

ANALYSIS OF B-VALUE AND PEAK GROUND ACCELERATION (PGA) IN WEST SUMATRA PROVINCE USING MAXIMUM LIKELIHOOD METHOD AND EMPIRICAL FORMULA (EARTHQUAKE DATA PERIOD 2007-2020)

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ABSTRACT

West Sumatra Province has four active fault segments, namely part of the Sumatran fault zone which causes frequent earthquakes. Therefore, it is necessary to research *b*-value analysis and PGA in the province of West Sumatra by using the maximum likelihood method and empirical formula for earthquake disaster mitigation efforts. This study aims to determine the *b*-value associated with rock stress and PGA as the level of earthquake activity and analyze the distribution map. The data used is earthquake data for the period 2007-2020 with a magnitude ≥ 5 SR and a depth of ≤ 100 km. The results of data processing produce a map of the distribution of *b*-value and PGA in the province of West Sumatra. The *b*-value in each region ranged from 0.8421-1.4477. Based on the *b*-value distribution map, the area that has the smallest *b*-value is in region 6, while the largest value is in region 2. A low *b*-value correlates with high rock stress conditions. This value illustrates that area 6 has a high chance of a major earthquake occurring. Furthermore, the calculation of the PGA value refers to the general form of Lin and Wu's empirical equation to obtain a new empirical formula model. The value of the coefficient $a=-1.20543$, $b=-0.839093$, and $c=6.88858$. The PGA value of West Sumatra province ranges from 10.87-376.98 gal. The city/regency with the largest PGA value is in the Mentawai Islands Regency, which ranges from 84.11-328.17 gal and the lowest value is in Dharmasraya Regency, which is between 10.87-35.28 gal.

Keywords : Earthquake; Seismicity; *b*-value; PGA.



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I. INTRODUCTION

Indonesia is an archipelagic country that is traversed by the path of three active tectonic plate encounters in the world, namely the Indo-Australian plate, the Pacific plate, and the Eurasian plate. The movement of these three tectonic plates results in the release of energy that radiates in all directions to the earth's surface, causing earthquakes. This situation makes Indonesia often hit by earthquakes.

Sumatra Island is one of the islands located in the western part of Indonesia which is the epicenter of the earthquake. The island of Sumatra has three tectonic systems that can affect the level of seismic activity. First, is the subduction zone which is the boundary between the Indo-Australian plate and the subducting Eurasian plate with the rock mass above it [1]. The speed of movement of the Indo-Australian plate with the Eurasian plate is 60-70 mm per year [2]. Second, the Sumatran fault was formed due to the subduction of the Indo-Australian plate and the Eurasian plate with a tilted direction of about 40-45 degrees. The sloping subduction resulted in the formation of the Sumatran fault zone [3]. Third, the Mentawai fault which stretches for 600 km and is located to the east of the Mentawai Islands between the fore-arc ridge and fore-arc basin. This fault is a fault parallel to the Sumatran fault or the Semangko fault [4].

West Sumatra is a province located on the island of Sumatra which has four active fault segments. This segment is part of the Sumatran fault zone. Among them, the Sumpur segment, Sianok segment, Sumani segment, and Suliti segment [5]. This geological condition causes frequent earthquakes in the province of West Sumatra. An earthquake is a sudden release of seismic wave energy. This release of energy is caused by the deformation of tectonic plates that occur in the earth's crust [6]. Earthquakes can cause loss, damage and even take many lives. The processes that cause large and destructive earthquakes in an area need to be understood with local tectonic stress conditions and the level of seismic activity [7].

Local tectonic stress conditions and the level of seismic activity can be determined by performing b-value analysis and peak ground acceleration (PGA). b-value is one of the parameters of tectonic conditions in an area that is being observed and depends on the nature of local rocks and the level of rock fragility [8][9]. b-value also reflects tectonic conditions related to rock stress in an area. High b-value correlates with low rock stress conditions and has a high heterogeneity medium, but a low b-value correlates with high rock stress conditions and has low heterogeneity medium [7][10]. b-value can be estimated using statistical analysis methods, one of which is proposed from Utsu (1965) known as the Maximum Likelihood method as defined in Equation (1) [11]:

$$b = \frac{\log e}{\bar{M} - M_0} \quad \text{or} \quad b = \frac{0.4343}{\bar{M} - M_0} \quad (1)$$

where \bar{M} is the average magnitude and M_0 is the minimum magnitude.

