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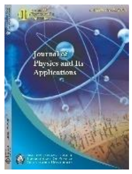

PGA Estimation of 346 Points in West Sumatra based on Earthquakes Scenario in West Pasaman with Si and Midorikawa Formula

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ABSTRACT

There was a destructive earthquake on February 25, 2022, at 08:39:29 WIB with a magnitude of 6,1 Mw that struck western Sumatra with an epicenter on land, and was located on a blind fault. The impact of the earthquake was felt quite widely in all Regencies/Cities in West Sumatra with an intensity of IV – VIII MMI. The earthquake caused damage, an estimated 6627 houses, 70 mosques, 41 offices, 208 schools, 25 medical infrastructure and 5 bridges. Therefore, it is necessary to conduct research in the province of West Sumatra on PGA using the Si and Midorikawa method and intensity with Murphy O'Brein's empirical formulation as an effort to mitigate earthquake disasters. This study aims to determine PGA as the level of earthquake activity and intensity as a measure of the damage caused by earthquakes and to analyze their distribution maps. The data used is earthquake data for the period 1936-2022 with a magnitude ≥ 5 Mw and a depth of ≤ 70 km sourced from the catalog of the National Earthquakes Information Center U.S Geological Survey (NEIC/USGS). The results of data processing produce PGA values in West Sumatra ranging from 0.4083 – 782.9839 gal with an intensity (MMI) ranging from I – IX MMI. Map of distribution of PGA values and the highest intensity is in West Pasaman Regency and the lowest value is in Mentawai Islands Regency. The West Pasaman Regency area and its surroundings should meet the requirements for earthquake-resistant buildings, because they have a fairly high PGA value.

1. Introduction

An earthquake is an event of releases seismic wave energy that occurs suddenly. This release of energy is caused by the deformation of tectonic plates that occur in the earth's crust. One of the islands located in the western part of Indonesia which is the epicenter of the earthquake is Sumatra Island. The position of the west coast of the island of Sumatra, which is the meeting area of the Eurasian and Indo-Australian plates, infiltrates under the Eurasian plate with an oblique direction of about 40-45 degrees so that it has high seismicity due to its tectonic activity [1]. The velocity of movement of the Indo-Australian plate with the Eurasian plate is 69.42-72.55 mm per year [2]. This oblique subduction resulted in the formation of the Sumatran fault zone [3].

West Sumatra is a province located on the west coast of the central part of Sumatra Island which has four active fault segments. Among them, are the Sumpur Segment, the Sianok Segment, the Sumani Segment, and the Tutupi Segment [4]. One of the regions in the zone is West Pasaman. West Pasaman is a regency located on the west coast of West Sumatra Province which is flat, undulating, hilly, and mountainous. The dominant geological structure in this region is the Great Sumatra Fault Zone consisting of Descending Faults, Folds, Shear Faults, and others. So based on this, West Sumatra has regions that are prone to landslides and ground movement with high ground movement vulnerability zones and medium ground movement zones as a result of the earthquake [5]. On February 25, 2022, at 08:39:29 WIB there was an unexpected earthquake with a magnitude of 6,1 Mw which struck Western Sumatra, on land, and was located on the blind fault. The epicenter of the earthquake was located at 0.15°N, and 99.98°E, 17 km northeast of West Pasaman and at a ground depth of 10 km, with impacts felt throughout the region including in Singapore and Malaysia. This earthquake is an active fault earthquake due to the slip strike of the Sumatra fault system. The earthquake caused damage in West Pasaman and the surrounding region, an estimated 6.627 houses were destroyed and 70 mosques were damaged, 41 offices were destroyed, 208 schools and educational institutions, 25 medical infrastructure, and 5 bridges were damaged. The impact of the earthquake which was felt quite broadly included Simpang Empat, Kinali, Kajai, and Talu, the intensity of which was recorded on the VIII MMI scale, VII MMI in Lubuk Sikaping and Malampah Regencies, VI MMI in Agam, Tanah Datar and Limapuluh Kota Regencies, V MMI in Payakumbuh, Bukittinggi, and Padang. Panjang City, IV MMI in Pariaman and Padang Pariaman Regencies, III MMI in Kampar, and Rokan Hulu Regency (Riau Province) [6]. With this incident, it is necessary to see how strong the impact of the earthquake which had its epicenter in the West Pasaman region was on West Sumatra Province. When the vibrations caused by this earthquake reach the surface, the ground that is passed by the seismic waves will experience acceleration. The acceleration of the ground at the earth's surface is called peak ground acceleration.

