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The Analysis Of Seismotectonics, Periodicity, And Changing Of Quakes Level In West Nusatenggara Area Based On 1973 – 2015 Data

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Abstract

This research was conducted as one of the earthquake disaster mitigation efforts in Nusa Tenggara Barat region, because this region is one of the regions in Indonesia which has a relatively high level of seismicity. The purpose of this research is to determine seismotectonic parameter, earthquake periodicity along with the average of seismicity rate changes in Nusa Tenggara Barat region. The data used in this research is the data sourced from the United States Geological Survey (USGS) and Badan Meteorologi Klimatologi dan Geofisika (BMKG) from Januari 1973 until February 2015 for Bali Strait region up to Banda Sea with coordinate boundaries of 114^0–130^0 East Longitude and 4^0-13^0 South Latitude. This research was conducted using the maximum likelihood method with second party of software Zmap ver 6.0 also software ArcGis ver 10 to map seismotectonic parameter, periodicity and the average velocity of seismicity rate changes. Variation b value range between 0.972–1.44, a low value of b are associated with high stress levels, and vice versa. The a value range between 6.67- 9.1, its show that the regions with high a value experience a relatively high earthquake incidence rate, and vice versa. The density of earthquake is about -2.63 to -2.01 logN/km^2 or the occurrence of earthquakes in the area is very rare. Earthquake periodicity with magnitude (M) 6 SR is 5 to 18 year, M 6.5 SR is 16 to 67 year, M 7 SR is 54 to 304 year, and M 7.5 SR is 178 to 1.386 year. The average of seismicity rate changes on a case that occurred in Sumbawa in 1982 is more than 125%, meanwhile the earthquake that occurred in 2009 is more than 75%.

Introduction

Most regions in Indonesia have relatively high levels of earthquakes, which the West Nusa Tenggara Region is one of them. Tectonically, West Nusa Tenggara is in the East Sunda Arc

Region, that extending from the Sunda Strait to the east to Sumba Island [1]. The eastern Sunda arc has several characteristics, i.e subduction zone, volcanic arc and earthquake pathway. The seismicity of West Nusa Tenggara is quite tight because it is influenced by the subduction activities of the Indo-Australian plate on the south and Flores back arc thrust fault in the north so that this area is vulnerable to earthquake hazards [2].
This study was conducted to analyze the seismotectonic parameters of the West Nusa Tenggara Region, including determining the density of earthquake events in each km square. The seismotectonic parameters is represented by *a* and *b* values, periodicity of earthquakes with a certain magnitude and changes in seismicity (seismicity rate changes). In this study, changes in seismic levels were carried out based on the 1982 and 2009 earthquake events, so the determination of the seismic level changes for the 1982 earthquake cases was carried out from 1973 - 1982 and 1982 - 2015, as well as the 2009 earthquake cases. 1973 - 2009 later in 2009 - 2015.

The value of *b* is a tectonic parameter that depends on the level of stress or material structure of a region [3]. The analytical method used in this research is the statistical method of seismicity, the maximum likelihood method which is based on the Gutenberg-Richter relation [4].

$$b = \frac{\log e}{\bar{M} - M_0} \tag{1}$$

where *b* is a tectonic parameter, $\bar{M}$ is the average value of earthquake magnitude, M_0 is a minimum magnitude of earthquake, and *e* is a natural number

While the value of *a* is a parameter of seismic activity which generally reflects the level of seismicity in a region during a certain period and is commonly referred to as a seismicity index. The *a* value can be determined using the Wekner formula (1965) as follows [5]:

$$a = \log N + \log(b \ln 10) + M_0 b \quad \text{with } M \geq M_0 \tag{2}$$

where *a* is seismic activity parameter, N is number of earthquake event, b is tectonic parameter, M is an earthquake magnitude, and M_0 is a minimum magnitude of earthquake.

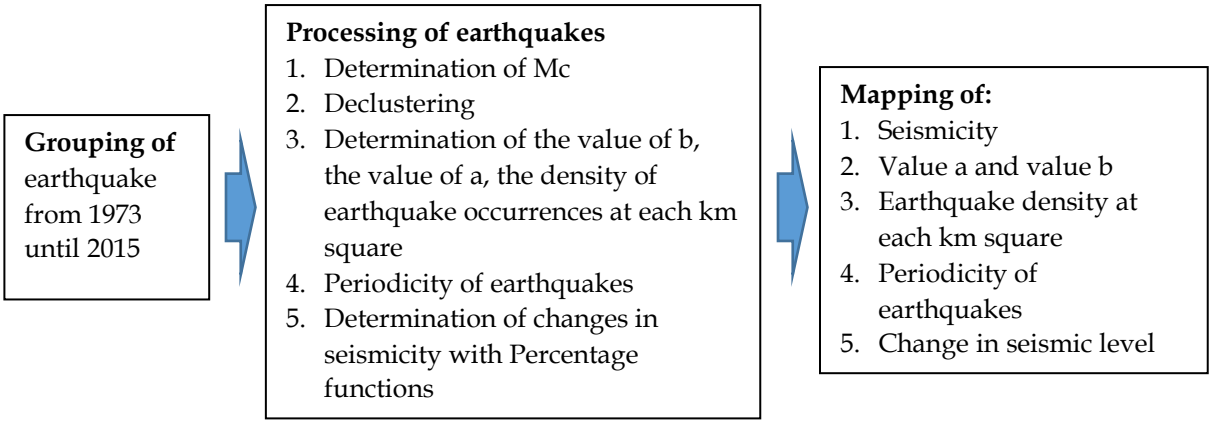
The West Nusa Tenggara Region and its surroundings are included in the Mediterranean mountainous path which is located adjacent to the plate collision zone. The collision of these two plates is convergent and the Indo-Australian plate infiltrates beneath the Eurasian plate. The boundary of the meeting of this plate is marked by the existence of a sea trough located south of Sumbawa Island known as the Java Trench [6].
The vulnerability of earthquakes that occur is due to the infiltration of plates in the south and due to the presence of tectonic structures of ascending faults behind the archipelago known as the back arc thrust. This structure is formed due to the backing of the Eurasian Plate against the Indo-Australian Ocean Plate. The arc-continent collision phenomenon is