Peak ground acceleration (PGA) is one of the parameters that determines the value of the largest ground acceleration that has ever occurred in an area caused by waves from an earthquake [12]. The size of the ground acceleration indicates the level of seismic activity or the risk of an earthquake that needs to be taken into account as one of the measuring points in the design of earthquake-resistant buildings [13]. This parameter can be calculated based on the magnitude and distance of the earthquake source that occurred at the measurement point [14]. The results of measuring PGA values are obtained either directly or through calculations using the Accelerograph and empirical formulations using earthquake data [15].

The calculation of the peak ground acceleration value in an area can use several empirical formulas, including the formula from Donovan (1973), Esteva (1970), and Lin and Wu (2010). The form of the equation formula from Donovan (1973) is [16]:

$$\alpha = \frac{1080 \times \exp(0.5Ms)}{(R+25)^{1.32}} \quad (2)$$

The form of the formula equation from Esteva (1970) is [17]:

$$\alpha = \frac{1230 \times \exp(0.8Ms)}{(R+25)^2} \quad (3)$$

The form of the formula equation from Lin and Wu (2010) is [18]:

$$\log \alpha = -0.395 \times \log R + 0.125 \times M + 1.979 \quad (4)$$

where α is the peak ground acceleration value (gal), R is the hypocenter distance (km), M is the magnitude, and M_s is the surface magnitude.

Based on the above formulas, in this study, in determining the empirical formula for the PGA model, it will refer to the Lin and Wu empirical equation. The general form of Lin and Wu's empirical formulation is:

$$\log \alpha = a \log R + bM + c \quad (5)$$

where α is the peak ground acceleration value (gal), R is the hypocenter distance (km), M is the magnitude, a is the Geometrical Spreading coefficient, b is the magnitude empirical coefficient, and c is a constant.

Mapping and analysis of local tectonic stress conditions and the level of seismic activity based on rock physical parameters are one of the efforts to mitigate earthquake disasters. The local tectonic stress conditions and the level of seismic activity can be determined by performing b-value analysis and peak ground acceleration (PGA). The magnitude of the value of peak ground acceleration indicates the risk of an earthquake that needs to be taken into account as a part of the planning of earthquake-resistant buildings [13]. Therefore, 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.

II. METHOD

This research is a descriptive study using secondary data in the form of earthquake data obtained from the catalog of the National Earthquakes Information Center U.S. Geological Survey (NEIC/USGS) and BMKG in the 2007-2020 period. This study examines local tectonic stress conditions and the level of seismic activity by analyzing b-value and peak ground acceleration (PGA) using the maximum likelihood method and empirical formulas to obtain new information. The parameters used in this study were latitude, longitude, magnitude, epicenter, hypocenter, earthquake depth, and peak ground acceleration value. The earthquake data used has a magnitude ≥ 5 SR and a depth of ≤ 100 km which is located in the province of West Sumatra with coordinates $3^{\circ} 50' S - 1^{\circ} 20' N$ and $98^{\circ} 10' - 102^{\circ} 10' E$. The steps of data processing carried out to produce the b-value and peak ground acceleration in this study are as follows.

The first is to calculate the distance between the coordinates of the earthquake epicenter to each of the coordinates of the calculation area so that the epicenter distance (D) is obtained using Equation (6).

$$D^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 \quad (6)$$

where D is the distance from the epicenter to the earthquake recording station, x_2 is the latitude of the earthquake recording station, x_1 is the latitude of the epicenter, y_2 is the longitude of the earthquake recording station, and y_1 is the longitude of the epicenter. The units for D , x_2 , x_1 , y_2 and y_1 are in degrees ($^{\circ}$). The epicenter distance obtained must be in km, so it must be converted first, where $1^{\circ} = 111.322$ km.

The second is to calculate the distance of the earthquake hypocenter (R) to each coordinate of the calculation area. The hypocenter distance (R) can be determined using Equation (7).

$$R^2 = D^2 + H^2 \quad (7)$$

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

After the parameters are obtained, then the value is substituted into the general form of the Lin and Wu empirical equation (5) to obtain a model of the empirical formula. The coefficients **a**, **b**, and **c** in Equation (5) can be found using the Gaussian elimination application on the Inversion Problem and processed using the MATLAB R2007b software. The peak ground acceleration data is taken from the occurrence of 15 earthquake points recorded on the accelerograph, with the same earthquake station, namely the Padang earthquake station (PDSI) with latitude 0.9118 and longitude 100.4617.

