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Seismotectonic Analysis and Seismic Potensial of the Sumatra Region Using the Guttenberg-Richter Method

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Abstract: Sumatra is one of the most seismically active regions of Indonesia. This is due to the presence of subduction zones and active faults that influence plate tectonic activity in this region, resulting in many earthquakes that cause damage and loss. One of the efforts to mitigate earthquake disasters is the analysis of seismotectonic parameters, which are indicated by the a-value and b-value of the Gutenberg-Richter equation in the earthquake frequency-magnitude relationship. Low seismotectonic parameters (a-value) and (b-value) can be interpreted as low seismic activity and high local rock stress conditions, and vice versa (a-value) and (b-value) are high. In orderto maximize disaster mitigation efforts, mapping, monitoring, information dissemination, socialization and counselling as well as earthquake early warning can be carried out in the research area. In this study, the spatial and temporal analysis was performed from the National Earthquake Information Center United States Geological Survey (NEISUSGS) earthquake catalogue. The data obtained in the form of longitude, latitude, depth, magnitude, time and location of the earthquake event, the data are limited to $M \geq 4.0$Mw and depth ≤ 350KM in the Sumatra region with restrictions of 6030'LU-6°30'LS and 94BT-106°BT for the period 1990-2022. Based on the estimation results of the Guttenberg-Richter method in ZMAP v6 software, the value of b is 0.92-1.04 and the value of a is 7.42-7.97, with a return period of 6.5 Mw earthquakes generally ranging from 5-25 years.

Keywords: Seismotectonics, Active Seismicity, Earthquake, a-value, b-value.

1. Introduction

Indonesia is one of the countries that are prone to potential earthquake disasters. This is because Indonesia is located at the confluence of three tectonic plates of the earth, namely the Indo-Australian Ocean plate, the Eurasian continental plate and the Pacific plate [1].

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These tectonic plates have a type of convergent boundary plane that forms subduction zones in the Indonesian Ocean as a result of the interaction between the Indo-Australian plate moving northwards and the Eurasian plate moving southwards.

Based on its seismotectonic setting, the island of Sumatra is part of a very active arc and active arc seismotectonic unit. This is because Sumatra lies within three active seismic zone systems of the Earth, namely the subduction zone, the Mentawai fault zone and the Sumatra fault zone [2]. The Sumatra Fault Zone is a zone that extends from the northern part of Sumatra (Aceh) to Semangko Bay (Lampung), the Mentawai Fault Zone is around the small islands in the northwestern part of Sumatra, and the Subduction Zone is around the northwestern part of Sumatra [3].

Based on the historical record of tectonic activity in the region, Sumatra has experienced several significant earthquakes due to plate and fault activity, including the Aceh-Andaman earthquake (2004, Mw 9.1 SR), the Nias - Simelue earthquake (2005, Mw 8.7 SR), the Pariaman earthquake (2009, Mw 7.6 SR) and the Mentawai earthquake (2010) [4]. This series of two large earthquakes that occurred in the northern part of the Sumatra subduction megathrust zone is the Mentawai fault [5]. Major earthquakes on the Mentawai fault occurred in 1797 (Mw 8.4) and 1833 (Mw 8.9). These large earthquakes generated large tsunamis that struck the coast of West Sumatra and Bengkulu. It is also a fact that in the 1300s and 1600s there were large earthquakes similar to the one in 1833. This suggests that the Mentawai megathrust has an earthquake cycle of about 200 years [6].

The high level of tectonic activity that has occurred in Sumatra can be demonstrated by performing a seismic analysis as an indicator of the potential for earthquakes to occur in Sumatra. This analysis can be done by correlating the frequency-magnitude distribution (FMD) using the Guttenberg-Ricther method. This method is one way of investigating seismic activity in the Sumatra region [7]. By analysing the frequency-magnitude distribution, the spatial variation of the tectonic parameters a-value and b-value of a region is obtained. Variations in a-value and b-value are seismotectonic parameters that can determine the level of seismicity of a region. The a- value can describe the level of seismic activity in a region [8], while the b-value reflects the tectonic conditions associated with rock stress in a region [9]. These seismotectonic parameters are based on the relationship between the frequency of the cumulative amount of catalogue data and the magnitude of the earthquake [10].

According to seismologists, the spatial distribution of low b-value tectonic parameters reflects high local rock stress conditions and, conversely, the spatial distribution of high b-value tectonic parameters reflects low local rock stress conditions. Meanwhile, the spatial distribution of low a-value tectonic parameters reflects a low level of seismicity, and conversely a high a-value spatial distribution reflects a high level of seismicity [11]. In seismological statistical terms, a measure of the level of seismicity of a region is known, and this measure is determined from the variation of the a-value and b-value. The b-variation is the logarithmic slope of the cumulative frequency of earthquakes with respect to magnitude, based on the Gutenberg-Richter relation $\log N(M) = a - bM$ [12].

As for temporal variation of b-values, the sliding time window method is used. A number of earthquakes are selected from a catalog, then the b-value is calculated for a number of earthquakes (N). Then the window is shifted with a fixed number of earthquakes and then the b-value is calculated for the next number of earthquakes and the process is repeated until the last earthquake [13].

Considering the high seismic activity and the number of large earthquakes that occur in the Sumatra region, a study entitled Seismotectonic Analysis and Potential Seismicity of the Sumatra Region with the Gutenberg-Richter Method in the earthquake frequency-magnitude relationship was conducted, which is useful for analysing, studying, mapping vulnerable areas and potential earthquakes in understanding seismotectonic parameters as information and first steps in earthquake disaster mitigation issues in the Sumatra region and can reduce the impact of earthquake damage.

2. Materials and Method

This type of research is a descriptive research including earthquake data collection in the form of historical or secondary earthquake data values obtained from the US Geological Survey National Earthquakes Information Center (NEIC USGS) catalogue and BMKG centre, which occurred in the Sumatra region, covering the boundaries of 6°30'LS - 6°30'LU and 94° BT - 106° BT, earthquake data used is during the period 1990 to 2022 with magnitude (M>4.0 SR) at depth (h<350 Km) using the Guttenberg- Richter method.

The Guttenberg-Richter method uses the earthquake frequency-magnitude distribution relationship,which is a linear relationship influenced by seismotectonic parameter constants [14]. This frequency- magnitude distribution relationship satisfies the following equation:

$$\text{Log } N\ (M) = a - b\ M \qquad (1)$$

where N (M) = number of cumulative frequencies of earthquake catalogues by magnitude, M= earthquake magnitude, and a and b are constants of seismotectonic parameters.

The a-value constant is a seismotectonic parameter that expresses the seismic activity of a region [15]. While the constant b-value is a seismotectonic parameter. According to Scholz in Bambang Sunardi's research, the b-value depends on the characteristics of tectonic rocks and the level of rock stress of an area [15]. Areas with a low b-value (level of rock fragility) and low seismic activity (a-value) are more likely to occur earthquakes. Conversely, if the b-value is high and the a-value is also high, the strength of the earthquake released will be low [16].

