An Investigation of Seismicity for the West Sumatra Region Indonesia

S Syafriani
Department of Physics, Faculty of Mathematic and Natural Sciences, Universitas Negeri Padang, Indonesia
syafri@fmipa.unp.ac.id

Abstract. The purpose of this research was to investigate the seismicity of the West Sumatra region in the coordinates area of 94° E – 104° E and 2° N - 4° S. Gutenberg-Richer magnitude-frequency relation and seismic risk have been computed. Historical data of earthquakes used from year of 1970 to 2017 with magnitude higher than 4. The study area was divided into 8 sub-regions based on seismotectonic characteristics, plate tectonic and geological models. The determination of seismotectonic characteristics was based on the level of seismic activity in a region (a value) and rock stress condition (b value). High a value was associated with high seismic activity, whereas high b values were associated with low stress rock conditions, and vice versa. Based on the calculation results, a and b values were obtained in the interval of 5.5 - 11.3 and 0.7 - 2. The highest b value was obtained in the sub region 5 (Nias islands), while the lowest b value was obtained in sub region 7 (the Mentawai islands). The sub region 7, Mentawai Islands was indicated as the seismic risk potential areas.

1. Introduction
The Western Region of Indonesia is part of the Eurasian plate and also an active tectonic area since it is at the confluence of several large and small plates [1]. The collision of two large plates, the Indo-Australian and the Philippine plate controlled by the Eurasian plate led to a change in the strong lateral variations that reflect dynamic processes in the past to the present. The collision between the Indo-Australian and Eurasian plates varies annually, for example near Sumatra about 60 mm / year and 78 mm / year in the eastern Sunda arc [2]. In addition, the Indonesian archipelago is an unique physiography, trenches, arc-trench, gaps, gravity anomalies, volcanic arcs and a series of young mountains with characteristics of earthquakes depth spreads along the subduction zone, high seismicity as well as sequences active volcanoes.

West Sumatra became part of the dynamics of the plate structure area. This is characterized by the high level of seismicity in this region and the presence of a series of active volcanoes in the land area. Besides, this region is also traversed by active fault that formed along Sumatera Island, which is also the source of the cause of earthquake. Major earthquakes have been recorded several times in West Sumatera, in 1926, 1943 and 2007, in the form of shallow earthquakes in land area, while the 2009 earthquake was sourced in the ocean, which has the potential to generate tsunamis [3].

The high intensity of the earthquake that occurred in this region of West Sumatra, requires an understanding of the tectonic conditions of this region. Based on the earthquake that happened in the
past, it can be figured how is the condition of local tectonic stress and seismic activity of this region. Also the amount of energy that still contained in the rock can be determined.

The local stress condition of the rock in an area can be determined by calculating some values of seismotectonic parameters. Characteristics of seismotectonic parameters can be identified by looking at the spatial distribution of b-values and a-values in the region based on the frequency-magnitude distribution relationship (FMD). The value a represents the seismic activity level of a region, whereas the b-value reflects the tectonic conditions associated with the region's stress conditions. Based on spatial distribution of low-a value means low seismic activity and indicates the presence of energy accumulation (asperity) [4], otherwise for a high-a-value. Whereas the spatial high-b values are associated with low rock stress conditions [5], [6]. High b-values have high heterogeneity medium conditions, but low b-values correlate with high stress rock conditions and have low heterogeneity medium [7]. A region with high stress, stress has a b-value of 0.4-0.9, while under low stress conditions the b-value is about> 1.2 [8]. This seismotectonic parameter value information is used to investigate seismicity at region of West Sumatra.

Based on the information obtained from these seismotectonic parameters can be understood how the current condition of seismotectonic parameters of West Sumatra region. The current seismotectonic condition of West Sumatra is seen by comparing it with other seismotectonic parameters of the observation period. Another observation period used as a comparison here is the observation period 1980 - 2016 [9].