The third is calculating the b-value in West Sumatra using the maximum likelihood method. The b-value calculation is done by dividing the research area into 8 regions and calculated using Equation (1). Next, calculate the peak ground acceleration value in the province of West Sumatra using Equation (8) based on historical data from earthquakes that occurred in the province of West Sumatra. The research area is on a grid with a distance of $0^{\circ} 10'$ or 0.167° as shown in Figure 1.

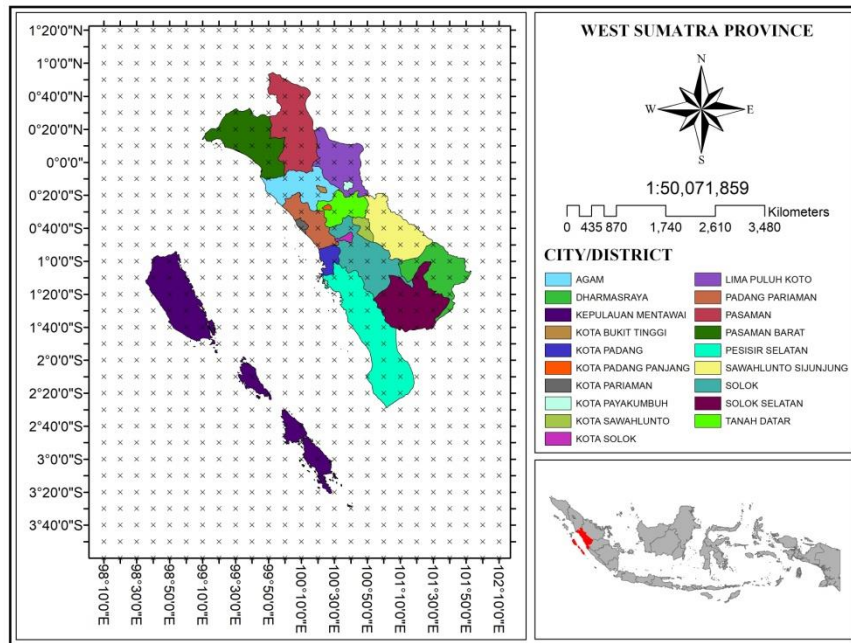


Fig. 1. Grid map of West Sumatra province.

Based on Figure 1 there are 800 calculation points, where each point is calculated from the peak ground acceleration value from earthquake data for the 2007-2020 period with a magnitude ≥ 5 SR and a depth of ≤ 100 km.

The fourth is analyzing and making a map of the distribution of b-value and the peak ground acceleration value in the province of West Sumatra based on the results of calculations using ArcGIS 10.8 software. 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.

III. RESULTS AND DISCUSSION

The results of this study are the b-value and the peak ground acceleration (PGA) value which is processed from secondary earthquake data sourced from the National Earthquakes Information Center U.S Geological Survey (NEIC/USGS) site and BMKG. The earthquake data in this study amounted to 255 events in the period from 1 January 2007 to 31 December 2020. The map of the distribution of earthquake data can be seen in Figure 2.

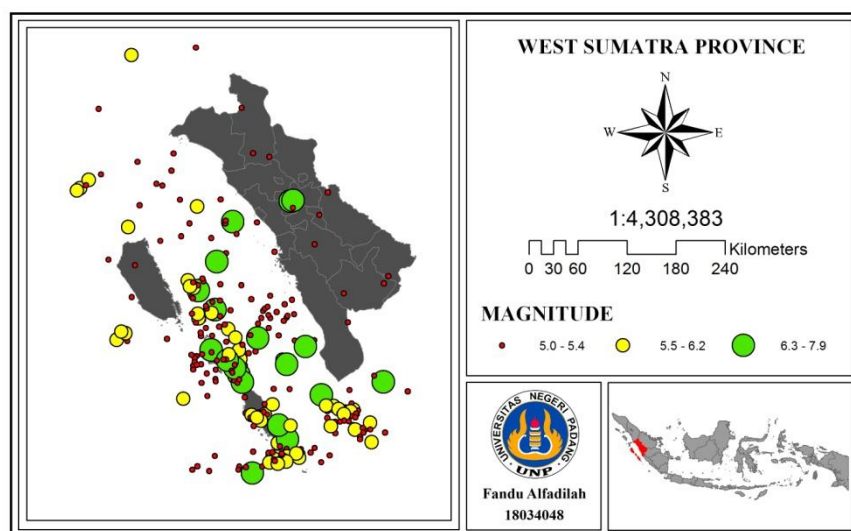


Fig. 2. Distribution map of the earthquake data in West Sumatra province.