Peak ground acceleration is one of the parameters that determines the value of the largest ground acceleration that has ever occurred in a region caused by waves from earthquakes [7]. This research aims to improve previous research, namely using 3 destructive earthquake events with epicenters in the West Pasaman area due to the Sumatra Fault. Earthquakes with a large magnitude greatly affect the damage to buildings, one of the factors that can cause it to determine the size and extent of the damage is the peak ground acceleration [8]. In this study, the empirical formulation Si and Midorikawa were used by conducting earthquake scenarios in West Sumatra using earthquake data for the period 1936-2022. This scenario was carried out to see the effect of the earthquake in the West Pasaman region on the peak ground acceleration (PGA) and earthquake intensity (MMI) values in 19 Regencies/Cities in West Sumatra. The earthquake had an epicenter in the West Pasaman region as a result of the Sumatra Fault as shown in Figure 1.

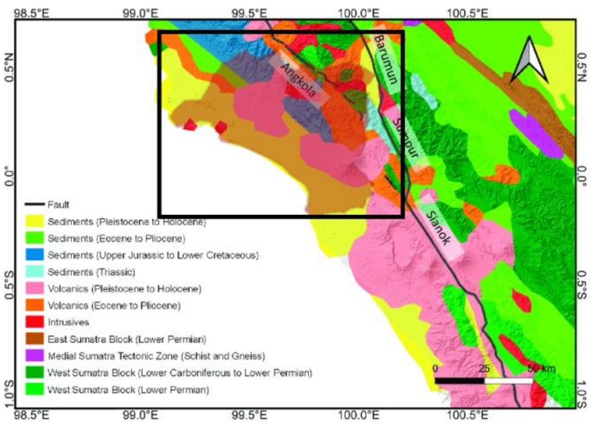


Fig. 1: Geological Map of Pasaman (Indonesia Geological Agency).

Figure 1 explains that the West Pasaman region is crossed by the Central Sumatra fault zone (consisting of Barumun, Angkola, Sumpur, Sianok, Sumani, Suliti, and Siulak). Generally, the oldest stage (Permian-Cretaceous) is represented by intrusive rocks and metamorphic rocks. The middle stage (Eocene-Pliocene) consists mostly of intrusive rocks, volcanic rocks, sedimentary and pelagic rocks. The youngest stage (Pleistocene-Holocene) is alluvial and volcanic deposits, which originated from Mount Talamau, Mount Malintang, and Mount Sorik Marapi [9].

The newness of this research is that the empirical formulation of Si and Midorikawa is used by conducting earthquake scenarios in the West Pasaman region using earthquake data for the period 1936-2022. This scenario was conducted to see the effect of earthquakes in the West Pasaman region on the value of peak ground acceleration (PGA) and earthquake intensity (MMI) with 341 calculation points with a 0.1° grid in 19 regencies/cities in West Sumatra. The area with the largest distribution of the estimated PGA values due to destructive earthquakes originating from nearby fault zones is directly proportional to the intensity value [10]. The PGA value is directly proportional to the earthquake intensity which is obtained as a function of Log and vice versa by carrying out a separate regression [11]. Therefore, earthquake disaster mitigation in these areas is most difficult to be aware of because the location tends to be close to the epicenter of the earthquake due to the arrival of the first seismic wave [12]. Therefore, it is necessary to map the distribution of the impact caused by the earthquake.