thought to be the controller of the fault deformation mechanism in the north of Sumbawa Island [7].

Historical records of earthquake and tsunami in West Nusa Tenggara include the earthquake and tsunami of Sumbawa on August 19, 1977 with magnitude 6.1 on the Richter Scale (SR). The earthquake killed 107 people and 54 people were lost due to the tsunami that hit the southern coast of Sumbawa and Lombok. The earthquake occurred again on Sumbawa on May 17, 2005 with a magnitude of 5.7 SR and a depth of 80 kilometers. On September 7, 2008 there was another earthquake in the northeast of Sumbawa with a magnitude of 6.6 SR and a depth of 10 kilometers. Furthermore, a strong earthquake shook the Sumbawa area again on November 9, 2009. The earthquake has a magnitude of 6.7 SR with a depth of 18 kilometers with an earthquake center on the coast [8].

Method

This research was conducted using secondary earthquake data from the United States Geological Survey (USGS) and the Meteorological, Climatological, and Geophysical Agency (BMKG) from 1973 to 2015 for the Bali - Nusa Tenggara region with coordinate boundaries of latitude 4o S – 13o S and longitude 114o E – 130o E. Even of earthquake spread from the Bali Strait to the Banda Sea. The software used in this study is: matlab 7.0.1, Zmap, ArcGis 10. Stages of research include data grouping, data processing, and spatial mapping as described below.



The number of earthquake events from January 1973 to February 2015 amounted to 16,353. Based on the Frequency Magnitude Distribution (FMD) graph, the Magnitude Completeness (Mc) value is 4.5 as shown in Figure 1. The next earthquake data used is earthquake data that has a magnitude ≥ 4,5 SR. The earthquake with its magnitude as many as 6,917 events.

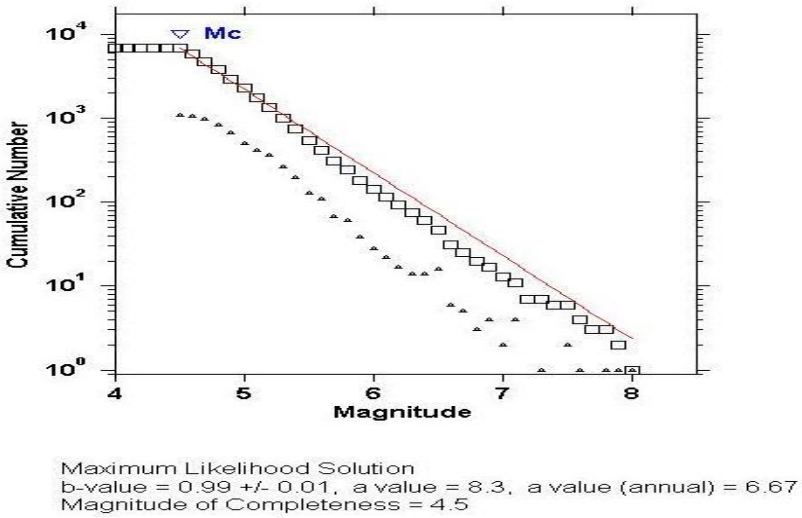


Figure 1. Frequency of Magnitude Distribution (FMD) of earthquake in the Bali-Nusa Tenggara region at the period of 1973-2015.

The next stage is the process de-clustering, which is separated main and aftershocks earthquake. To minimize systematic errors, earthquake data used in research only uses main earthquake only. The results of the de-clustering process obtained earthquake data as many as 6,514 event. The data is used in determining the *b* and *a* value, the density in each km square and the periodicity of earthquakes in the West Nusa Tenggara Region, and determining changes in the average seismic level in the West Nusa Tenggara Region.

Result and Discussion

West Nusa Tenggara Region and the surrounding area has relative seismic activity high due to seismotectonic conditions at the region. From January 1973 to February 2015 a lot of earthquake happened in the region. Distribution earthquake events in the Bali Strait Region - Banda Sea in 41 years shown in Figure 2. The region has a relatively high level of seismic activity high with various magnitudes and magnitudes depth. Earthquake Activities in the West Nusa Tenggara Region and its surroundings in part large has a depth of less than 218.7 km. Medium earthquake distribution is also a lot concentrated in the Sumbawa region, Dompu, and Bima. Seismicity on Lombok Island is relative lower than the Island Sumbawa and its surroundings. Earthquake with depth of up to 437.4 km and depth up to 729 km (deep earthquake) concentrated in the north of the Nusa Tenggara. Earthquake activity with hypocenter in the north of Sumbawa Island it seems the distribution is quite tight describing earthquake activity in very high. Distribution pattern this earthquake hypocenter can explain that getting to the north, then the pattern the hypocenter of the earthquake is getting deeper.