Based on Figure 2, it can be seen that the province of West Sumatra has a fairly high level of seismicity. This is indicated by the number of earthquakes that occurred in the province of West Sumatra. Earthquakes marked in red have a magnitude of 5.0-5.4, in yellow with a magnitude of 5.5-6.2, and in green with a magnitude of 6.4-7.9. After going through the processing process using calculations, in this study, the results were obtained in the form of b-value and peak ground acceleration (PGA) as well as a map of the distribution of these two values.

The results of the b-value calculation using the maximum likelihood method can be seen in Table 1.

Table 1. Result of b-value calculation in each region.

No.	Region	Total Mag	N	M ₀	M _{average}	b-value Estimate
1	1°20' - 0°40' LU and 98°10' - 102°10' BT	10.6	2	4.95	5.3	1.2409
2	0°40' - 0°0' LU and 98°10' - 102°10' BT	21	4	4.95	5.25	1.4477
3	0°0' - 0°40' LS and 98°10' - 102°10' BT	101.4	19	4.95	5.34	1.1227
4	0°40' - 1°20' LS and 98°10' - 102°10' BT	92.2	17	4.95	5.42	0.9172
5	1°20' - 2°0' LS and 98°10' - 102°10' BT	329	62	4.95	5.31	1.2184
6	2°0' - 2°40' LS and 98°10' - 102°10' BT	382.6	70	4.95	5.47	0.8421
7	2°40' - 3°20' LS and 98°10' - 102°10' BT	438.4	82	4.95	5.35	1.0958
8	3°20' - 3°50' LS and 98°10' - 102°10' BT	101.1	19	4.95	5.32	1.1705

Based on the results of the calculations in Table 1, the b-values for 255 earthquake events with a magnitude ≥ 5 SR and a depth of ≤ 100 km in each region ranged from 0.8421-1.4477. The b-value distribution map is shown in Figure 3.

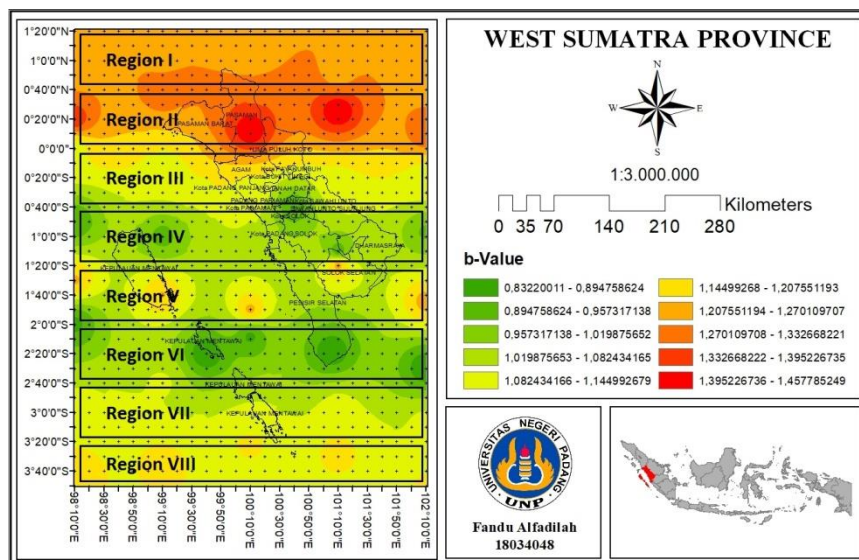


Fig. 3. Map of b-value distribution in West Sumatra province.