Mapping and analyzing peak ground acceleration and earthquake intensity is one of the efforts to mitigate earthquake disasters by knowing the local tectonic conditions and the level of seismicity. These values provide important information about the seismic risk in an area related to infrastructure development plans [13]. To limit the vulnerability of infrastructure concerning future earthquake hazards, the empirical data collected is exploited to derive an improvement level function for earthquake-resistant buildings [14]. Distribution maps of earthquake hazards can help policymakers and administrators prioritize which areas should be further investigated to assess the seismic risk of structures and infrastructure to be built [15]. The peak ground acceleration value can be used as information for earthquake disaster mitigation, especially for the province of West Sumatra in the process of building earthquake-resistant structures and infrastructure facilities [16].

2. Method

This research is a descriptive study using secondary data in the form of earthquake data obtained from catalogs National Earthquakes Information Center U.S. Geological Survey (NEIC/USGS) in the period 1936-2022. This study examines the local tectonic conditions and the level of seismic activity by analyzing the peak ground acceleration (PGA) using the empirical Si and Midorikawa Formula. The parameters used in this study are latitude, longitude, magnitude, epicenter, hypocenter, earthquake depth, and peak ground acceleration value. The earthquake data used has a magnitude ≥ 5 Mw and a depth of ≤ 70 km which is in the West Pasaman region with coordinates 00° 33' North Latitude - 00° 11' South Latitude and 99° 10' East Longitude -100° 04' East Longitude. The data processing steps carried out to produce peak ground acceleration and earthquake intensity in this study are as follows.

The first is to calculate the distance between the earthquake epicenter coordinates to each coordinate of the calculation region, to obtain the epicenter distance (D) using Equation (1).

$$D^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 \qquad (1)$$

Where, D is the distance from the epicenter to the calculation point, x_1 is the latitude of the epicenter, x_2 is the latitude of the calculation point, y_1 is the longitude of the epicenter, and y_2 is the longitude of the calculation point. Unit of D, x_1, x_2, y_1, and y_2 in degrees (˚). The epicenter distance obtained must be in km so it must be converted first, where 1˚ = 111 km.

The second is to calculate the distance from the earthquake hypocenter (R) to each coordinate point of calculation. The hypocenter distance (R) can be found using Equation (2).

$$R^2 = D^2 + H^2 \qquad (2)$$

Where, R is the hypocenter distance (km), D is the epicenter distance (km), and H is the depth of the earthquake (km).

Then after the parameters are obtained, these values are substituted into the general form of the empirical equation Si and Midorikawa. The peak ground acceleration can be estimated using statistical analysis methods, one of which is known as the method Si and Midorikawa as defined in Equation (3) [17].

$$\log A = aM_w + hD + \Sigma d_i s_i - \log X_{eq} - kX_{eq} + e + \varepsilon \qquad (3)$$

Where A is the peak ground acceleration (cm/s^2 ; gal), X_{eq} is the hypocenter distance (km), Mw is the moment magnitude, D is the depth of the earthquake, d is the distance coefficient from the epicenter of the earthquake to the location (crust = 0.00 ; inter-plate = 0.09 ; intra-plate = 0.28), s is a dummy variable for the type/type of fracture (s=1), a, h, k, and e is the regression coefficient (0.50; 0.0036; 0.003; 0.60), and ε is the standard deviation (0.24).

The PGA value obtained from Equation 1 is converted to the Modified Mercalli Intensity (MMI) scale to indicate an intensity scale using the Murphy & O'Brien empirical formula in Equation 4 [18].

$$MMI = 2{,}86 \log(PGA) + 1{,}24 \qquad (4)$$

where MMI is Mercally Modified Intensity. Next, calculate the peak ground acceleration value in West Sumatra province using Equation (1) based on historical earthquake data that occurred in the West Pasaman region. The study region is on the grid with a distance of 0,1° as shown in Figure 2 below.