To determine the seismotectonic parameters (a-value) and (b-value), the maximum likelihood methodis used where the b-value is obtained using the equation [17]:

$$b = \frac{\log e}{M^{-} - M_{min}} \qquad (2)$$

If log e = 0.434, $\bar{M}$ = the mean magnitude and M0 = the minimum magnitude, then the a-value is obtained by the equation:

$$a = \log N\ (\bar{M} \geq M_0) + \log (b \ln 10) + M_0 b \qquad (3)$$

Data processing was carried out in several stages, including: classification of the earthquake catalogue data into parameters such as: latitude, longitude, year, month, date, magnitude, depth, hour and minute. Next, the magnitude scale of the earthquake data was converted from body magnitude (Mb) to momentmagnitude (Mw) [8]. The earthquake data are then declustered to map the distribution of seismicity [18]. The next step is to plot the cumulative frequency-magnitude distribution curve of the earthquake catalogue and then to analyse the spatial and temporal variation of the seismotectonic parameters by defining an area of constant radius of 110 km with a grid system where the distance of each grid is 0.1° x 0.1° and enteringthe value of the minimum number of earthquakes in each grid, which is calculated as 30 earthquakes withthe fixed Mc value obtained. It is then processed using Zmap software version 6.0 and the mapping is done on Arcgis 10.8 software.

$dccd$

3. Results and Discussion

Data obtained from the USGS earthquake catalogue for the Sumatra region in the period 1990 to 2022 with the boundaries of the region 6°30'LS - 6°30'LU and 94°BT-106° BT, obtained earthquake data as many as 10880 earthquake events and seismic activity in the Sumatra region. The Sumatra region, where the value of spatial seismotectonic parameters a-value and b-value will be determined, is divided into 3 (three) researchareas based on latitude-longitude coordinates as shown in Table 1.

Table 1. Research Area Coordinate Boundary

Region	Research Areas	Coordinate boundary
Region I	6.30° LU - 2.01° LU and	94° BT – 106° BT
Region II	2.00° LS - 2.00° LU and	94° BT – 106° BT
Region III	2.01° LS – 6.30° LU and	94° BT – 106° BT

From the table, the seismicity map of the earthquake that occurred in the study area can be displayed. This seismicity map illustrates the distribution pattern of seismic activity in the three regions of Sumatra as shown in Figure 1.

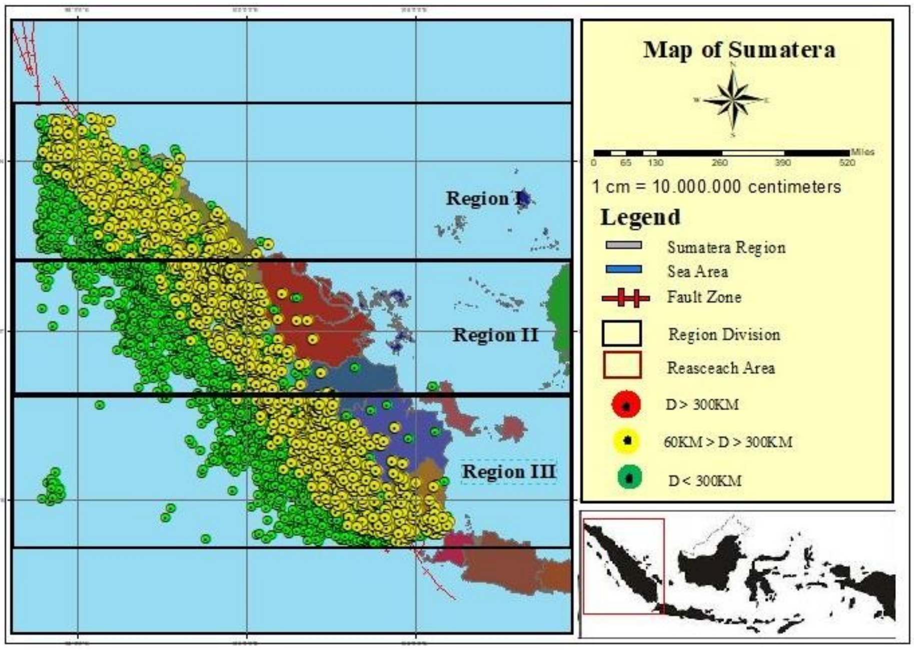


Figure 1. Map of Seismicity in Sumatra from 1990-2022.

The data obtained were 10880 earthquakes, the declustering process of the catalogue data used was Reseanberg declustering, the data declustering aims to make the earthquake data obtained are the main earthquakes and eliminate the initial and aftershock data, so the number obtained is 8738 earthquake data. In addition to the earthquake data declustering process, the earthquake data conversion process was also carried out from body magnitude (Mb) to moment magnitude (Mw), this was done because this magnitude is saturated on a higher scale compared to other magnitudes.

Based on the results of the earthquake data declustering, a graph of the cumulative number of earthquakes that have occurred in the study area is obtained, as shown in Figure 2.

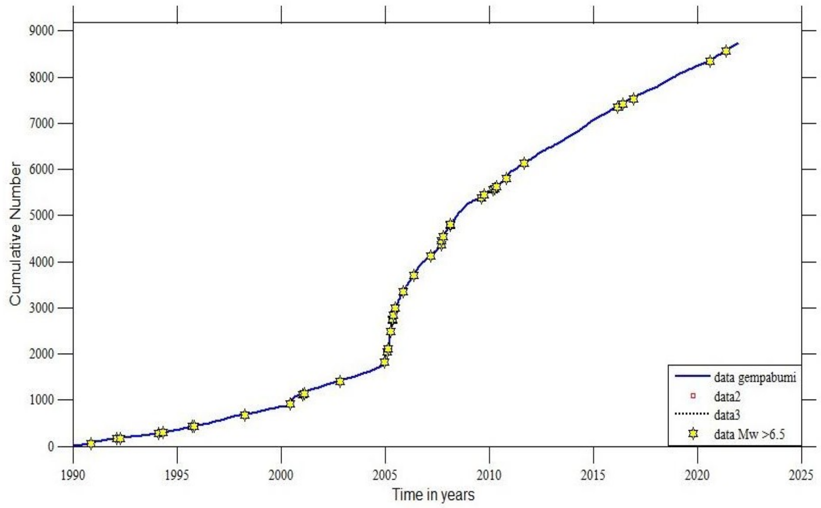


Figure 2. Graph of the cumulative number of earthquakes in the three regions of Sumatra from 1990 to 2022.

Based on Figure 2, we can see the cumulative plot of seismicity that has occurred in the study area, this cumulative plot illustrates the increase in the cumulative number of earthquakes that is relatively steady, meaning that there are increases and decreases. However, the figure shows that there was an increase in earthquake activity in 2005 due to the earthquake in the Aceh region on 26 December 2004, so there was a lot of data added to the catalogue. From 1990 to 2022, there were earthquakes marked with yellow stars indicating large magnitude earthquake events with M ≥ 6.5, which means that in this study there were 53large earthquake events with magnitudes greater than 6.5. An earthquake magnitude histogram is also obtained based on the results of deckulstering the earthquake data, as shown in Figure 3.

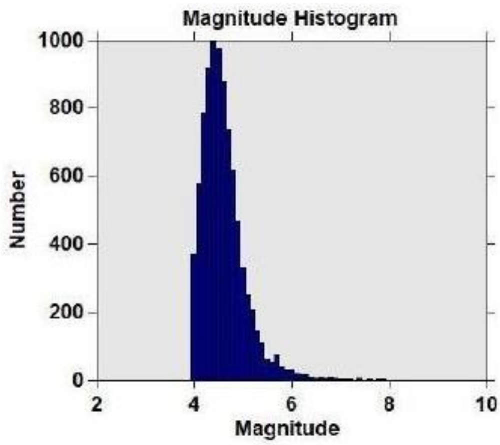


Figure 3. Histogram of the magnitude versus the number of earthquakes in the USGS NEIC catalogue(1990-2022).