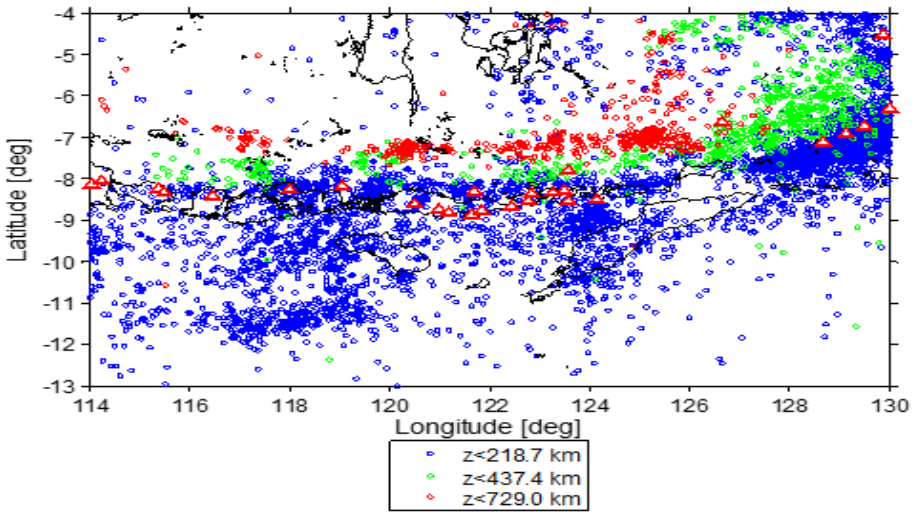
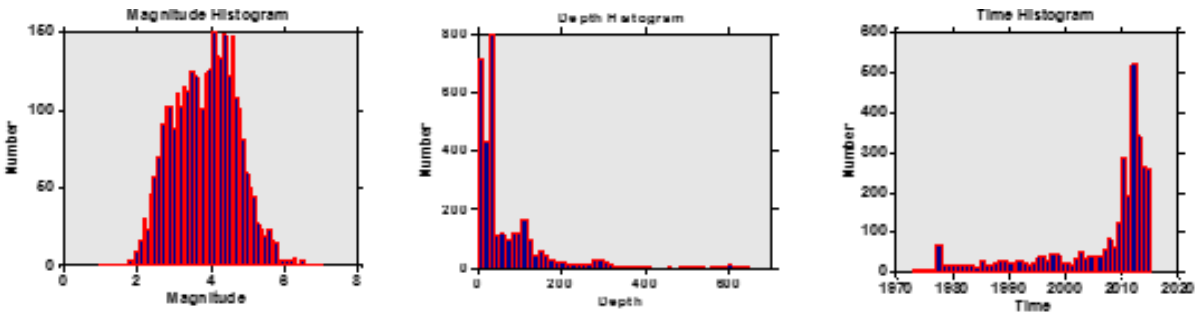


Figure 2. Seismicity map of the Bali-Nusa Tenggara region at the period of 1973-2015.

Based on the catalog of earthquakes, the earthquake in West Nusa Tenggara region dominated by an earthquake with a magnitude ≥ 4 SR histogram as in Figure 3a. Distribution of earthquakes to dominant depths by earthquakes with a depth of about 50 km (Figure 3b), whereas from time, most earthquakes occur in 2012 (Figure 3c).



(a) **(b)** **(c)**

Figure 3. Histogram of earthquake in West Nusa Tenggara and surroundings at the period of 1973-2015 from USGS and BMKG (a) magnitude (b) depth and (c) time of events

The calculation results of earthquake density in the West Nusa Tenggara region based on the USGS-BMKG earthquake data from January 1973 to February 2015 are shown in Figure 4. The earthquake density values of the West Nusa Tenggara Region range from (-2.63 to -2.01) log (N)/km^2, where N is the number of earthquakes. Based on the figure 4, it can be seen that in each area (km square) it ranges from 0.002 to 0.009. This value indicates that in the west area of the earthquake is very rare. The Dompu, Bima and its surrounding areas have higher levels of earthquake density compared to other regions in West Nusa Tenggara.