Based on Figure 2 there are 346 calculation points in 19 Regencies/Cities in West Sumatra, where each point is calculated for the value of peak ground acceleration and earthquake intensity from earthquake data for the period 1936 - 2022 with a magnitude ≥ 5 Mw and a depth of ≤ 70 km. After that, analysis and making a distribution map of estimated peak ground acceleration values and earthquake intensity in the province of West Sumatra based on the calculation results. These two values can be used as information on earthquake disaster mitigation, especially for the province of West Sumatra in the process of building earthquake-resistant structures and infrastructure facilities.

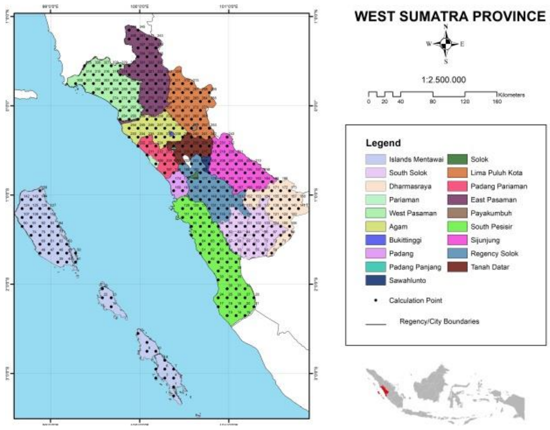


Fig. 2: Map of Calculation Points of West Sumatra Province.

3. Results and Discussion

The results of this study are the value of peak ground acceleration (PGA) and earthquake intensity (MMI) which is the processing of earthquake secondary data sourced from the site National Earthquakes Information Center U.S Geological Survey (NEIC/USGS) and BMKG. Earthquake data in this study totaled 3 events in the period 26 October 1936 to 25 February 2022. Earthquake data can be seen in Table 1.

Table 1: Earthquake data scenarios in the West Pasaman region.

No	Time	Latitude	longitude	depth	mag
1	2022-02-25T01:39:28.817Z	0.174	99.950	10	6.18
2	2022-02-25T01:35:50.827Z	0.249	100.002	10	5
3	1936-10-26T19:32:06.320Z	0.281	99.724	15	6.29

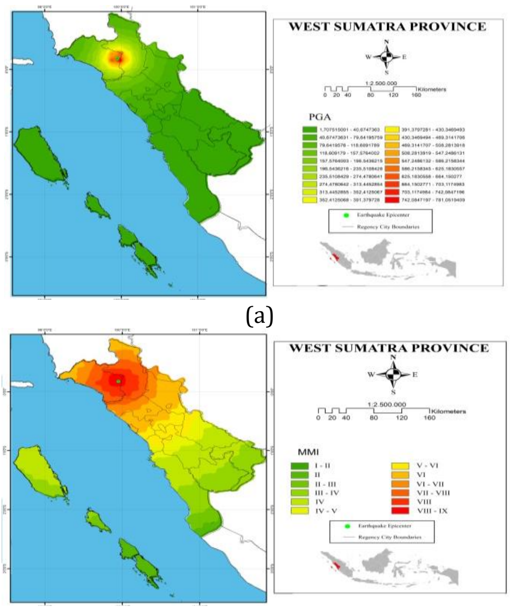
The region for which the peak ground acceleration and earthquake intensity values will be determined from the earthquake scenario in the West Pasaman region are 19 Regencies/Cities in West Sumatra. The parameters used are the latitude and longitude coordinates of the calculation point in West Sumatra, epicenter latitude and longitude coordinates, magnitude, hypocenter depth, and hypocenter distance. The calculation point is in the province of West Sumatra with coordinates 3º 50' S - 1º 20' N and 98º 10' - 102º 10' E which is 11.1 km for each point. First, based on the research that has been done, the peak ground acceleration and intensity values are obtained for 346 calculation points in 19 Regencies/Cities in West Sumatra, from the earthquake scenario in the West Pasaman region which can be seen in Table 2.