Figure 3 shows that the magnitude of earthquakes in the study area ranges from the smallest of 4.1 Mw to the largest of 7.9 Mw. Earthquakes with a magnitude of 4.1 - 5.5 Mw dominate the seismicity, with a total of about 9229 earthquakes, which is 84% of the total earthquakes, which belong to the type of moderate and even destructive earthquakes. Earthquakes with a magnitude of 5.6 - 7.9 Mw, on the other hand, account for only 1651 earthquake events.

Based on this, a frequency-magnitude distribution (FMD) analysis was performed, which describes the distribution of the catalogue distribution of how magnitude relates to the cumulative number of earthquakes occurring in the study area. The most important parameter in determining the b-value and a-value is the magnitude completeness (Mc), which requires an accurate description of the local Mc, since Mc varies greatly in the study area. The Mc value itself is used to spatially explore the b-value and then discard earthquake catalogues with values less than the MC value [19]. b-value describes the degree of rock fragility or tectonic parameters, while a- value describes tectonic activity. The red line indicates the slope, ∆ is the frequency of data from the USGS earthquake catalogue, while □ indicates the cumulative frequency.

Based on this, we analysed the frequency-magnitude distribution of earthquakes in each region of Sumatra. The cumulative plot of the earthquake frequency-magnitude distribution in Region I is shown in Figure 4.

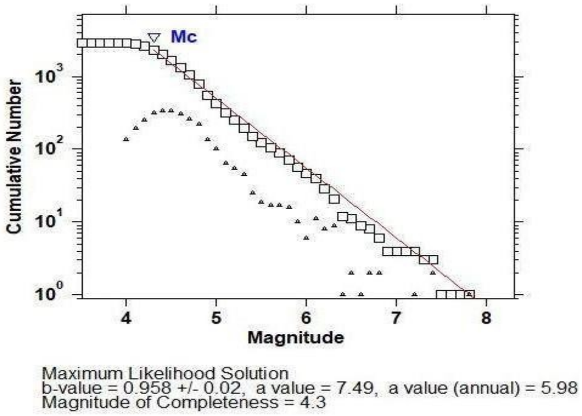


Figure 4. Graph of the frequency-magnitude distribution in Region I Sumatra

Based on Figure 4, Region I has an a-value of 7.49. This shows that in general the level of seismic activity in Region I is quite high and for the b-value obtained is quite low at 0.958, meaning that in general in Region I the stress conditions in the area are not too high and magnitude completeness is obtained around 4.3 SR. This magnitude value shows the largest magnitude recorded in the earthquake data catalogue during the observation period. In addition, a cumulative plot of the distribution of the frequency and magnitude of the earthquakes in Region II can be seen in Figure 5.

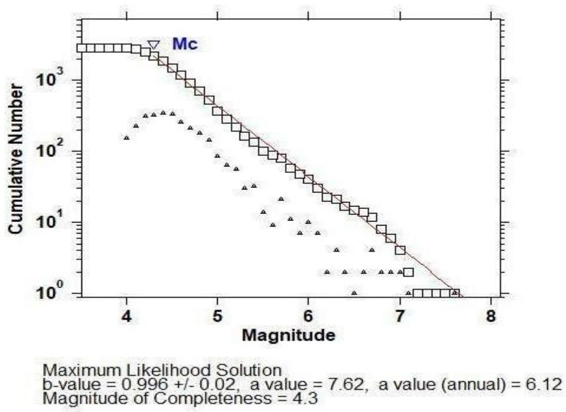


Figure 5. Graph of the frequency-magnitude distribution in Region II Sumatra

Based on Figure 5, Region II obtained a relatively high a-value of 7.62, this means that the level of seismicity in Region II is quite high and the b-value results that occur also look high at 0.996, so it can be interpreted that Region II has a fairly low local stress condition. The magnitude completeness value is 4.3 SR, this magnitude value can be interpreted as the largest magnitude that occurs and is recorded in the earthquake data catalogue during the observation period.

In addition, a cumulative plot of the distribution of the frequency and magnitude of the earthquakesin Region III can be seen in Figure 6.

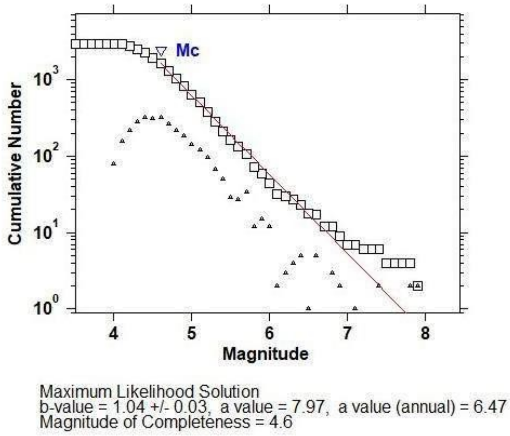
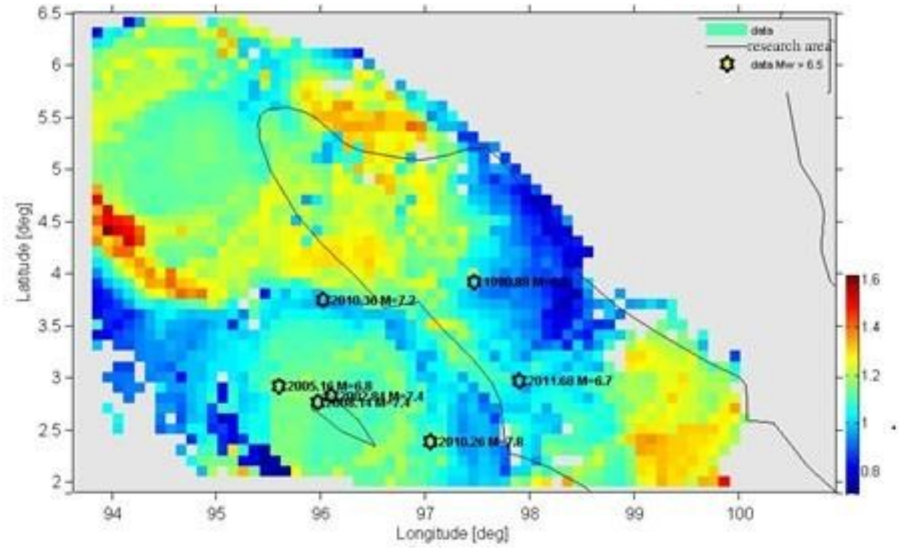


Figure 6. Graph of the frequency-magnitude distribution in Region III Sumatra.

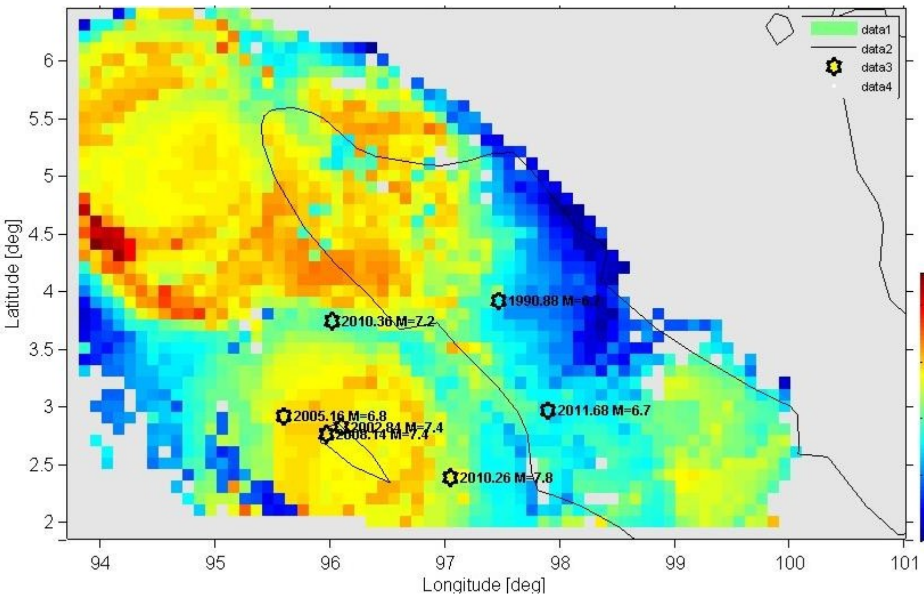
Based on Figure 6 cumulative plots in Region III, the a-value parameter produced is relatively high at 7.97. This means that Region III has a high level of seismicity and the results of the b-value also look high more than one, which is 1.04, so it can be interpreted that Region III has a fairly low local stress condition. The magnitude completeness value obtained is 4.6 SR, this magnitude value can be interpreted as the largestmagnitude recorded in the earthquake catalogue data in the study area.

