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Mapping of Destructive Tectonic Earthquakes in the West Nusa Tenggara (NTB) Region Based on the Zhao Attenuation Function

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Abstract

NTB is a group of small islands located between the earthquake zone, namely a subduction zone of the Eurasian and Indo-Australian plates in the south, and a back-arc fault or Flores Thrust in the north. Earthquakes in this area are very active in the form of shallow tectonic earthquakes of large magnitude, so the risk of disaster is very high. Based on this, our research aims to map the distribution of destructive earthquakes using the Zhao attenuation function, released in 2006. The Zhao attenuation function has been applied to earthquake sources in subduction zones which are inputs for seismic hazards in various parts of the world due to the distance uncertainty factor used has better accuracy. The distribution of earthquake epicenter points in the West Nusa Tenggara region is clustered in four places, namely the Eurasian and Indo-Australian plate subduction zones in the sea south of the West Nusa Tenggara islands, the non-volcanic zone to the south of the West Nusa Tenggara islands, the volcanic zone to the east, and the Back Arc Thrust zone in the waters north of the NTB islands. Meanwhile, the hypocenter distribution is spread majorly on the Eurasian plate. Most of the islands of West Nusa Tenggara are characterized on the MMI VII-VIII intensity scale, and only a small part is characterized on the V-VI MMI intensity scale. The implications of the results of this research are useful in disaster mitigation, so it is hoped that there will be a reduction in disaster risk.

Keywords: *Tectonic Earthquake; West Nusa Tenggara; Zhao Attenuation*

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INTRODUCTION

West Nusa Tenggara (henceforth NTB) is a group of small islands located between the earthquake zone, namely a subduction zone of the Eurasian and Indo-Australian plates to the south [1-3], and a back-arc fault or Flores Thrust to the north [4,5]. Earthquakes in this area are very active in the form of shallow tectonic earthquakes of large magnitude. Based on earthquake frequency data from 2009 to 2019, the number of earthquake occurrences in NTB was 6802 times [6]. Earthquakes are disasters that pose a serious threat to human infrastructure on a certain scale [7,8]. In 2018, the number of victims of the 7.0-magnitude earthquake in Lombok, NTB was recorded reached 515 people and 7,145 people were injured, and the number of refugees reached 431,416 people [9]. The losses and damage from the impact of the Lombok earthquake to date is Rp 7.7 trillion [10,11]. Two quite large aftershocks occurred again on August 19, 2018, first at 11.10 a.m. with a magnitude of 6.5 and second at 09.56 p.m. with a magnitude of 6.9 [12]. For this reason, it is important to map earthquake-prone areas in NTB as a reference for disaster mitigation [13-15] and regional development so that in the future, the risk of earthquakes that occur can be minimized [16-18].

Several current attenuation functions can be applied to determine the acceleration of ground vibrations (PGA) in a place, some of which have been pioneered by previous researchers like Fukushima and Tanaka [19], Atkinson and Boore [20], and Zhao et al. [21]. The study developed by each researcher refers to several earthquake parameters by developing different uncertainty parameters. The results or achievements of each model will be different and do not necessarily match the results of verifying facts in the field, or the direct measurements using seismographs.

The attenuation function of Fukushima and Tanaka [19] still uses the magnitude surface (Ms) without considering the seismic wave propagation velocity factor at the ground site that it passes. Atkinson and Boore [20], in addition to using the moment magnitude (Mw), also consider the soil site class with reference to Vs30. Meanwhile, in addition to using the moment magnitude (Mw) and considering the soil site class with reference to Vs30 as a parameter of rock dynamic properties, the attenuation function proposed by Zhao et al. [21] also considers the distance uncertainty factor. At present, the attenuation function of Zhao et al. [21] has been applied to earthquake sources in subduction zones which become seismic hazard inputs in various parts of the world because the distance uncertainty factor used has better accuracy.

Mapping areas prone to destructive earthquakes using the Zhao attenuation method for mitigation reference is relatively new. Previous research has covered the seismic tectonic studies in the NTB region [22], disaster management education [10], and earthquake vulnerability of the NTB region [11]. Previous research in NTB Earthquake distribution is based on the fractals [23]. Further, a study on the seismic vulnerability map for Lombok Island with the PSHA method in the form of a PGA value finds out how far the effect of the earthquake source is on Lombok Island [24]. Ground acceleration mapping using the probabilistic seismic hazard analysis method in Nusa province found west southeast in the megathrust zone [25]. There has been no research using the Zhao attenuation function for destructive mapping earthquakes in NTB.