Based on Table 2, it can be seen that the peak ground acceleration value and the largest earthquake intensity are located in West Pasaman Regency. The peak ground acceleration value is 72.8864 – 782.9839 gal with an earthquake intensity of VI – IX MMI.

Table 2: Peak ground acceleration and intensity values from the earthquake scenario with the epicenter at coordinates 0.174° LU and 99.95° BT which has a magnitude of 6.18 Mw at a depth of 10 km.

No	Regency/City	PGA (gal)	MMI
1	Islands Mentawai	1.7074 – 16.2654	I -IV
2	South Pesisir	3.4337 – 22.2974	II - V
3	South Solok	6.0528 – 13.2189	III - IV
4	Sawahlunto	6.7159 – 35.8339	III - V
5	Tanah Datar	36.4694 – 62.1692	V - VI
6	Padang Pariaman	39.5980 – 99.6050	V - VI
7	Agam	29.4714 – 189.4032	VI - VII
8	Lima Puluh Kota	39.5722 – 148.1054	V - VII
9	West Pasaman	72.8864 – 782.9839	VI - IX
10	East Pasaman	72.0839 – 457.0671	VI - VIII
11	Padang	25.6485 – 37.0426	V
12	Solok	28.4364	V
13	Payakumbuh	60.3935	VI
14	Bukittinggi	71.8278	VI
15	Padang Panjang	60.5778	VI
16	Regency Solok	11.4701 – 35.9006	IV -V
17	Dhamasraya	5.6153 – 12.6203	III - IV
18	Sijunjung	10.9727 – 18.7086	IV
19	Pariaman	49.9107	VI

The peak ground acceleration value and the smallest earthquake intensity are found in the Mentawai Islands Regency of 1.7074 – 16.2654 gal with an earthquake intensity of I - IV MMI. Based on the data obtained, a map of peak ground acceleration and earthquake intensity is generated for earthquake scenarios in the West Pasaman region which can be seen in Figure 3.



(a)

(b)

Fig. 3: (a) Map of peak ground acceleration (PGA) and (b) earthquake intensity (MMI) from an earthquake scenario with a magnitude of 6,18 Mw with an epicenter at coordinates of 0,174° LU and 99,95° BT at a depth of 10 km.

Based on Figure 3, the Regency/City with the largest peak ground acceleration value is in West Pasaman Regency because the area is near the epicenter of the earthquake. When viewed from the tectonic conditions, West Pasaman Regency is in the Sumatra Fault zone which extends on the island of Sumatra. Then the lowest value is in the Mentawai Islands Regency because it is far from the epicenter of the earthquake, and has a relatively safe geological structure from the Sumatra Fault. Second, based on the research that has been done, the peak ground acceleration and intensity values are obtained for 346 calculation points in 19 Regencies/Cities in West Sumatra, from the earthquake scenario in the West Pasaman region which can be seen in Table 3.

Table 3: Value of peak ground acceleration and intensity of the earthquake scenario with the epicenter at coordinates 0.249° LU and 100.002° BT which has a magnitude of 5 Mw at a depth of 10 km.

No	Regency/City	PGA (gal)	MMI
1	Islands Mentawai	0.4083 – 3.6880	I - II
2	South Pesisir	0.8386 – 5.3156	I - III
3	South Solok	1.5036 – 3.2354	I - II
4	Sawahlunto	1.6950 – 9.0926	I - III
5	Tanah Datar	9.0610 – 15.3005	III - IV
6	Padang Pariaman	9.2343 – 21.8679	IV - V
7	Agam	15.7525 – 38.0165	IV - V
8	Lima Puluh Kota	10.1651 – 40.7619	IV - V
9	West Pasaman	16.8849 – 215.6755	IV - VII
10	East Pasaman	21.5613 - 162,9326	V - VII
11	Padang	6.1197 – 8.7555	III
12	Solok	6.9698	III
13	Payakumbuh	15.388	IV
14	Bukittinggi	17.2791	IV
15	Padang Panjang	14.449	IV
16	Regency Solok	2.8653 – 8.7449	II - III
17	Dhamasraya	1.4002 – 3.1653	I - II
18	Sijunjung	4.6900 – 2.8175	II - III
19	Pariaman	11.4423	IV