The number of parameters obtained in this study depends on the number of events and, for certain regions, on the determination of the volume and time window. After estimating the b-value, a-value andMc-value, the spatial distribution of b-value and a-value variations was analysed to identify areas of low andhigh rock fragility and tectonic activity.

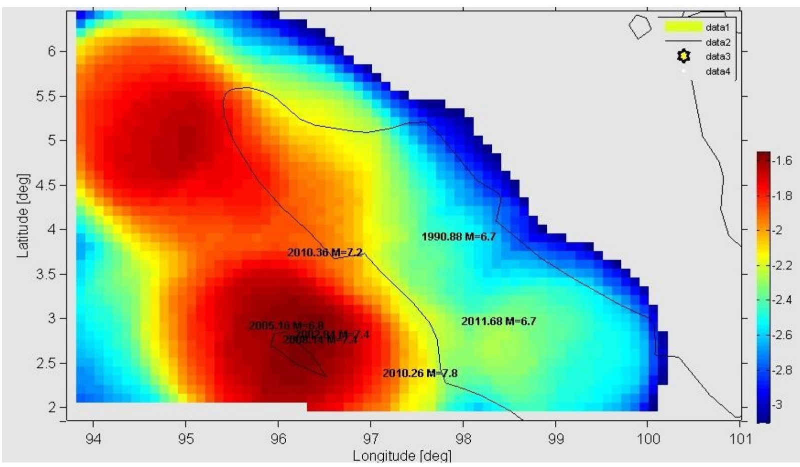
Based on this, the spatial variation of a-value and b-value seismotectonic parameters is mapped in Region I, which includes Andaman, Banda Aceh, Meulaboh, Lhokseumawe, Sibolga, Langsa, Aceh South Sea, Simeuleu Island, Pagai Island, Enggano Island, Nias and Medan. Region II includes Nias Island, Mentawai Islands, Pesisir Selatan, Padang, Pasaman, Pariaman and Bukittinggi. Region III includes the coastal areas of Mukomuko, Jambi, Sungai Penuh, Mentawai Islands, Sumatra coast, Lubuk Linggau and Bengkulu. The mapping of the spatial variation of a-value, b-value, earthquake density, return period ofmagnitude ≥ 6.5 SR and standard deviation in Region I can be seen in Figure 7.


data
research area
data Mw > 6.5
Latitude [deg]
Longitude [deg]
2010.36 M=7.2
2005.16 M=6.8
2011.68 M=6.7
2010.26 M=7.8

(a)


data1
data2
data3
data4
Latitude [deg]
Longitude [deg]
2010.36 M=7.2
2005.16 M=6.8
2011.68 M=6.7
2010.26 M=7.8

(b)


data1
data2
data3
data4
Latitude [deg]
Longitude [deg]
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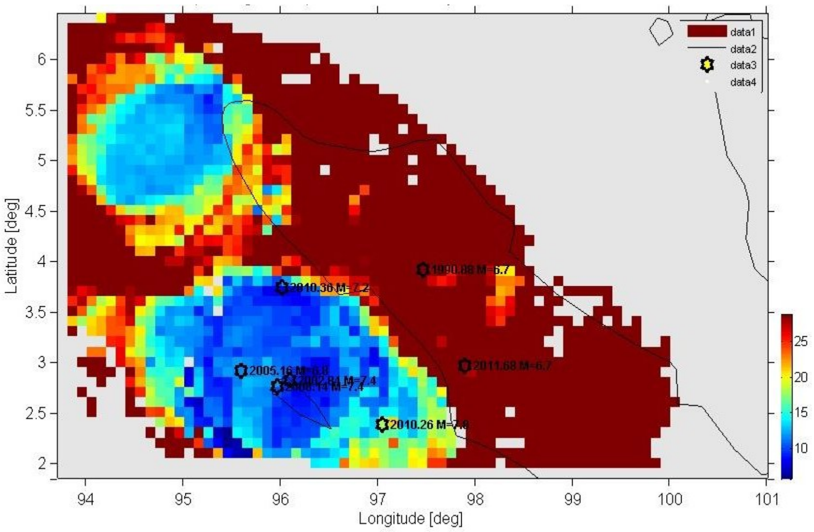
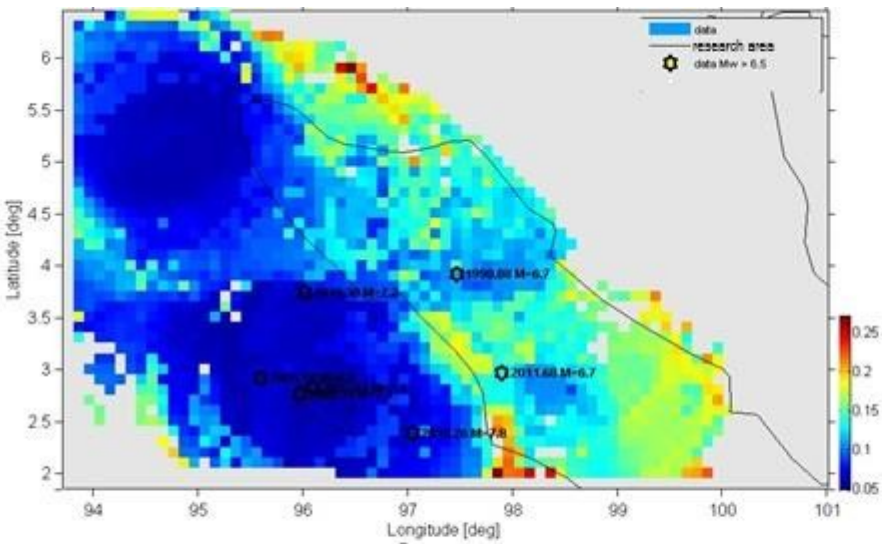
2010.36 M=7.2
2005.16 M=6.8
2011.68 M=6.7
2010.26 M=7.8

(c)



(d)



(e)

Figure 7. (a) Spatial distribution of b-value, (b) Spatial distribution of a-value, (c) Earthquakes density map, (d) earthquake return period, and (e) standard deviation of b-value.

Figure 7 is the result of spatial analysis of seismotectonic parameters (a-value, b-value, earthquake density, return period and standard deviation) occurring in Region I. Based on the results of spatial b-value study (Figure 7a), it can be seen that the spatial variation of b-value is in the range of 0.8 to 1.6. Low spatial variation of b-value is observed in Meulaboh, Lhokseumawe, Langsa and South Aceh Sea with spatial variation of b-value around 0.8 to 1.1. Meanwhile, relatively high spatial variation of b-value is observed in Andaman Sea, Banda Aceh, Sigli, Simeulue and Medan with b-value ranging from 1.2 to 1.6.

