variation of MMI using empirical Wald attenuation gives values ranging from 2.9 - 7.7 MMI. The most vulnerable zone is located around Sorowako city with PGA value of 326.55 gals and MMI value of 7.5 MMI. This area is between ultra-basic rock and metamorphic rock formation. The vulnerable zone is near largest earthquake 6.2 M on 15-02-2011.

1. Introduction
Macro-zonation and micro-zonation are efforts to evaluate and to map disaster prone area in the region. The zonation figures out how strong the effect of earth movement caused by earthquake [1]. Macro-zonation gives basic data and regulatory information on earthquake vulnerability in the level of region under consideration. Macro-zonation must be prepared in advance prior to evolve micro-zonation [2]. Calculations on earthquake shocks can be conducted using intensity, PGA, PGV, and spectral analysis. To measure the strength of shock, the PGA approach is more reliable than the scale of seismic intensity [3]. In this connection, intensity values are obtainable theoretically derived from PGA through empirical calculations [4].

High PGA values correspond to most vulnerable areas of earthquake hazard. The value of PGA is influenced by attenuation factors related to distance of hypocentre to observation area as well as local geological factors and site local effect [5]. Variations of attenuation and acceleration factors depend on the strength, location, and movement of the faults [6]. Shake-map is a zone of vulnerable zonation generated by the model to illustrate the level of shock hazard and be a means to give estimates and respond to potential hazards [7].

Intensity is a qualitative scale of observation of people and buildings due to earthquake shocks this is related to vulnerability in the zone [8]. One of the most important factors is the sediment in the area [9]. The PGA of rock is the most vulnerable to earthquake hazard, and it is related to rock formation
This study used PGA, intensity, and geological factors for macro-zonation earthquake investigation.

This macro-zonation study of the vulnerability of natural disasters caused by this earthquake will be applied to the Matano Fault that extends horizontally in the central part of Sulawesi Island. The PGA calculation model is a simple way of determining the vulnerable zone around the fault because it only uses the earthquake analysis parameter input. The empirical PGA formulas produced by [11, 12, 13] can be applied to this study because they have the same characteristics in the research zone. The PGA model to be generated in this study will be converted to the intensity to be combined with local geological data.

2. Theory

The lack of data from the acceleration instrument around the Matano Fault makes the empirical method a feasible study in obtaining PGA values. Some experts have provided some empirical formulas that fit the criteria in their research zone. The models listed below are some of the empirical equations that will apply to this research.

1. McGuire (1977)
\[ E_v = \alpha 10^{bM(R + 25)^{-c}} \]
where \( E_v \) = eventuality of acceleration (gal), \( \alpha \) (\( \alpha \)) is a constant of 472, \( b \) is 0.278, and \( c \) is 1.301. While \( M \) = Magnitude, and \( R \) = distance of hypocentre. The depth of the earthquake being input from 9 to 70 km. This empiric is more efficient for an earthquake with strength of 6.5 and hypocentre not more than 50 km.

2. Humbert and Viallet (2008)
\[ \log(A) = aM + bR - \log(R) + c \]
The \( A \) is a PGA calculated value (cm/s\(^2\)), the alpha (\( \alpha \)) is a constant of 0.31, \( b \) is -0.00091, and \( c \) is 1.57. While \( M \) = Magnitude, and \( R \) = distance of hypocentre. Focal depths of earthquakes are between 0 and 30 km. This empiric is more efficient for earthquakes with magnitudes between 4.0 – 7.8 \( M_S \) and distances of hypocentre less than 140 km.

3. Akkar and Bommer (2010)
\[ \log \gamma = b_1 + b_2 M + b_3 M^2 + (b_4 + b_5 M) \log \sqrt{R_{fb}^2 + b_6^2 + b_7 S_S + b_8 S_A + b_9 F_N + b_{10} F_R} \]
This empirical has result \( \gamma \) that shows PGA in cm/s\(^2\), the constant \( b_1 = 1.04159 \), \( b_2 = 0.91333 \), \( b_3 = 0.08140 \), \( b_4 = 2.92728 \), \( b_5 = 0.28120 \), \( b_6 = 7.86638 \), \( b_7 = 0.08753 \), \( b_8 = 0.01527 \), \( b_9 = 0.04189 \), \( b_{10} = 0.08015 \), \( \sigma_1 = 0.2610 \) (intra-plate event) and \( \sigma_2 = 0.0994 \) (inter-plate event). Most records from earthquakes with magnitudes between 4.0 – 7.6 \( M_S \) and the distance of hypocentre less than 200 km.

4. Wald (1999)
\[ I_{MM} = 3.66 \log \alpha - 1.66 \]
where \( I_{MM} \) is intensity of earthquake in Modified Mercalli Intensity (MMI). The range intensity is between 1 to 10 MMI. \( \log \alpha \) is PGA logarithmic at the study area.