Based on Table 3, it can be seen that the peak ground acceleration value and the largest earthquake intensity are located in West Pasaman Regency. The peak ground acceleration value is 16.8849 – 215.6755 gal with an earthquake intensity of IV - VII MMI. The peak ground acceleration value and the smallest earthquake intensity are found in the Mentawai Islands Regency of 0.4083 – 3.6880 gal with an earthquake intensity of I - II MMI. Based on the data obtained, a map of the peak ground acceleration and earthquake intensity for earthquake scenarios in the West Pasaman region can be seen in Figure 4.

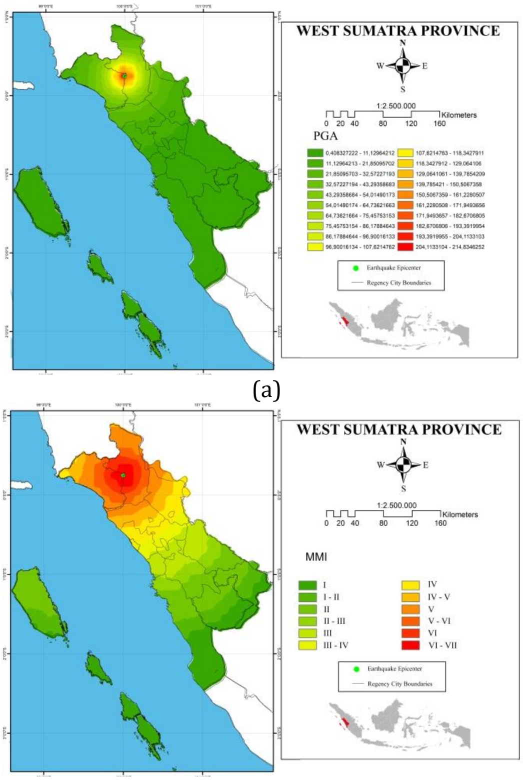


Fig. 4: (a) Map of peak ground acceleration (PGA) and (b) earthquake intensity (MMI) from an earthquake scenario of magnitude 5 Mw with an epicenter at coordinates 0.249° North Latitude and 100.002° East Longitude at a depth of 10 km.

Based on Figure 4, when the magnitude decreases to 5 Mw, it can be seen that the peak ground acceleration value and intensity map has a narrower radius of vulnerability compared to the earthquake scenario for a magnitude of 6.18 Mw. Third, based on the research that has been done, the peak ground acceleration and intensity values are obtained for 346 calculation points in 19 Regencies/Cities in West Sumatra, from the earthquake scenario in the West Pasaman region which can be seen in Table 4.

Table 4: The peak ground acceleration and earthquake intensity values from the earthquake scenario with the epicenter at coordinates 0.281° LU and 99.724° BT which has a magnitude of 6.29 Mw at a depth of 15 km.