2. Data and Methods
Investigation of seismicity in West Sumatera is done by looking at the relationship between the seismotectonic parameters of earthquake events. This seimotectonic parameter is obtained from viewing the relationship of frequency-magnitude-distribution relationship that satisfies the equation as follows [9].

\[ \text{Log} \ N (M) = a - b \ M \]  \hspace{1cm} (1)

where \( N (M) \) = number of cumulative frequencies of earthquake with magnitude \( M \); \( a \) and \( b \) constants of seismotectonic parameters, showing the area and length of observation time and \( M = \) earthquake magnitude determined on the Richter scale. Statistically, \( b \) value indicates the slope of the log \( N \sim M \) of the straight-line equation that formed from equation 1. The value of \( b \) also indicates the heterogeneity of the medium where the high \( b \) value is associated with a low rock stress condition, and vice versa. Meanwhile, the high of \( a \) value is relates to seismic activity in a region.

The data used in this study was taken from the USGS/NEIC earthquake catalogues. The study area lies between latitude 2°LU and 4°LS and longitude 94°BT and 104°BT with depth of earthquakes less than 350 km and magnitude bigger than 4.0 SR. The data is also removed from foreshock and aftershock in the decluttering process. In addition, the cumulative number curve of earthquake is also plotted to determine the trend of earthquake events in a matter of years. The value of \( M_c \) is determined by plotting the earthquake frequency distribution curve. Meanwhile, spatial distribution analysis of seismotectonic parameters is digested by using gridding technique with a space of grid 0.1° x 0.1° with the expected number of earthquakes for each grid is \( N = 50 \).

3. Results and Discussion
For this study, all earthquakes in the periods of 1970-2017 have been used. The amount of data that has been through the process of the cluster into 4728 events. The seismicity of the West Sumatera region are shown Figure 1. The density of seismicity of West Sumatera is most visible around the island of Nias (Zone 5), south of Siberut Island, around the Mentawai Islands (Zone 7), along the active fault zone of Sumatra and also in the subduction path. This high seismic density was caused by tectonic activity beneath Sumatra island. These tectonic activities include subduction zones located in the western part of Sumatra Island and stretching along its coastline, also the active fault activities
such as the Mentawai fault, and Sumatran Fault. Most of the earthquakes caused by the subduction zone and the active fault of Sumatra.

The tendency of earthquake occurrence in West Sumatera is shown by the cumulative number curve in Figure 2. This cumulative number shows the occurrence of earthquake with time for data that has been done declustering process. The trend of earthquake events increases from year to year, as can be seen in figure 2. In period between 1971 and 2005 there was little change in seismic activity, whereas after 2005 seismic activity changed significantly. Figure 3 shows the earthquake frequency distribution curve in West Sumatera region. The value of Magnitude Completeness (Mc) in the West Sumatra region according to the catalog used is 4.5. This indicates that the earthquake catalog used to record well the earthquake with the smallest magnitude of 4.5 in the region of Sumatra.

The spatial distribution of b-values for the observation period in this study, 1971-2017 can be seen in Figure 4. The low-b values was represented by blue. The low b-values are in the south of Nias Island, subduction lines, and south of Siberut Island. These three areas are seismic zones (regime stress) are quite dynamic and has the potential to cause significant and destructive earthquake. A region with a low-b value is an active seismic area that is still locked called a locked zone. Locked zone can someday bring significant and destructive earthquakes. Thus, areas with low-b values as mentioned above need to be aware of significant earthquakes. While areas with a high b-value as seen in the north of Nias Island are referred to as creeping zones, are active fault zones that do not experience energy.
accumulation and do not experience slippage. This is in accordance with previous research that low b-values are associated with rock stress conditions in the area high, and vice versa.

Figure 4. Spatial Distribution Map of b-values in West Sumatra in the observation period from 1971 to 2017.

Figure 5. Spatial Distribution Map of a-values in West Sumatra in the observation period from 1971 to 2017.