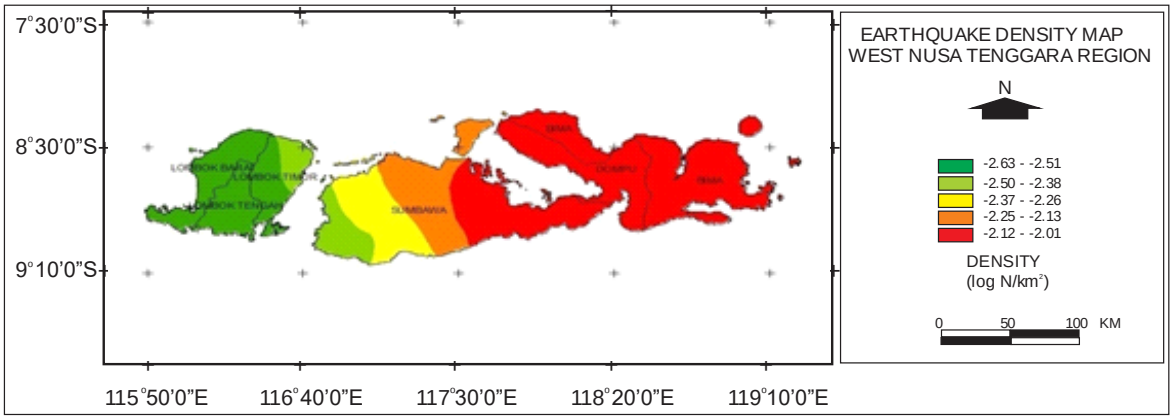


Figure 4. Earthquake Incidence Map for the 1973-2015 period in the West Nusa Tenggara Region and its surroundings (based on USGS - BMKG data).

Based on the figure 4, it can be seen that in each area (km square) it ranges from 0.002 to 0.009. This value indicates that in the area of the earthquake is very rare.

The result of the calculation of the value of *b* (*b* value) varies with the value in the range of 0.972 to 1.44, as shown in Figure 5. Areas with low b values associated with high stress levels and vice versa. Regions with a lower value of *b* have a relatively higher potential for earthquakes with greater strength compared to areas with a high value of *b*. This is understandable because regions with low *b* values experience accumulated stress that has not been released.

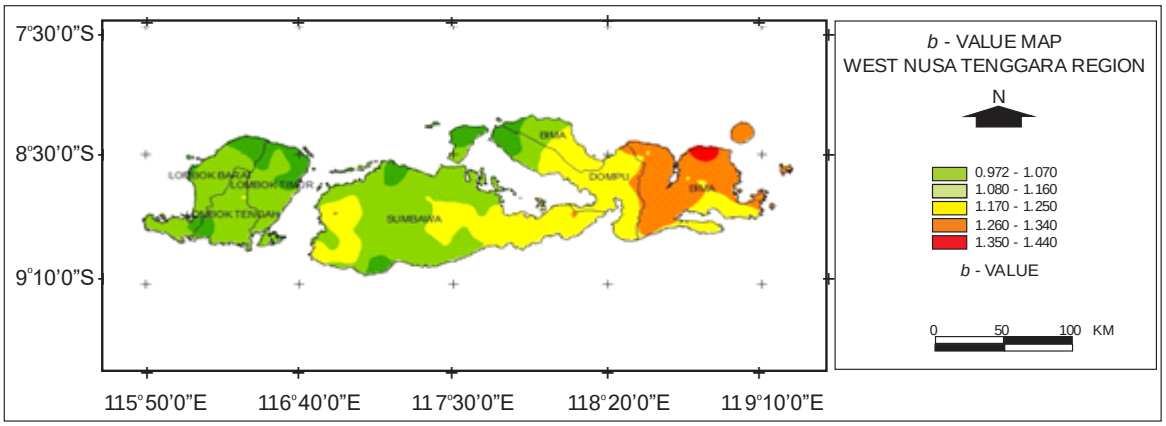


Figure 5. Map of spatial variation in the value of b from the 1973-2015 earthquake data in the West Nusa Tenggara region

Based on Figure 5, reas that have a relatively high value of *b* are in the eastern Bima region, which ranges from 1.26 to 1.44, so that in the region has a high value heterogeneity in the study area which indicates low rock stress conditions, this is due to the Bima Region and the surrounding area there are two earthquake generators, namely in the south there are subduction zones and on the north there is a rear arc fault Flores. Whereas the area that has a *b* value is relatively low in the Lombok Region which ranges from 0.972 to 1.16, where the value of b in the study area is quite low which shows high rock stress conditions, this is because in Lombok there is only one earthquake generator, namely a zone subduction

located south of the area. Therefore, it can be seen that in the eastern Bima region the frequency of earthquakes is higher than in other regions.

The variation of standard deviation scores for West Nusa Tenggara region spatially shown in Figure 4.6. In general, the standard deviation of the value of the West Nusa Tenggara Region is relatively small, ranging from 0.082 - 0.156. Thus the results of determining the value of *b* in the region have a relatively high level of accuracy. The standard deviation of the values of *b* for the Sumbawa, Bima and Dompu Regions ranges from 0.082 to 0.126, therefore it is known that in the region the calculation of b values is more accurate than the Lombok Region and its surroundings which have a greater standard deviation range of 0.097 to 0.156.