No	Regency/City	PGA (gal)	MMI
1	Islands Mentawai	1.7401 – 20.8238	I - V
2	South Pesisir	3.2501 – 19.6914	II - IV
3	South Solok	5.4748 – 11.7013	III - IV
4	Sawahlunto	5.960 – 28.2762	III - V
5	Tanah Datar	29.0508 – 46.1285	V
6	Padang Pariaman	33.7449 – 75.7111	V - VI
7	Agam	51.4279 – 126.8874	VI - VII
8	Lima Puluh Kota	30.7510 – 89.4759	V - VI
9	West Pasaman	142.2869 – 606.0647	VII - IX
10	East Pasaman	88.4666 – 382.6088	VI - VIII
11	Padang	22.2709 – 31.1400	V
12	Solok	23.5598	V
13	Payakumbuh	59.6707	VI
14	Bukittinggi	52.7161	VI
15	Padang Panjang	46.3314	VI
16	Regency Solok	10.0114 – 29.1380	IV - V
17	Dhamasraya	5.0617 – 10.9187	III - IV
18	Sijunjung	9.4402 – 15.8011	IV
19	Pariaman	42.1613	V

Based on Table 4, it can be seen that the peak ground acceleration value and the largest earthquake intensity are located in West Pasaman Regency. The peak ground acceleration value is 142.2869 – 606.0647 gal with an earthquake intensity of VII - IX MMI. The peak ground acceleration value and the smallest earthquake intensity are found in the Mentawai Islands Regency of 1.7401 – 20.8238 gal with an earthquake intensity of I - V MMI. Based on the data obtained, a map of peak ground acceleration and earthquake intensity for earthquake scenarios in the West Pasaman region can be seen in Figure 5.

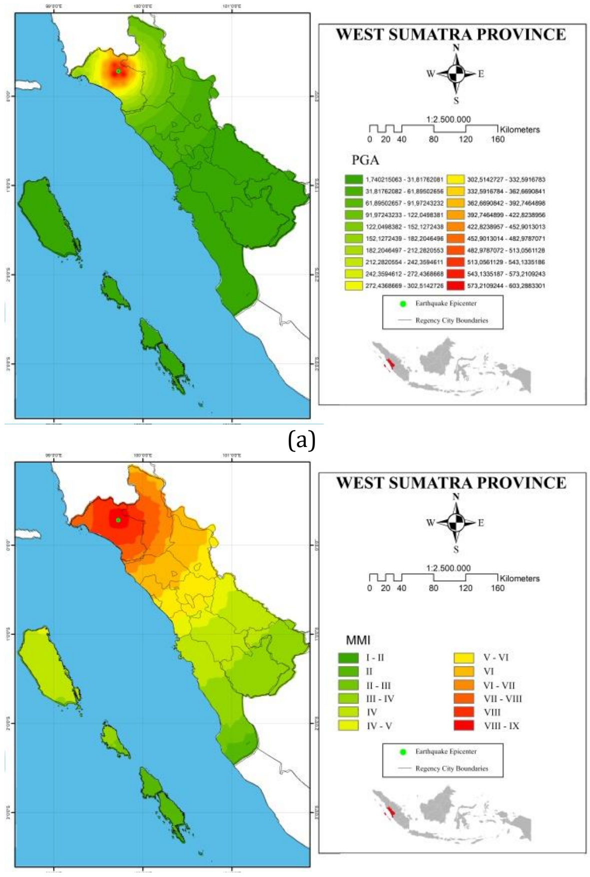


Fig. 5: (a) Map of peak ground acceleration (PGA) and (b) earthquake intensity (MMI) from an earthquake scenario with an epicenter at coordinates 0,281° North Latitude and 99,724° East Longitude with a magnitude of 6,29 Mw at a depth of 15 km.

Based on Figure 5, it is found that when the magnitude increases to 6.29 Mw, it can be seen that the map of the peak ground acceleration value and intensity has a wider radius of vulnerability compared to the earthquake scenario for a magnitude of 5 Mw. Apart from being affected by magnitude, the two values are also affected by the distance from the point of calculation to the epicenter of the earthquake [19]

Based on the map of peak ground acceleration (PGA) and earthquake intensity (MMI) 19 Regencies/Cities with the largest peak ground acceleration value is in West Pasaman Regency which ranges from 72.8864 – 782.9839 gal with earthquake intensity of VI - IX MMI. Furthermore, the lowest value is in the Mentawai Islands Regency, which ranges from 0.4083 – 3.6880 gal. On the map of peak ground acceleration and earthquake intensity, it can also be seen that the closer the position of an area is to the epicenter, the greater the earthquake vibration felt [20]. This is indicated by the appearance of a more intense color towards a dark red color for areas near the epicenter, and a color appearance towards a dark green color for areas far from the epicenter.