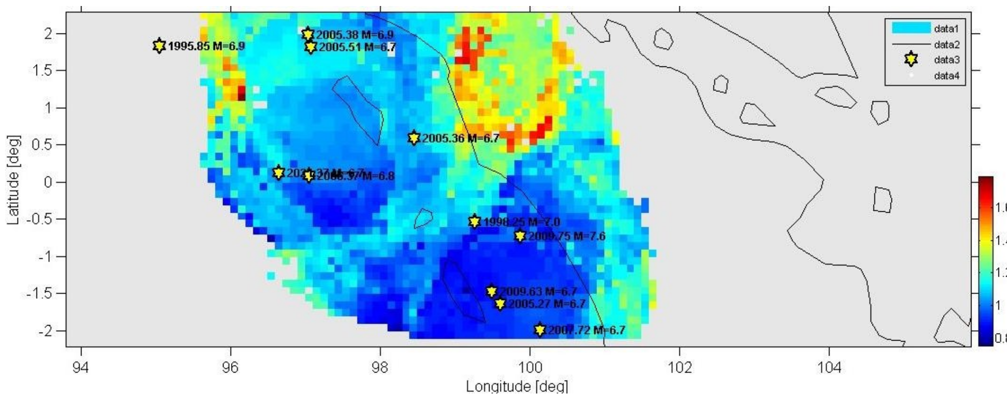
Based on Figure 7b, it can be seen that the spatial variation of a-value in Region I ranges from 5.0 to 9.0. Low spatial variations of a-value ranging from 5.0 to 6.0 occur along the northern part of Aceh and the southern sea of Sumatra. Then, for high a-values, spatial variations occur in the Andaman Sea, Simeulue,Medan and Banda Aceh with a-values ranging from 7.0 to 9.0.

From Figure 7c it can be seen that the spatial variation of the seismotectonic parameters of seismicdensity indicates the existence of a seismic gap zone in the area between Simeulue Island and the Andaman Sea, which must also be monitored as a zone with the potential for large earthquakes. The phenomenon of earthquake emptiness in this region may also be the result of a weakness in the earthquake parameter analysisprogramme, which never has an epicentre latitude of exactly zero.

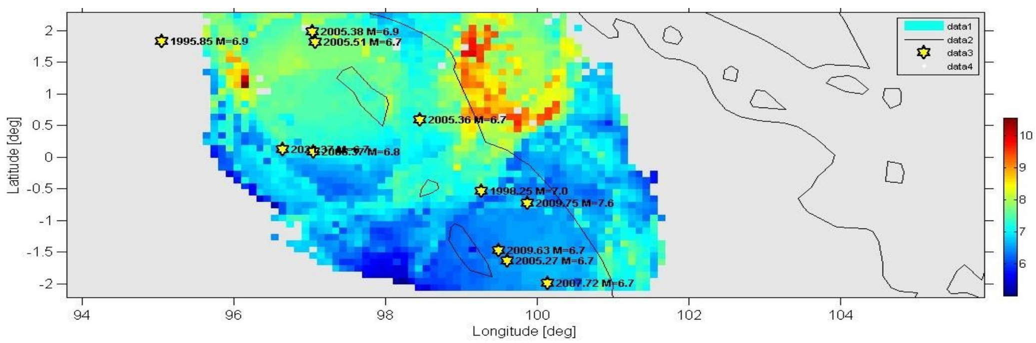
Figure 7d shows that magnitude 6.5 earthquakes in Region I have different return periods, rangingfrom about 8 to about 25 years. The 8-15year return period covers the islands of Simeulue and Banda Aceh. The 16-25year return period covers the Andaman Sea, Aceh and Medan. Short return periods tend to correlate with low b and a- values. Short earthquake return periods correlate with areas of relatively highseismic activity.

Based on Figure 7e, it can be seen that the standard deviation map that occurs in Region I Sumatra,obtained the results of calculating the standard deviation of b-value in the range of values 0.0 - 0.25. The high and low value of the standard deviation can show the size of the spread of earthquake events that occur, to avoid this, adequate data is needed to determine the level of rock fragility (b-value) that occurs in Region I.

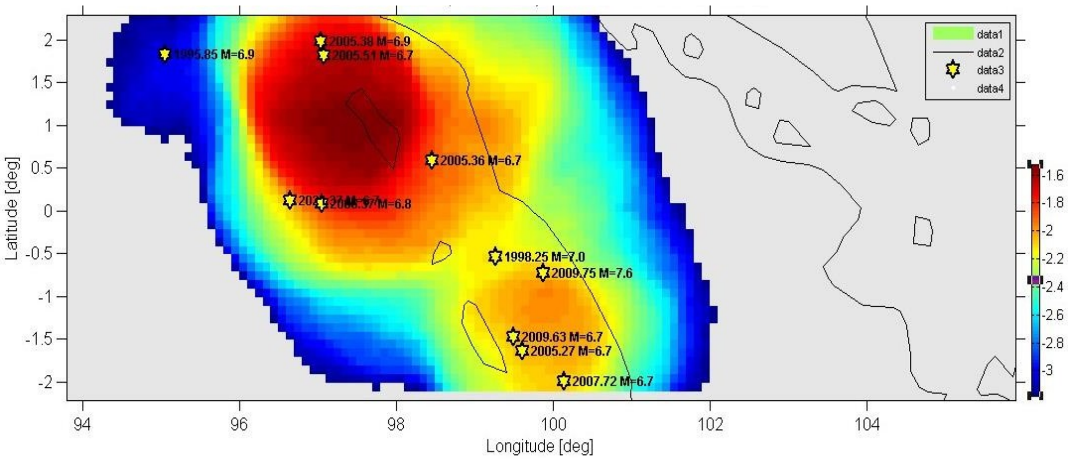
Furthermore, the mapping of spatial variations of seismotectonic parameters of spatial variations of a- value, b-value, earthquake density, return period of magnitude ≥ 6.5SR and standard deviation to identifyareas of high rock fragility and high tectonic activity in Region II can be seen in Figures 8.



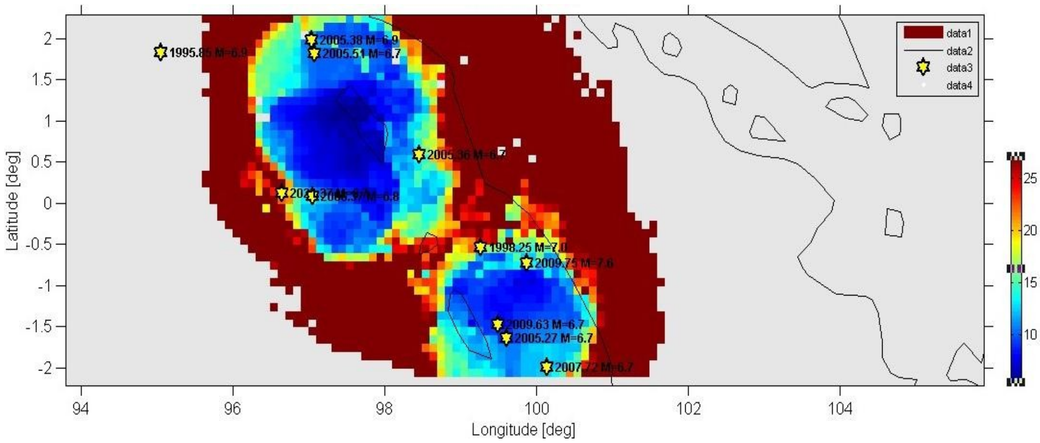
(a)