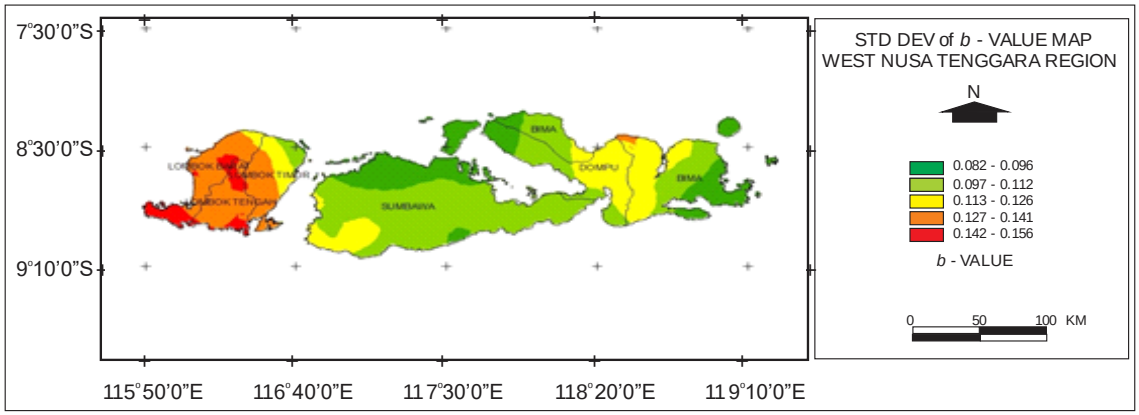


Figure 6 Variation Deviation Standard Map from the 1973-2015 USGS-BMKG earthquake data West Nusa Tenggara Region and its surroundings

The standard deviation of the *b* value of the Lombok Region is relatively larger than the Sumbawa Region because the number of earthquake events in the Lombok Region is relatively smaller compared to the number of earthquake events in the Sumbawa Region. The standard deviation of the value of b is related to the amount of earthquake data used in the calculation.

Spatial variations in the value of *a* (*a* value) for The West Nusa Tenggara region ranges from 6.67 to 9.1 as shown in Figure 4.7. From the observation of variations in *a* value it is known that the value of *a* is a seismic parameter whose magnitude depends on the number of earthquake events.

The West Nusa Tenggara region which has a relatively higher value of a is in most of the Dompu region and in the eastern Bima region which ranges from 7.65 to 9.1, so that based on *a* value in the region the earthquake incidence is relatively more common. Whereas the regions that have a relatively low value in Lombok and surrounding areas are ranged from 6.67 to 7.64, based on the *a* value in the region, the incidence of earthquakes is relatively smaller. Thus, the greater the value of a in an area means that the region has experienced an earthquake that is also higher, whereas the area that has a relatively small value of *a* has a relatively lower earthquake incidence.

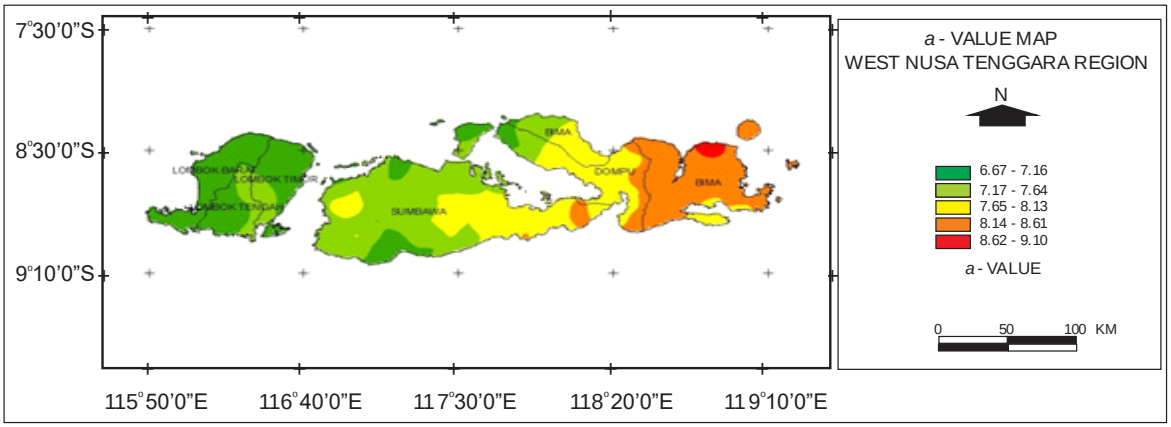


Figure 7. Map of Spatial Variation in Value of *a* from the 1973-2015 USGS-BMKG earthquake data West Nusa Tenggara Region and its surroundings

Periodicity of earthquakes can be estimated using Zmap software. The results of earthquake periodicity mapping can be related to variations in the values of a and b values, where from the illustrated patterns indicate that regions that have earthquake activity and rock stress conditions can be related to the periodicity of earthquake events. According to some previous researchers [5] that the short periodicity of earthquakes is related to the value of *a* and the high value of *b*. In this case, the periodicity of the earthquake depends on the magnitude, that is, regions with *a* value and a value of *b* which are highly likely to occur with periodicity of earthquakes with a large magnitude will be longer. And conversely, a region with *a* value and a value of *b* which is less likely to occur with the periodicity of an earthquake with a large magnitude will be faster.

Periodicity of earthquakes with magnitude 6.0 SR is shown in Figure 8.