Based on earthquake scenarios that have been carried out in the West Pasaman region, it can be seen that the peak ground acceleration and earthquake intensity increase when the variation in magnitude is greater. This is following research by Suzuki on the 2016 Kumamoto earthquake investigating seismic damage due to crustal earthquakes and the nature of the earthquake. The spatial distribution of peak ground acceleration is more complex for larger magnitudes [21]. The complexity is a result of fault motion processes and locally induced earthquakes. The value of peak ground acceleration and earthquake intensity increases with increasing magnitude, because if the magnitude is greater, the ground vibrations due to earthquakes are also greater, so that the value of peak ground acceleration and earthquake intensity increases [22]. Variations in the earthquake data scenarios show that earthquakes with epicenters in the Sumatra Fault Zone have peak ground acceleration (PGA) and earthquake intensity (MMI) values for each region in West Sumatra.

In terms of geology, the West Pasaman region is formed by surface deposits of mountainous rock formations. Geomorphological units of the region are Fault-Folds, Karst Hills, Coastal Plain and Alluvial units. Peak ground acceleration is one of the critical factors affecting the determination of earthquake intensity. Judging from the estimated value, it shows that the greater the PGA value, the greater the resulting intensity value. PGA is commonly used to describe ground motion in a particular region, and is able to efficiently predict site ground motion parameters for the design of engineering structures [23]. The resulting PGA depends on local site characteristics and distance from the earthquake epicenter [24].

The peak ground acceleration value can be used as information on earthquake disaster mitigation, especially for the province of West Sumatra in the process of building earthquake-resistant structures and infrastructure facilities. Rapid and accurate estimation of seismic intensity after a damaging earthquake provides critical information for coordinating immediate and adequate emergency response, properly targeting rescue missions by government and emergency management teams, assisting in identifying broken faults, and enabling evaluation for the potential for strong aftershocks [25]. Based on the research results, the regions of West Pasaman Regency and East Pasaman Regency have a fairly high peak ground acceleration value. Therefore, buildings built in that region should meet the requirements for earthquake-resistant buildings, because they have a relatively high peak ground acceleration value.

4. Conclusion

Peak ground acceleration (PGA) and earthquake intensity (MMI) values in West Sumatra due to earthquakes that occurred in the West Pasaman region in 1936 - 2022 with a magnitude ≥ 5 Richter scale and a depth of ≤ 70 km using the Si and Midorikawa empirical formula equation with a value the highest was in West Pasaman Regency which ranged from 72.8864 – 782.9839 gal with earthquake intensities ranging from VI – IX MMI, while the lowest value was in Mentawai Islands Regency which ranged from 0.4083 – 3.6880 gal with intensity values earthquakes of I – II MMI. Map of the distribution of peak ground acceleration values and earthquake intensity due to earthquakes that occurred in the West Pasaman region in 1936 - 2022 with the largest values being in West Pasaman Regency due to being close to the earthquake epicenter, while the lowest value is in the Mentawai Islands Regency because it is far from the Sumatra fault zone so it doesn't have an impact on the earthquake. So it is obtained from the three scenarios that affect the estimated value of ground acceleration (PGA) are magnitude, epicenter distance, and calculation point distance. On the distribution map of the estimated PGA value and intensity, it can be seen that the risk of earthquake disaster is spread almost evenly throughout the region, especially along the Sumatra fault line. Therefore, West Sumatra Province should have met the requirements for earthquake-resistant buildings, because it has a fairly high peak ground acceleration value.

Acknowledgments

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