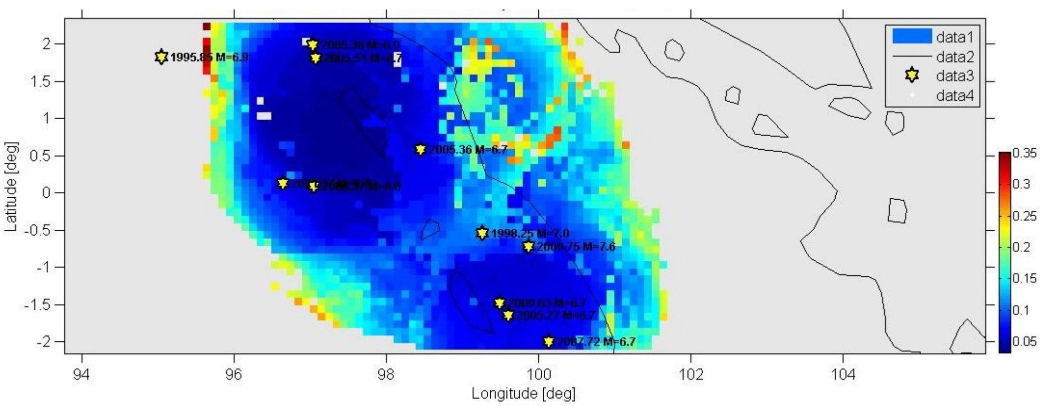
(b)



(c)



(d)



(e)

Figure 8. (a) Spatial distribution of b-value, (b) spatial distribution of a-value, (c) earthquake density map, (d) earthquake return period, (e) standard deviation of b-value.

Based on Figure 8, which is the result of spatial analysis of seismotectonic parameters (a-value, b-value,earthquake density, return period and standard deviation) occurring in Region II. Based on the results of the spatial b-value study shown in Figure 8a, it can be seen that the spatial variation of b-value is in the rangeof values from to 1.7. Low spatial variation of b-value is observed in Nias Island, Mentawai, Padang, Pasaman andBukittinggi with spatial variation of b-value around 0.8 to 1.0. While the relatively high spatial variation of b-value is observed in the western sea part of Nias Island, West Pasaman, Pesisir Selatan, Padang Sidempuanand Padang Lawas with b-value ranging from 1.3 to 1.7.

Based on Figure 8b, the spatial variation of a-value in Region II ranges from 5.0 to 10.0. Low spatial variations of a-value ranging from 5.0 to 6.5 occur along the northern part of Aceh and the southern sea of Nias Island, Mentawai, Padang, Pasaman and Bukittinggi. Then for high a-value spatial variations occur in parts, Nias Island, North Nias Island Sea, West Pasaman, South Coast, Padang Sidempuan and PadangLawas with a-values ranging from about 7.5 to 10.0.

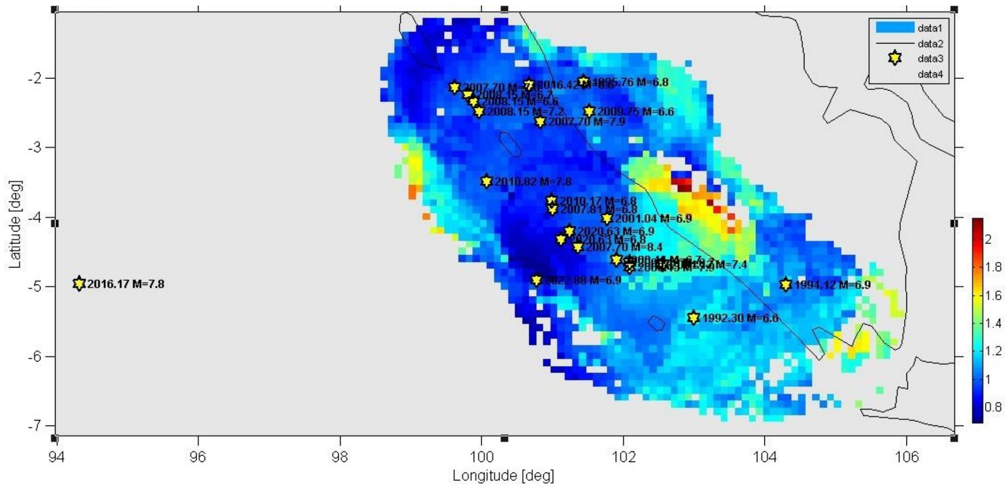
Based on Figure 8c, it can be seen that the spatial variation of seismotectonic parameters of seismic density indicates that there is a seismic gap zone in the area between Batu-Batu and Mentawai Islands, which also needs to be monitored as a potential large earthquake zone. The earthquake gap phenomenon in this region may also be a result of the weakness of the earthquake parameter analysis programme, which never has an epicentre latitude of exactly zero.

The b-value has a clear relationship with the stress within a rock volume. In his experiments he observed that a decrease in b-value corresponds to an increase in stress in the rock [20]. Recent work on various global and regional catalogues has shown that the b-value is significantly lower for thrust earthquakes than for normal and strike-slip faults [21]. Since the fault type is directly generated by the orientation and magnitude in the stress regime of a region, this proves that stress has an influence on the b-value.

Figure 8d shows that magnitude 6.5 earthquakes in Region II have different return periods, ranging from about 6 to about 26 years. The return period of about 6-15 years covers the islands of Nias and Mentawai. The return period of about 16-25 years covers the islands of Batu, Padang, Pesisir Selatan and the western sea of Mentawai. Short return periods are usually correlated with low b and a-values. Short earthquake return periods correlate with areas of relatively high seismic activity.

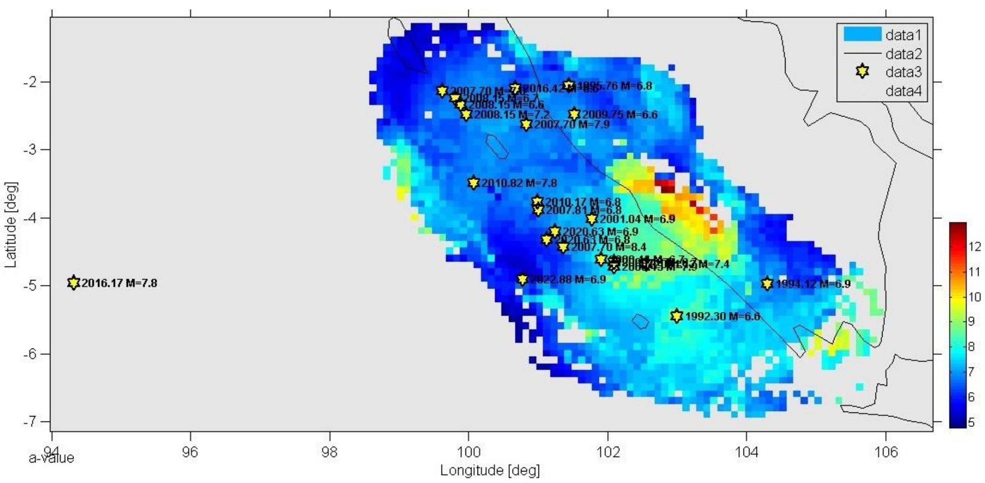
Based on Figure 8e, it can be seen that the standard deviation map that occurs in Region I Sumatra, obtained the results of calculating the standard deviation of b-value in the range of values 0.05-0.35. The high and low value of the standard deviation can show the size of the spread of earthquake events that occur, to avoid this, adequate data is needed to determine the level of rock fragility (b-value) that occurs in Region II.