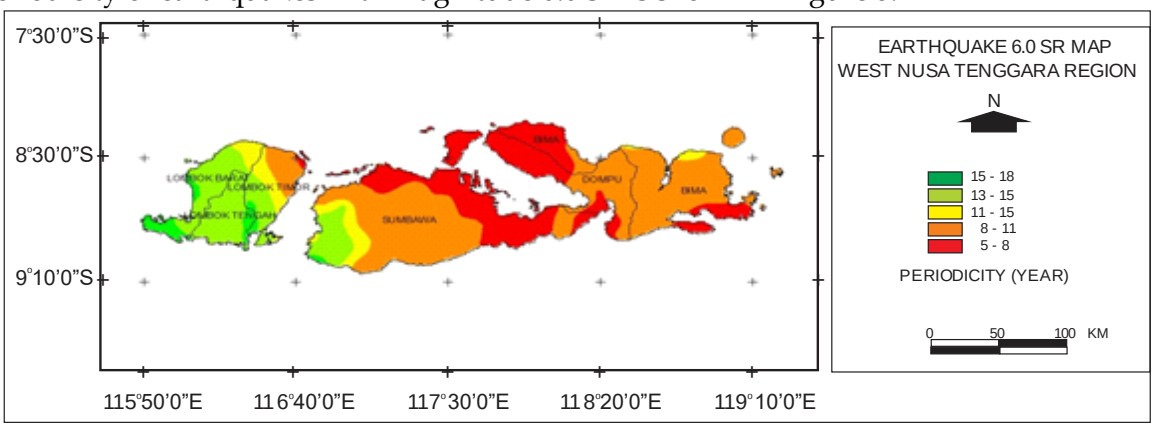


Figure 8. Periodic Map of Earthquake Magnitude 6.0 SR from the 1973-2015 earthquake data of the USGS-BMKG West Nusa Tenggara and surrounding areas

Periodicity of earthquakes with magnitude 6.5 SR is shown in Figure 4.9. Areas that have a recurrence time of the magnitude 6.5 magnitude earthquake are relatively faster including the northern part of Sumbawa, northern Dompu region, and northern Bima region with estimated periodicity of earthquakes ranging from 16 to 27 years.

The Bima region in the northeast, Sumbawa in the west and most of Lombok has a relatively longer periodicity compared to other regions around the Bima Region. While in general, the Sumbawa and its surrounding areas experienced higher earthquake events compared to Lombok Island, but the earthquakes that occurred in the area were dominated by earthquakes with a small magnitude.

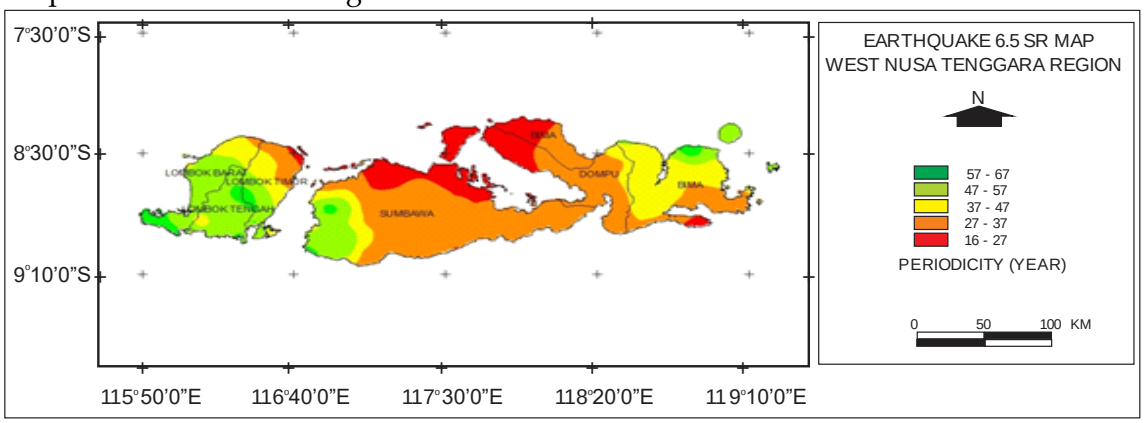


Figure 9. Periodic Map of the Magnitude 6.5 Earthquake Earthquake from the 1973-2015 earthquake data of the USGS-BMKG in the West Nusa Tenggara Region and beyond.

The periodicity of earthquakes with magnitude 7.0 SR is shown in Figure 4.10. Periodicity of earthquakes ranges from 54 - 304 years. Similar to the periodicity map of earthquakes with magnitude 6.5 SR, regions that have a faster periodicity of earthquakes include the northern part of Sumbawa, the northern part of the Dompu region, and the northern part of the Bima region with a range of 54 to 104 years, while the Bima region in the north-east , The western part of Sumbawa and most of the Lombok region have a relatively longer periodicity ranging from 154 to 304 years. So based on the map of the northeastern Bima region, western part of Sumbawa which experienced a long periodicity of earthquakes because in the region the earthquake that occurred was dominated by earthquakes with relatively low magnitude, so the possibility for a greater magnitude would be very rare in the region. Whereas for the Lombok region and its surroundings, there is a long periodic earthquake due to the region. These earthquakes are rare but have the potential for earthquakes with relatively large magnitudes such as magnitude 7.0 SR