The geological structure will affect the value of the variables of seismic activity, the acceleration of the ground, the intensity of seismicity, and attenuation. These variables can be used as a method to describe the risk parameter of earthquake disaster vulnerability in a region. PGA is the suitable choice among the method for this research, besides that is the simple, quick access data from regional earthquake centre in BMKG agency. Perhaps this method is more accurate if complementary other methods.
3. Data and Processing
An empirical approach is needed due to the lack of accelerated ground data from accelerograph instruments for strong earthquakes. Using the empirical model obtained the calculation of the intensity and maximum ground acceleration for each point of coordinate observation. From the data of intensity and maximum ground acceleration for each coordinate point, we get the contour of intensity and maximum land acceleration.

The data of earthquakes used in this research is the earthquake BBMKG database Region IV Makassar in the period of year 2009-2017. These earthquake parameters are the position of the epicenter (latitude and longitude), depth, magnitude, and earthquake occurrence time. During 8 years of observations, we obtained data of 547 earthquakes which is depicted in figure1.

![Figure 1. The Seismicity of Matano Fault.](image)

Data processing includes:
1. We selected four significant earthquakes events as PGA variable input (table 1).

| No. | Date       | Time       | Location      | Depth (km) | Magnitude ($M_b$) |
|-----|------------|------------|---------------|------------|-------------------|
| 1.  | 15/02/2011 | 13:33:55 GMT | 2.47 S - 121.55 E | 34         | 6.2               |
| 2.  | 03/12/2014 | 00:27:05 GMT | 2.87 S - 122.39 E | 10         | 5.9               |
| 3.  | 16/04/2012 | 02:17:50 GMT | 2.63 S - 121.85 E | 10         | 5.8               |
| 4.  | 24/05/2017 | 09:10:16 GMT | 2.78 S - 122.17 E | 10         | 5.7               |

2. Determining the observation point with grid interval 0.10 x 0.10 (longitude-latitude) at the research location.
3. Calculating the PGA value of by the equation (1), (2), and (3) at the observation point.
4. Mapping the results of the maximum PGA calculation at the latitude - longitude of the observation point then determining the contour and interpolation
5. Plot the intensity (MMI) value on each grid with the Wald attenuation equation.

4. Result and Discussion
4.1 Result
From the empirical calculation data the PGA of 4 earthquake events produce 68 grids of point observations, where in each grid there is the maximum value of PGA in Matano Fault as depict figure 2 below.
Figure 2. The number of observation point (I), the result of PGA at each point from McGuire empiric method (II), the result of PGA from Humbert and Viallet empiric method (III), and the result of PGA from Akkar and Bommer empiric method (IV).

From the results it is shown that the McGuire equation is more acceptable than other empiric equation, because the value of PGA is appropriate with the PGA region of Indonesia [14] and the deviation not too big. The PGA result of Humbert and Viallet empiric method has big deviation (between 13.4 and 15025.3) and the PGA result of Akkar and Bommer empiric method has very small value. The result from McGuire equation gives lowest PGA at the observation point of 1 (18.4 gal) and the highest PGA at the observation point of 38 (363.5 gal). This highest PGA is near the epicentre 18 km northeast of Sorowako on February 15, 2011 at 10:33:55 WITA depth of 34 km with magnitude of 6.2 M.

The McGuire’s PGA distribution is as follows:

Figure 3. Macro-zonation Maximum PGA around Matano Fault.
Intensity is obtained from the PGA of [13] Wald equation intensity is between II to VII MMI. The PGA results and intensity can be compared with the geological map (figure 4). It is shown that the intensity correlate to the direction of Matano Fault, which decrease inland from east to west.

![Figure 4. The zonation of Intensity (MMI) and geology map of Matano Fault [15].](image)

Based on comparison between the intensity and local rock type (figure 3), it is shown that highest intensity is dominated by ultrabasic rocks, medium intensity with a composite combination between metamorphic and ultra-basic rocks and lowest intensity has composition of metamorphic rocks. It can be concluded that the vulnerable areas are dominated by ultrabasic rocks with high PGA and MMI.

4.2 Discussion
Matano fault is an active area of the earthquake (figure 1). Several large earthquakes at Matano Fault (table 1) caused the loss of property and caused some people to be injured. Soroako City is the area most affected by the earthquake because it is nearest to the epicentre of the largest earthquake in the area. To describe the level of disaster in Matano Fault required some PGA analysis using PGA interpolation by means of empiric equation.

Employed some empirical methods (equation 1, 2 and 3 in theory) can be used to conclude that McGuire is most suitable than the others [11, 12]. Obviously, the parameter data used by McGuire have similarities with the data parameter in this study. The similarity data is the focal depth of earthquakes at shallow layer and the distribution of earthquakes in the land area. The focal depth in Matano Fault dominated by shallow earthquakes and input data for PGA calculation are between 10-34 km depth of earthquakes.