Furthermore, the mapping of spatial variations of seismotectonic parameters of spatial variations of a- value, b-value, earthquake density, return period of magnitude ≥ 6.5SR and standard deviation to identify areas of high rock fragility and high tectonic activity in Region III can be seen in Figures 9.



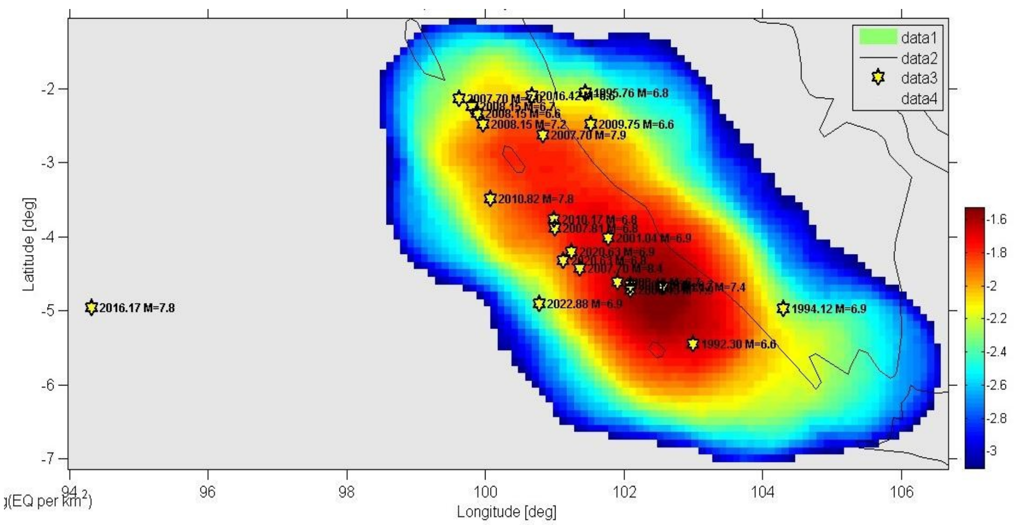
Latitude [deg]
Longitude [deg]
data1
data2
data3
data4
2016.17 M=7.8
2010.82 M=7.8
2009.75 M=6.6
2007.70 M=7.9
2001.04 M=6.9
1992.30 M=6.8
1994.12 M=6.9

(a)



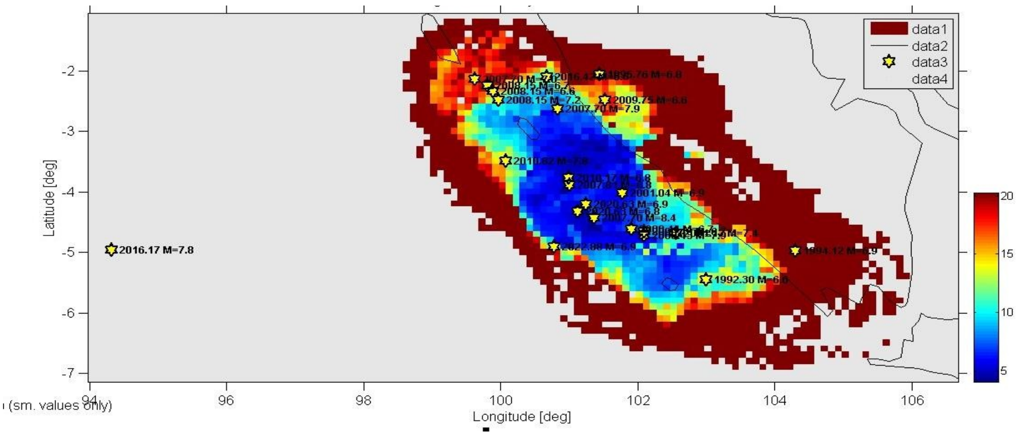
Latitude [deg]
Longitude [deg]
a-value
data1
data2
data3
data4
2016.17 M=7.8
2010.82 M=7.8
2009.75 M=6.6
2007.70 M=7.9
2001.04 M=6.9
1992.30 M=6.8
1994.12 M=6.9

(b)

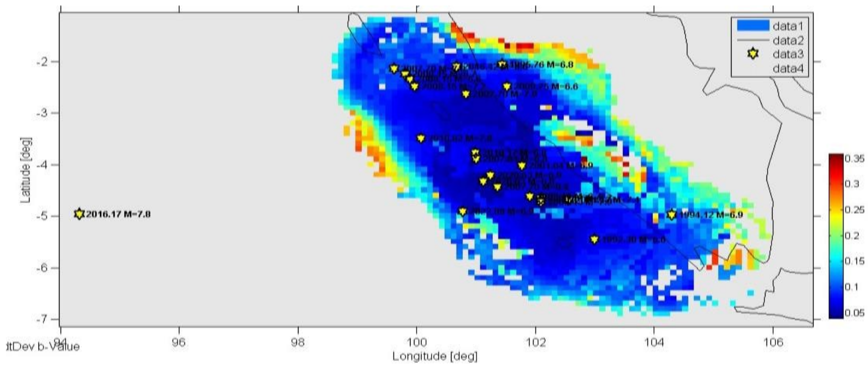


Latitude [deg]
Longitude [deg]
data1
data2
data3
data4
2016.17 M=7.8
2010.82 M=7.8
2009.75 M=6.6
2007.70 M=7.9
2001.04 M=6.9
2022.88 M=6.9
1992.30 M=6.8
1994.12 M=6.9

(c)



(d)



(e)

Figure 9. (a) Spatial distribution of b-value, (b) spatial distribution of a-value, (c) earthquake density map, (d) earthquake return period, (e) standard deviation of b-value.

Figure 9 is the result of the spatial analysis of the seismotectonic parameters (a-value, b-value, earthquake density, return period and standard deviation) occurring in Region III. Based on the results ofthe spatial b-value study shown in Figure 9a, it can be seen that the spatial variation of b-value is in the rangeof values 0.8 to 2.0. Low spatial variation of b-value is observed in Mentawai Islands, Coastal Sumatra Island, Sungai Penuh and Pagar Alam with spatial variation of b-value around 0.8 to 1.1. While the relatively high spatial variation of b- value is observed in the southern Mentawai Islands Sea, Bengkulu, Lubuk Linggau and Bandar Lampung with b- values ranging from 1.3 to 2.0.

Figure 9b shows that the spatial variation of a-value in Region III ranges from 5.0 to 13.0. Low spatial variations of a-value ranging from 5.0 to 7.5 occur along the coast of Mukomuko, Sungai Penuh, Mentawai Islands, Sumatra Coast and Lubuk Linggau. Then, for high a-values, spatial variations occur in BandarLampung and Bengkulu with a-values ranging from about 8.0 to 12.0.

From Figure 9c it can be seen that the spatial variation of the seismotectonic parameters of seismic density indicates a seismic gap zone in the area between the Mentawai Islands and Bandar Lampung, which also needs to be monitored as a potential large earthquake zone. The seismic gap phenomenon in this region may also be the result of a weakness in the earthquake parameter analysis programme, which never has an epicentre latitude of exactly zero. Since fault types are directly generated by the orientation and magnitude of a region's stress regime, this proves that stress has an influence on the b-value.