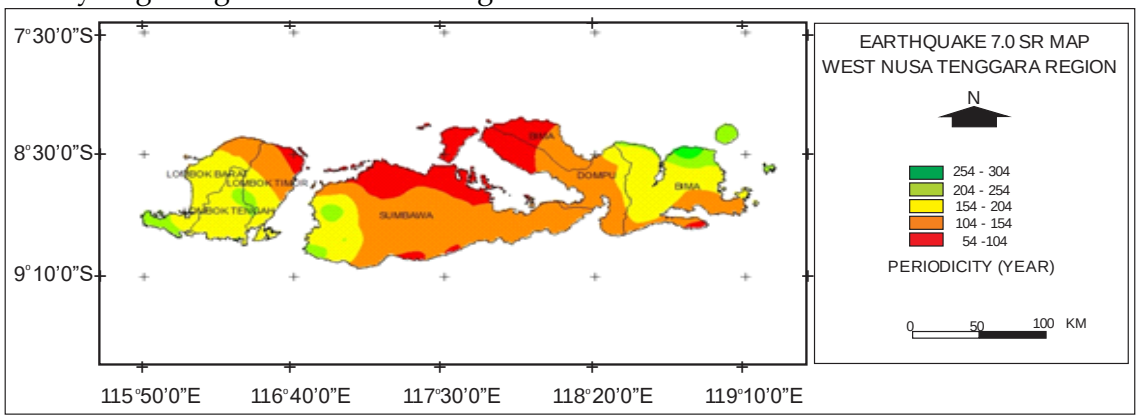


Figure 10 Periodic Map of the Magnitude 7.0 earthquake Earthquake from the 1973-2015 earthquake data of the USGS-BMKG in the West Nusa Tenggara Region and its surroundings.

The periodicity of earthquakes with magnitude 7.5 SR is shown in figure 10. Periodicity of earthquakes ranges from 178 - 1,386 years. Areas with earthquake periodicity are relatively faster or shorter, namely the northern part of Sumbawa and the southern part of Sumbawa, the northern part of Dompu region, and the northern part of the Bima region with a span of 178 to 419 years. The eastern part of Bima has a period of time period which is relatively longer or longer than other regions around Sumbawa Island.

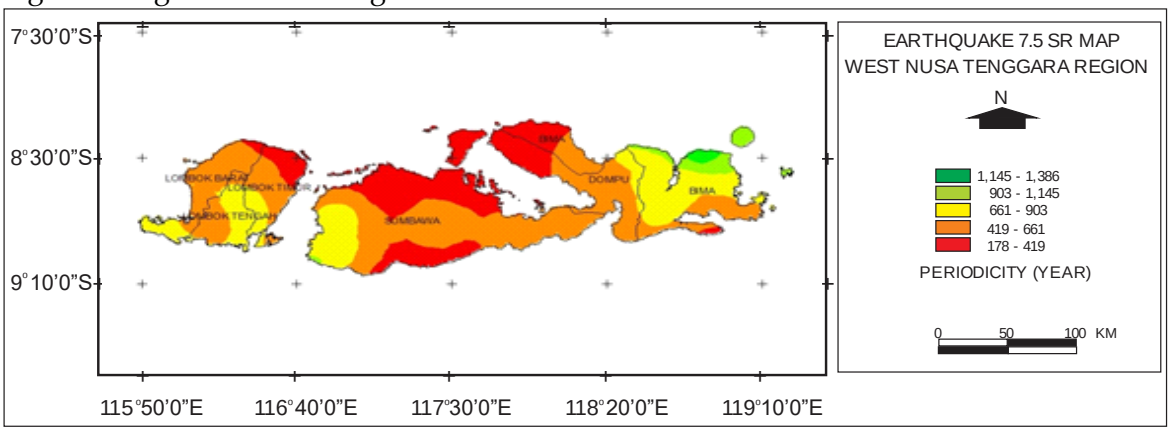


Figure 11. Periodic Map of the Magnitude 7.5 SR Earthquake from the 1973-2015 earthquake data of the USGS-BMKG West Nusa Tenggara Region and its surroundings

Based on earthquake data used in this study, earthquake events that have occurred in the West Nusa Tenggara Region with a magnitude of 8 SR have only occurred once in the region. So the earthquake periodicity for earthquakes with a magnitude of 8 is not carried out. Analysis of changes in the average level of seismicity is done by taking two case studies of significant earthquakes in the region of West Nusa Tenggara. Analysis of changes in seismic rate on average was carried out by the Z function percentage. The data used for the analysis of changes in the average seismic level uses earthquake data from January 1973 to February 2015.

The analysis of changes in the average seismic level was carried out on the Sumbawa earthquake case on March 11, 1982 with a magnitude of 6.5 SR with the location at 118.48 BT and 9.27 LS and a depth of 33 km. The change in the average seismic level in the Sumbawa earthquake case is shown in Figure 12.