METHOD

Data Source

The earthquake data used has a magnitude of M≥5 SR, a hypocenter depth of 60 km, and an epicenter distance of 600 km in the NTB region in 1997-2018 Vs30 data. Earthquake data are be obtained through the BMKG catalog http://repogempa.bmkg.go.id/repo_new/repository.php and USGS catalog https://earthquake.usgs.gov/earthquakes/search. Then the Vs30 data was obtained from the USGS catalog http://earthquake.usgs.gov/data/vs30/. The Vs30 data is in the form of values on each observation grid that has been determined in the research area using GMT software.

Data Analysis Technique

The analysis technique follows steps as:

1. Determining the characteristics of significant destructive tectonic earthquakes by plotting a graph of their magnitude versus frequency of occurrence, distribution of epicenter points, and hypocenter points.
2. Determining the Peak Ground Acceleration (PGA) [26] in the NTB region by first calculating the:
   a. Seismic moment (Mo) and Magnitude moment (Mw), parameters that show the strength of an earthquake [27]:
   $$\log M_o = 1{,}5M_s + 16{,}1 \tag{1}$$
   and
   $$Mw = (\log Mo) / 1{,}5 - 10{,}73 \tag{2}$$
   b. Distance from the hypocenter to the grid point of the observation station using the equation:
   $$r = x + c\exp(dM_W) \tag{3}$$
   c. Peak Ground Acceleration (PGA) at each point of the observation grid using the attenuation function by Zhao et al. [21]:
   $$\log(Y) = aM_w + bx - \log(r) + e(h - h_c)\delta_h + F_R + S_I + S_S + S_{SL}\log(x) + C_k \tag{4}$$
3. Data validation of the results of the analysis will be matched with previous research and reports from BMKG.

Mapping the Hazard Level of Destructive Tectonic Earthquakes

To obtain the acceleration of ground vibration or Peak Ground Acceleration (PGA) on each observation grid that has been determined, the following steps will be taken:

1. West Nusa Tenggara (NTB) area, the observation grid area used is 9.46 km x 9.46 km (0,0852° x 0,0852°), as shown in Figure 1

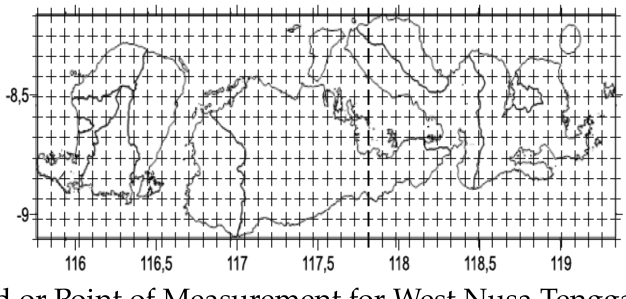


Figure 1. Grid or Point of Measurement for West Nusa Tenggara (NTB) Region

2. Determining the distance of the earthquake epicenter to the observation grid point.
3. Calculating Peak Ground Acceleration (PGA) using Zhao et al. [21] with predetermined

parameter values.

4. The results of the PGA calculation for each grid are then converted into data on the level of tectonic earthquake hazard by the QGIS 10.4 software in the NTB region

Data Interpretation

Interpretation of the results of data processing in the form of:

1. Characteristics of tectonic earthquakes are significantly destructive in the NTB region. Characteristics of significant destructive tectonic earthquakes will be obtained by plotting the magnitude versus frequency of occurrence, the distribution of the earthquake epicenter, and the distribution of the hypocenter of the earthquake in each region.
2. Map of the hazard level of significant destructive tectonic earthquakes in the NTB region based on historical data of significant destructive tectonic earthquakes from 1997-2018.

RESULTS AND DISCUSSION

Tectonic earthquake data in the NTB area was obtained from as many as 159 events. The data was then plotted in the form of a graph in order to recognize characteristic patterns based on the characteristics of the magnitude and frequency of occurrence in each region as shown in Figure 2.

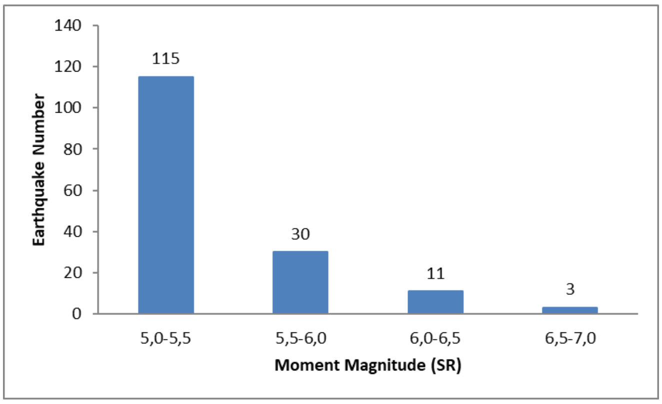
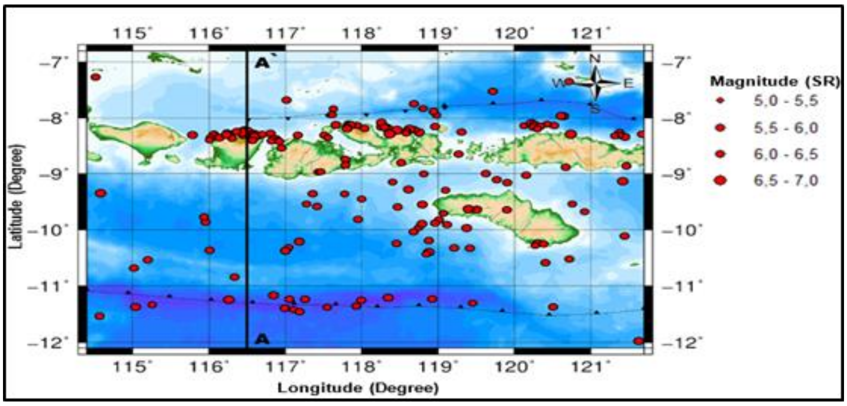