The spatial distribution of a-values for the observation period in this study 1971-2017 can be seen in Figure 5. The low a-values represented by blue that clearly seen in the area around the subduction path, south of Nias Island, and south of Siberut Island. Areas with low a-value are indicated to have relatively low seismicity. This low level of seismicity indicates the accumulation of energy (asperities) in the area. Low seismicity or low seismic activity is associated with a low a-value spatial distribution. Areas with low seismic activity that potentially significant earthquakes will be happened. Low seismic activity means the accumulation of energy in the region was doing. In west Sumatra region, the area that has high quake level are north of Nias Island. This condition is in accordance with the spatial distribution of earthquake density of West Sumatra as shown in Figure 6 and the distribution of Magnitude of Completeness (Mc) in Figure 7.

Figure 6. Earthquake density in West Sumatra Region in period time 1971 to 2017

Figure 7. Magnitude Distribution of Completeness (Mc) in the observation period from 1971 to 2017.

The distribution of magnitude completeness (Mc) values in West Sumatera shows that the area around the Nias Island is dominated by an earthquake with magnitude between 4.5 - 4.8 SR. The area around Batu island is dominated by a magnitude 4.8 - 4.9 SR, as well as the area around Siberut Island, the earthquake that often happens with magnitude 4.2 - 4.6 SR. Variations of Mc values were analyzed
using the position of the recording station used. In addition, other factors that affect the variation of Mc values are real time data from the earthquake recording station.

4. Conclusion
In this paper, the spatial distribution of a-values and b-values in West Sumatra and surrounding areas, proposed. It is found that significant areas of potential earthquake are Siberut Island and Southern part of Nias Island. Although the b-value in this area during this period is still higher than in the previous period. This area still needs to be wary of significant and destructive earthquakes as the overall b-value of this region is still low that mean the potentially significant and damaging earthquake in the future. The distribution of density of earthquake in this area also figured and found that the highest seismic density was Nias Island. This is because in this area often occur small earthquake.

Acknowledgement
This work was supported DIPA Universitas Negeri Padang Tahun Anggaran 2017 no. 1649/UN35.2/PG/2017. We also thank the operators of the BMKG and USGS-NIED data for making their earthquake catalog.

References
[1] Natawidjaja, D.H., and W. Triyoso. (2007) The Sumatran fault zone: from source to hazard, 1 (No.1), 21-47.
[2] Putra, R.R., Kiyono, J. Shaking Characteristic of Padang City, Indonesia . Graduate School of Engineering, Kyoto University, Japan . Ono Y. Department of Urban Social System and Civil Engineering, Tottori University, Japan . 15 WCEE. LISBOA 2012
[3] Wiemer, S., (2001), A software package to analyze seismicity: ZMAP. Seismological Research Letters, 72(2):373–382.
[4] Katsumata, K. 2011. A Long Term Seismic Quiescence Started 23 Years Before The 2011 of The Pacific Coast Of Tohoku Earthquake (M=9.0). Earth Planet Space. 63.709-712.
[5] Sunardi, Bambang dkk. 2013. Analisis Periodesitas dan Perubahan Tingkat Kegempaan Wilayah Jawa Barat Berbasis Statistik. Conference Paper. BMKG Pusat.
[6] Rohadi, dkk. (2007). Variasi Spasial Seismsitas di Zona Subduksi Jawa. Jurnal Meteorologi dan Geofisika. Vol. 8 No.1 Juli 2007 : 42 – 47.
[7] Scholz, C.H. 1968. The frequency-magnitude relation of microfracturing in rock and its relation to earthquakes, Bull. Seis. Soc. Amer., 58, 399- 415.
[8] Wyss, M., S. Wiemer, and S. Tsuboi. 1973. Mapping b-value anomalies in the subducting slabs beneath Japan, using the JUNEC data, Bull. Seism. Soc. Am., submitted.
[9] Gibowicz, S.J. 1973, Variation of the frequency-magnitude relation during earthquake sequence in New Zealand, Bull. Seimol. Soc. Am, 63, 517 – 528.