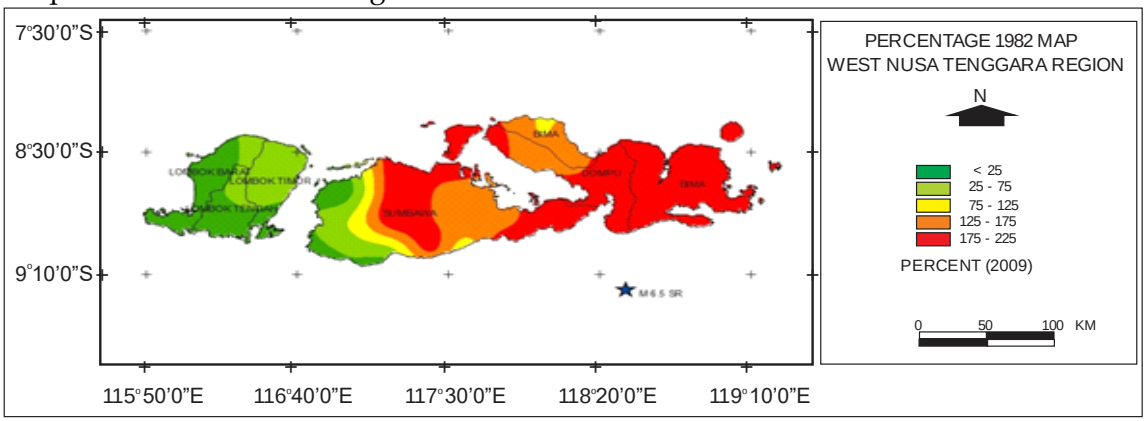


Figure 12. Map Earthquake Level Change average with Function Percentage Sumbawa Earthquake Case on March 11, 1982

Based on changes in the level of seismicity map of the average case Sumbawa 1982 earthquake appears that the seismicity rate changes of up to 225%. For the central part of Sumbawa, eastern part of Sumbawa, Dompu and Bima experienced a relatively higher rate of seismic rate which is more than 125%, the area has increased earthquake incidence compared to the Lombok Region and the western part of Sumbawa which has a rate change the average earthquake is relatively lower.

As well as changes in the average seismic level based on earthquake events in 1982. The data used for the analysis of changes in the average seismic level also uses earthquake data from January 1973 to February 2015. Changes in the average seismic level are based on earthquakes Sumbawa on July 15, 2009 with magnitude 7 SR with locations at 117.97 BT and 8.92 LS and a depth of 244 km. Changes in the average seismic level in the 2009 earthquake cases are shown in Figure 4.13.

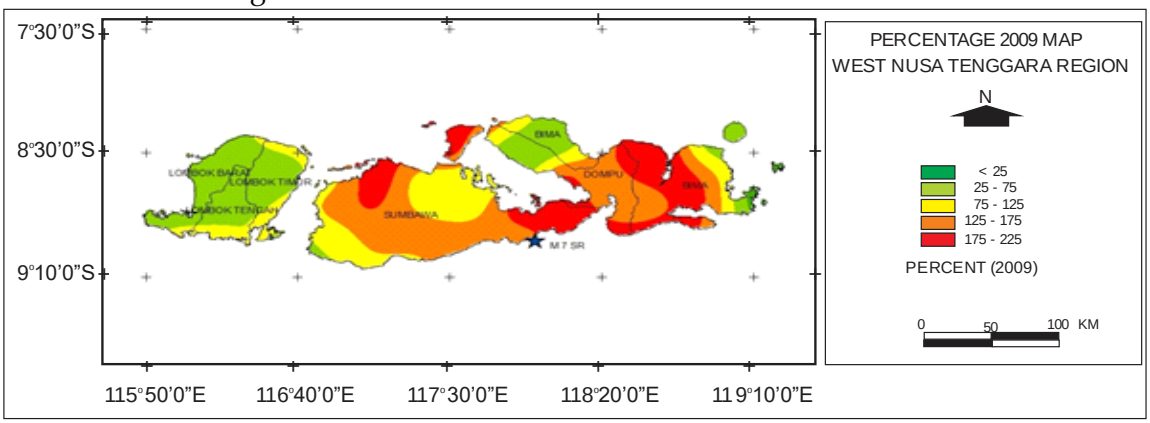


Figure 13. Map of Change in the Average Seismic Level with Percentage Function in Sumbawa Earthquake Cases July 15, 2009

Based on changes in the level of seismicity map of the average case Sumbawa earthquake of 2009, it appears that most of the central part of Sumbawa region, Dompu and Bima experiencing seismicity rate changes on average relatively high at more than 125%. Furthermore, in the eastern Bima region and the western part of Sumbawa, the average seismic rate changes are relatively lower at more than 75%. While the area of Lombok and its surrounding areas experienced a decrease in the average seismic level, this is because the Lombok region and the surrounding area have a change in the average seismic level which is relatively lower compared to other regions around the West Nusa Tenggara Region.

Conclusion

The conclusion of this study are: The variations in the value of *b* of West Nusa Tenggara region is ranging from 0.972 - 1.44, regions with a low value of b are associated with high stress levels, and vice versa. The value of *a* (*a*-value) varied from 6.67 to 9.1 where, regions with high a value experience a relatively high earthquake incidence rate, and vice versa and the density of earthquake events at each km square is varied from (-2.63 to -2.01) log N/km^2, so that the occurrence of earthquakes in the area is very rare. The periodicity of earthquakes in the West Nusa Tenggara Region for magnitude 6.0 SR ranges from 5 to 18 years, 6.5 SR ranges from 16 to 67 years, 7.0 SR ranges from 54 to 304 years, and for magnitude 7.5 SR ranges from 178 to 1,386 years. Changes in the seismic rate on average

Sumbawa earthquake cases in 1982 in the central Sumbawa, eastern Sumbawa, Dompu and Bima are more than 225% and in the cases of earthquakes in 2009 in parts of the central part of Sumbawa, Dompu and Bima experienced changes in the average earthquake rate of more than 125%. Whereas in the eastern part of Bima and the western part of Sumbawa, the rate of change in the average earthquake rate is more than 75%.

Acknowledgments

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