The largest earthquake (6.2 M) in February, 15, 2011 about 19 km North East direction of Soroako City gives maximum PGA at least 363.5 gal. It causes Soroako City is the most vulnerable area. The city has a dense population and heterogeneous building structures. Vulnerability factors are influenced by residents and building structures [8]. The largest PGA is near the source of the earthquake [6]. The variations in PGA values are increasing to east direction of Soroako city where it’s dominated by ultrabasic rock. By using Wald equation, maximum intensity can obtained so at least VI-VII MMI felt around eastern part. Therefore, eastern Soraako city is most vulnerable area.

The macro-zonation of earthquake in this study based on PGA, intensity, and type of rock has developed to describe the risk parameters of earthquake disaster vulnerability in Matano Fault. However, it is not satisfied to know exactly the condition of earthquake disaster in this area. It still needs other macro-zonation method and should be complemented by micro-zonation of earthquake vulnerability.

5. Conclusions
From the paper have presented, it can be deduced that PGA is simply method for macro-zonation study because only used magnitude and distance of earthquakes for input data. Empirical calculations are done because of lack of instruments. This study is preliminary research of macro-zonation then
combined with other methods. McGuire's PGA empirical method is more suitable to study earthquake macro-zonation in Matano Fault compared to other methods. It has appropriate criteria for earthquake data of this area and the deviation from the result is not big.

The value of PGA and intensity is decreasing in the direction of the Matano Fault pattern that stretches from east to west. Geological observations show that high PGA values are in the area dominated by Ultra-basic rock. In the middle of a matano fault there is a town of sorowako that is threatened by earthquakes. The city is the most vulnerable area because it has high PGA and densely populated settlements.

Reference

[1] Wang Z 2008 Understanding Seismic Hazard and Risk Assessments: An Example in the New Madrid Seismic Zone of the Central United States Proceedings of the 8th U S National Conference on Earthquake Engineering April 18-22 2006 416 (San Francisco California USA)
[2] Nath S K and Thingbaijam K K S 2009 Seismic Hazard Assesment – A Holistic Micro-zonation Approach Natural Hazard and Earth System Science 9 1445-1449
[3] Mihalic S, Ostric M and Krkac M 2011 Seismic Micro-zonation: A review and Principle Practice Geofizica 28 1
[4] Wald D J, Quitoriano V, Heaton T H and Kanamori H 1999 Relationships Between Peak Ground Acceleration, Peak Ground Velocity and Modified Mercalli Intensity in California The Professional Journal of the Earthquake Engineering Research Institute 15 3 557-564
[5] Ganapaty G P 2010 First Level Seismic Micro-zonation Map of Chennai city – a GIS Approach Natural Hazard and Earth System Science 11 549-559
[6] Ardeleanu L, Grecu B and Raileanu V 2012 Peak Ground Acceleration, Velocity, and Displacement from Moderate Magnitude Undercrustal Earthquakes of Vrancea Region Romanian Report on Physics 64 2 555-570
[7] Atkinson G M and Kaka S I 2007 Relationships between Felt Intensity and Instrumental Ground Motion in the Central United States and California Bulletin of the Seismological Society of America 97 2 497-510
[8] Edward M R, Robinson D, McAneney K J and Schneider J 2004 Vulnerability of Residential Structures In Australia 13th World Conference on Earthquake Engineering, B C Canada 1-6 2985
[9] Langston C A 2003 Local Earthquake Wave Propagation Through Mississippi Embayment Sediments, Part I: Body-Wave Phases and Local Site Responses Bulletin Seismological Society of America 93 2664-2684
[10] Schanabel P, Seed H B and Lysmer J 1973 Modification of Seismograph Records for Effects of Soil Conditions Bulletin Seismology Society of America 62 1649-1664
[11] Akkar S and Bommer J J 2010 Empirical Equations for The Prediction of PGA, PGV and Spectral Accelerations in Europe the Mediterranean Region and The Middle East Seismological Research Letters 81 (2) 195–206
[12] Humbert N and Viallet E 2008 An Evaluation of Epistemic and Random Uncertainties Included in Attenuation Relationship Parameters Proceedings of Fourteenth World Conference on Earthquake Engineering 07-0117
[13] McGuire R K 1997 Seismic Design Spectra and Mapping Procedures Using Hazard Analysis Based Directly on Oscillator Response Earthquake Engineering Structural Dynamics 5 211–234
[14] Irsyam M, Sengara I W, Aldiamar F, Widiyantoro S, Triyoso W, Natawidjaja D H, Kertapati E, Meilano I, Suhardjono, Asrurifak M and Ridwan M 2010 Ringkasan Hasil Studi Tim Revisi Peta Gempa Indonesia (Bandung-Indonesia)
[15] Simanjutak T O, Rusmana E, Suroso and Supandjono 1991 Peta Geologi Lembar Malili Sulawesi Selatan (Bandung: PPPG Bandung)