Figure 3 shows the b-value distribution in the province of West Sumatra with coordinates 3° 50' S - 1° 20' N and 98 10' - 102° 10' E. Based on the b-value distribution map, the area that has the smallest b-value is in region 6, while the largest value is in region 2. b-value is one of the parameters of tectonic conditions in an area where an earthquake occurs and depends on the nature of local rocks and the level of the brittleness of the rock. b-value also reflects tectonic conditions related to rock stress in an area. A high b-value correlates with low rock stress conditions, meaning that the rock's resistance to stress is small and has a high heterogeneity of medium

conditions, but a low b-value correlates with high rock stress conditions, meaning that the rock's resistance to stress is large and has low heterogeneity. [7][10].

Deformation or changes in the shape and dimensions of rocks occur due to stress and strain in the earth's layers. The movement of tectonic plates causes strain to occur. The rock strain will continue to increase or accumulate over time until the maximum rock stress is exceeded so that the bearing capacity of the rock will reach its maximum limit and eventually cause sudden fractures or fractures. The accumulated energy is released causing a sudden movement that is an earthquake.

Low rock stress conditions will have a high level of rock fragility. The speed of propagation of seismic waves that propagate in rocks that are not dense or with a high level of rock fragility is greater than that of rocks that have a low level of rock fragility. As a result, the accumulation of energy in the earth is relatively fast or the time it takes to accumulate rock strain until the maximum rock stress is fast, so that the accumulation of energy produced is smaller and results in the possibility of an earthquake with a low level of seismicity. Then the condition of high rock stress will have a low level of rock fragility, meaning that the speed of seismic wave propagation in dense rock is smaller than that of rocks that have a high level of rock fragility. As a result, the accumulation of energy in the earth is relatively long or the length of time for the accumulation of rock strain until the maximum rock stress is slow, so that the accumulation of energy produced will also be greater and result in a great chance of a large earthquake with a high level of seismicity. Based on the results of the calculation, area 6 is an area that has a great chance of a major earthquake occurring. When viewed from the number of earthquakes, this region has a fairly large frequency of earthquakes compared to other regions. Therefore, the b-value in this study depends on the seismic activity in the study area.

The level of seismic activity can be determined by calculating the peak ground acceleration value. The calculation of the peak ground acceleration value in this study uses an empirical formula model that is sought by using the Gaussian elimination application in the Inversion Problem. The empirical formula model obtained can be shown in Equation (8).

$$\log \alpha = -1.20543 \log R + -0.839093 M + 6.88858 \quad (8)$$

where α is the peak ground acceleration (gal), M is the magnitude, and R is the distance to the hypocenter (km).

In this study, the data matching process was carried out from the peak ground acceleration value obtained using a new empirical formula with the data recorded on the accelerograph. This matching process is carried out to get the RMS error value. The matching process is done by comparing the results measured on the accelerograph with the results of calculations from the empirical formula. The graph of the comparison of the peak ground acceleration value can be seen in Figure 4.

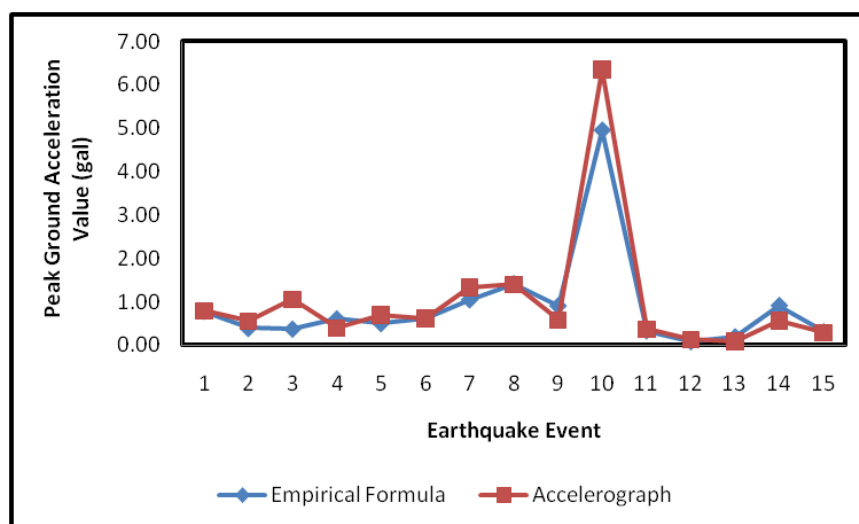


Fig. 4. Comparison of peak ground acceleration value from the Accelerograph with the empirical formula.