Figure 2. Graph plotting magnitude versus frequency of significant tectonic earthquakes damaging the NTB Region

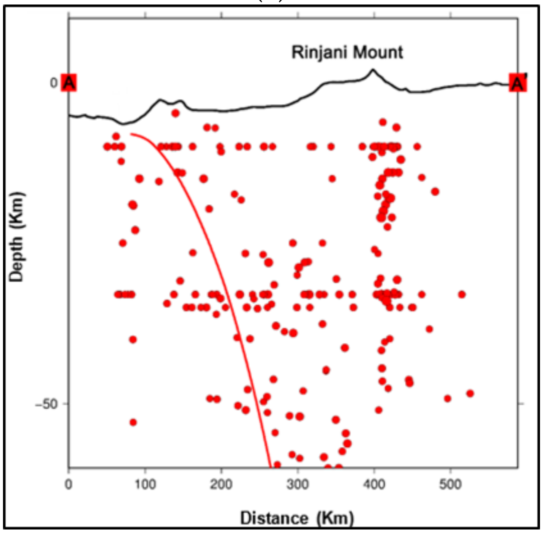
Based on Figure 2, the frequency of occurrence of significant destructive tectonic earthquakes in the NTB region is dominated by earthquakes with a scale of 5.0-5.5 SR and 5.5-6.0 SR. Only a small part of the frequency of occurrence of tectonic earthquakes is significantly destructive on a scale of 6.0 SR and above. Meanwhile, the results of plotting the distribution of the epicenter and hypocenter points for significant tectonic earthquakes in the NTB region can be seen in Figure 3.

Based on Figure 3, within the NTB area, the distribution of epicenter points for tectonic earthquakes significantly damages clusters in four places, namely a plate subduction zone in the southern waters of the NTB, a non-volcanic and a volcanic zone in the east, and Back Arc Thrust zone in the north. The north is the most prone area to tectonic earthquakes [28].

Some of the most influential parameters are the position of the earthquake epicenter, the depth of the earthquake's hypocenter, and the earthquake magnitude. The closer the epicenter and the shallower the source of the earthquake to an area, the greater the potential for damage. Likewise, the greater the magnitude of the earthquake, the greater the potential impact. This will implicate that the epicenter of the earthquake that occurs in the volcanic zone of the NTB islands will have the potential to cause major damage to the area.



(a)



(b)

Figure 3. Plotting of the distribution of epicenter points and hypocenter points for destructive tectonic earthquakes in the NTB region (a) Epicenter points and (b) Hypocenter points.

To see the impact of damage caused by an earthquake or the level of earthquake hazard to an area or region, an empirical approach to the Zhao attenuation function [21] can be outsourced. Figure 4 shows the result of processing data in the form of a maximum Peak Ground Acceleration map in the NTB region.