Figure 9d shows that magnitude 6.5 earthquakes in Region III have different return periods, rangingfrom about 5 to about 20 years. The 5-10year return period covers Pagai Island, Enggano Island and the Bengkulu coast. The 11-20year return period covers Siberut Island, the southern sea of the Mentawai Islands, Mukomuko, Sungai Penuh and Bengkulu. Short return periods are usually correlated with low b and a-values. Short earthquake return periods correlate with areas of relatively high seismic activity.

Based on Figure 9e, it can be seen that the standard deviation map that occurs in Region III Sumatra,obtained the results of calculating the standard deviation of b-value in the range of values 0.05-0.35. The high and low value of the standard deviation can show the size of the spread of earthquake events that occur, to avoid this, adequate data is needed to determine the level of rock fragility (b-value) that occurs in Region III.

Based on Figure 1, the seismic activity that occurred in the Sumatra region at the time of the research from 1990 to 2022 with the boundaries of 6°30'LU-6°30'LS and 94°BT-106°BT. in the research in region I there were 3303 earthquake events. There were 4075 earthquake events in Region II and 3502 earthquake events in Region III. The earthquake events are caused by plate tectonic activity, namely: in the west there is a subduction zone of the Indo-Australian plate with the Eurasian plate moving obliquely with a convergent movement system that penetrates quite shallowly and in the south in the form of active faults under the sea such as; active fault Mentawai. In addition, the distribution of earthquake seismicity is also quite high on land, which occurs along the Bukitbarisan Sumatra. The seismicity of earthquakes occurringin the Bukitbarisan of Sumatra is due to the presence of active Sumatran faults. Large and destructive earthquake events are mostly caused by the activity of the Sumatra subduction zone and the active Sumatra fault. The results for the seismicity distribution of relatively active earthquakes at an average depth of 60- 350 km in the Sumatra region are mostly along the coastal margin of Sumatra. The earthquakes that occur in this region are influenced by subduction zone activity that penetrates deep enough and occurs beneath the subduction plate.

Based on the seismicity mapping of the seismic activity that occurs in the Sumatra subduction zone, the cumulative number of earthquake frequencies in the three research areas is plotted in Figure 2, the cumulative plot has a relatively smooth relationship with the b-value slope. However, there has been an increase in earthquake frequency, the increase occurred after the Aceh region earthquake on 26 December 2004 with M 9.1SR, this caused many earthquakes and the active subduction zone, so there was an increase in earthquake frequency after the earthquake, and in the following year the earthquake frequency decreased and started to stabilise. This is also shown by the high a and b parameters in that year and the decrease after the event.The spatial variation of the seismotectonic parameter b-value in the three study areas in Figures 7a, 8a and 9a is relatively low, occurring in Region I around Andaman, Meulaboh, Lhokseumawe, Langsa, South Aceh Sea, for Region II Nias Island, Mentawai, Padang, Pasaman and Bukittinggi, and Region III along the coast of Mukomuko, Sungai Penuh, Mentawai Islands, Sumatra coast and Lubuk Linggau. The correlation between high stress and relatively low b-value is clear, as evidenced by the occurrence of large earthquakes in areas with low b-values during the study year. Based on previous research, low b-values are usually correlated with high levels of stress, while high b-values are the opposite. In addition, regions with high heterogeneity correlate with high b-values.

The spatial distribution of a-values in Figures 7b, 8b and 9b is similar to that of b-values, with low a- values also occurring around Simeuleu Island, Nias, Mentawai Islands and around Bengkulu. Parameters with low a-values indicate relatively low seismic activity, which means that there is an accumulation of energy (asperity) in these areas, and vice versa for areas with low a-values. The absolute value of b and its variability is highly dependent on the accuracy of the earthquake catalogue, the homogeneity and length of the catalogue, the calculation techniques and algorithms used.

The spatial distribution patterns of a and b-values are similar, with areas of high b-values also having high a-values. The absolute value of seismotectonics and its variability depend on the accuracy of the earthquake catalogue, the homogeneity and length of the catalogue, the computational techniques and algorithms used.

Based on the previous analyses, it can be interpreted that this region is still likely to experience large earthquakes in the future. This is also indicated by the spatial variation of the seismic parameters or a-value, where the region has a relatively low a-value. From the spatial variations of seismotectonic parameters and seismicity density in Figures 7c, 8c and 9c, it is also evident that there is a seismic gap zone in the area west of Padang, Nias Island, Meulaboh, Sibolga, West Pasaman and Lampung, which also needs to be monitored as a potential large earthquake zone. The earthquake gap phenomenon in this region may also be the result of a weakness in the earthquake parameter analysis programme, which never has an epicentre latitude of exactly zero.

According to [20], the b-value has a clear relationship with the stress within a rock volume. In his experiments, he observed that a decrease in b-value corresponds to an increase in stress in the rock. Recent studies on various global and regional catalogues have shown that the b-value is significantly lower for thrust earthquakes than for normal and strike-slip faults [21]. Since the fault type is directly generated by the orientation and magnitude in the stress regime of a region, this proves that stress has an influence on the b- value parameter.

Figures 7d, 8d and 9d show that magnitude 6.5 earthquakes in the study area have different return periods ranging from about 5 to about 25 years. Return periods of about 5-10 years include Simeulue, Banda Aceh, Nias Island, Mentawai, Pagai Island, Enggano Island and Bengkulu Coast, while return periods of about 11-25 years include the Andaman Sea, Aceh, Medan, Batu, Padang, Pesisir Selatan, Mentawai Islands, Mukomuko, Sungai Penuh and Bengkulu. Short return periods are usually associated with areas that have low b and a seismotectonic parameters. In other words, short return periods correlate with areas of high seismic activity and vice versa.

The standard deviation maps in Figures 7e, 8e and 9e show the standard deviation maps that occur in the three regions of Sumatra, which shows the size of the distribution of earthquake events that occur to determine the level of rock fragility (b-value) that occurs in Sumatra.

4. Conclusion

Based on the results of seismotectonic parameter research, a-value and b-value have a value that is directly proportional, in the 1990-2022 research period in 3 (three) regions of Sumatra obtained low seismotectonic parameters in region I with b-value of 0.958 and a-value of 7.49, followed by region II with b-value of 0.996 and a-value of 7.62 and in region III with b-value of 1.04 and a-value of 7.97. As for the spatial variation of b-value and a-value, it was found that in Region I with low b-value (0.8-1.1) and low a- value (5.0-6.0), the areas with high potential for significant earthquakes occur, namely in Meulaboh, Lhokseumawe, Langsa and the South Aceh Sea. In Region II with low b-value (0.8-1.0) and low a-value(5.0-6.5), the areas with high potential for significant earthquakes are Nias Island, Mentawai, Padang, Pasaman and Bukittinggi. In Region III with low b-value (0.8- 1.1) and low a-value (5.0-6.5), areas with high potential for significant earthquakes are along the coast of Mukomuko, Sungai Penuh, Mentawai Islands, Sumatra coast and Lubuk Linggau. This area has high seismic potential because areas with low b-values store large amounts of stress due to high rock fragility. Meanwhile, areas with high b-value and high a-valueindicate that seismic activity in the region is high because the low level of rock fragility causes the stored stress to not be large as the channelled stress is directly released in micro earthquakes. Based on the temporal variation of b-value, there is a pattern of decreasing b-value before a significant earthquake occurs, namely in 2004 (9.1Mw in Aceh) and 2010 (7.9Mw in Bengkulu). This decrease in b-value correlates with an increasein energy in the form of stress in the region. The return period of Mw 6.5 earthquakes in the three regionsof Sumatra varies from about 5 to about 20 years.

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