Figure 4 shows that the difference between the peak ground acceleration value recorded on the accelerograph and the value obtained using the new empirical formula is quite small. This is evidenced by the RMS error value of 0.438937. So, the possibility of error in the new empirical formula is quite small. The peak ground acceleration value in the province of West Sumatra based on the calculation results is in the range of 10.87-376.98 gal. The distribution map of the peak ground acceleration value in the province of West Sumatra is shown in Figure 5.

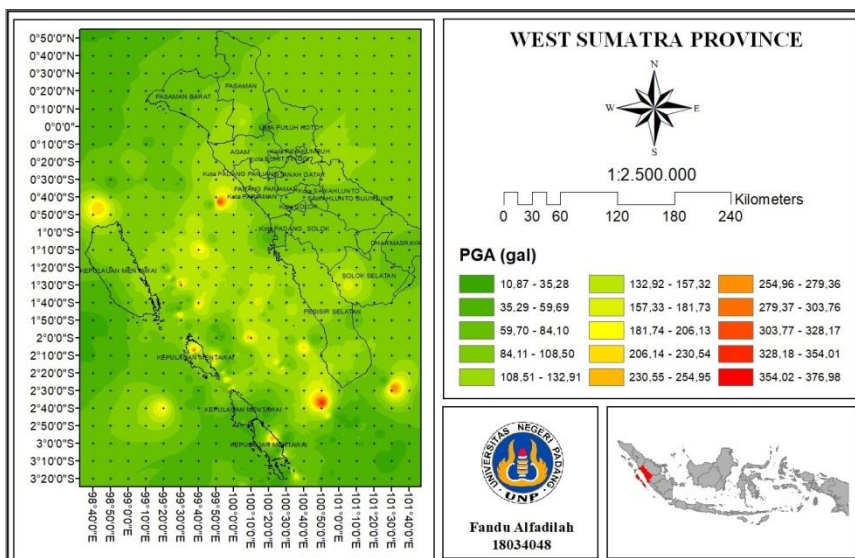


Fig. 5. Distribution map of the peak ground acceleration value in West Sumatra province.

Based on Figure 5, the cities or districts with the largest peak ground acceleration values are in the Mentawai Islands Regency, which is in the range of 84.11-328.17 gal. This is because the Mentawai Islands are near the epicenter of the earthquake, so they have a high peak ground acceleration value. When viewed from the tectonic condition, the Mentawai Islands Regency is in the Mentawai Fault Zone that extends around the sea of the Mentawai islands, so it can be a threat to the province of West Sumatra in the event of an earthquake. Then the lowest value is in Dharmasraya Regency, which is in the range of 10.87-35.28 gal. Apart from being far from the epicenter of the earthquake, Dharmasraya Regency also has a geological structure that is relatively safe from faults or earthquake paths.

The results of this study show the same thing as previous studies. Previous research showed that the highest peak ground acceleration value in the West Sumatra region using the 2007 - 2017 earthquake data period was in the Mentawai Islands Regency, namely 138.79 gals using the Mc. Guirre empirical formula, 348.31 gals using the Si and Midorikawa empirical formula, and 34.47 gals by using Donovan's empirical formulation [12].

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. The Mentawai Islands Regency and Padang City based on the results of the study have a fairly high peak ground acceleration value. Therefore, buildings built in the Mentawai Islands Regency and Padang City should have met the requirements for earthquake-resistant buildings, because they have a fairly high maximum ground acceleration value.

IV. CONCLUSION

The results of the b-value and peak ground acceleration (PGA) analysis in the province of West Sumatra using the maximum likelihood method and the empirical formula for the 2007-2020 earthquake data period can be seen that for the b-value due to an earthquake with a magnitude ≥ 5 SR and a depth of ≤ 100 km the value is in each region ranged from 0.8421-1.4477. Based on the map, the area that has the smallest b-value is in region 6, while the largest value is in region 2. Then for the peak ground acceleration value, the value is between 10.87-376.98 gal. Based on the city/district map, the highest peak ground acceleration value is in the Mentawai Islands Regency, which is in the range of 84.11-328.17 gal, while the lowest value is in Dharmasraya Regency, which is between 10.87-35.28 gal.

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