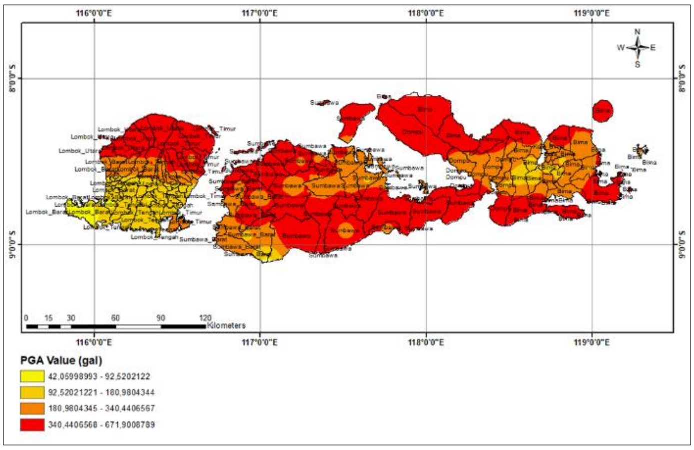


Figure 4. Map of Maximum Ground Vibration Acceleration (PGA) of the NTB Region

Based on Figure 4, some of the NTB regions have the highest maximum ground vibration acceleration (PGA) value, namely the districts of Sembalun, Sambelia, Pemenang, Tanjung, Alas Barat, Pekat, and Parado. Tambora, Ganges, Alas, Kayangan, Lambu, East Sakra, Buer, Taliwang, Poto Tano, Hu'u, Labangka, Concentrated, Utan, Orong Telu, Sanggar, Masbagik, Lenangguar, Lopok, Lambu, Wera, Ambalawi, Soromandi, bayan [29], Montong Gading, Maronge, Empang, Kilo, Sape, Langgudu, Seteluk, Terara, Sandubaya, Labuhan Badas, Monta, Aikmel, Ropang, Pringgabaya, Moyohilir, Lunyuk, and North Batukliang sub-districts [30,31] with a maximum PGA value of 340,4406 – 671,9008 gal. This is in accordance with previous research related to the area with the largest earthquake magnitude [32] and is considered an area that has the potential for a large earthquake in the future [13]. The areas that have the maximum ground vibration acceleration (PGA) are in the sub-districts of Manggelewa, Jereweh, Sumbawa, Batulanteh, Selong, Belo, Utan, Labuhan Aji, Jerowaru, East Rasanae, Poto Tano, Plampang, Wera, Moyohulu, Lingsar, Narmada, Sikur, Lape, Unter Iwes, Raba, Rasanae Barat, Woja, Tarano, Sape, Langgudu, Lape, Sukamulia, Donggo, Rhee, Wanasaba, Kempo, Lape, North Moyo, Asakota, Dompu, Maluk, Brang Rea, Mataram, Wawo, Batu Layar, Selaparang, Brang Ene, Tarano, and Gunung Sari sub-districts with a maximum soil vibration acceleration (PGA) of 180.9804-340.4406 gal. For the districts of Pujut, Sekarbela, Cakranegara, Suela, Pajo, Sape, Pringgarata, Ampenan, East Praya, Maronge, Batukliang, Lantung, Palibelo, Kopang, Labu Api, Keruak, Sekongkang, Kediri, Suralaga, Labuhan Haji, West Praya, Mpunda, Woha, Sambelia, Kuripan, Lambitu, Jonggat, Bolo, Pringgasela, Gerung, Praya, Southwest Praya, Janapria, West Sakra, and Mada Pangga sub-districts have a maximum ground vibration acceleration value of 92.5202-180.9804 gals. This is followed by Sakra, Central Paraya, Lembar, and Sekotong sub-districts which have the lowest maximum ground vibration acceleration (PGA) of 42.0599-92.5202 gal.

The level of danger posed by tectonic earthquakes is usually expressed on an intensity scale [33-35]. The results of the conversion of the PGA map to the intensity scale for the NTB region are shown in Figure 5.

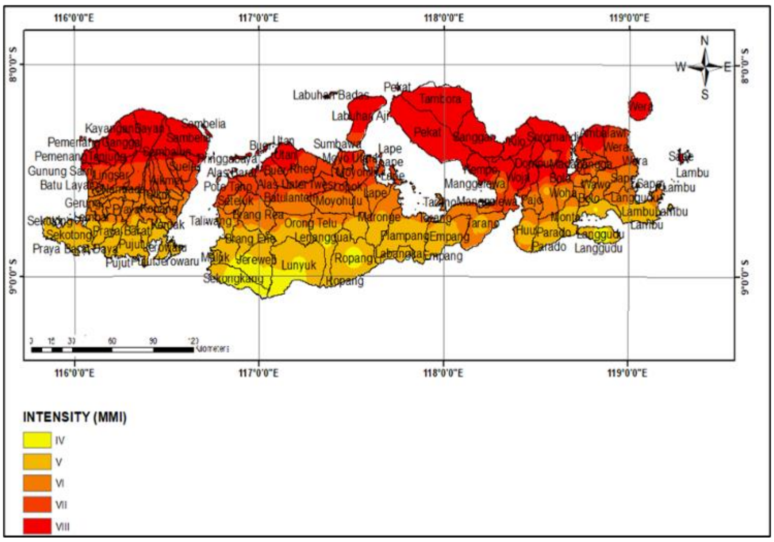


Figure 5. Intensity Map of the NTB Region

Based on Figure 5, the map for each region shows that most of the northern regions of the West Nusa Tenggara and East Nusa Tenggara islands have relatively large intensity values (VII-

VIII MMI). This is in accordance with the results of BMKG mapping and previous studies [36,37]. This indicates that the NTB archipelago is vulnerable to the danger of a tectonic earthquake, which is significantly damaging and could have a negative impact on the damage to infrastructure buildings in the region [10,4].

The results of mapping the intensity scale of tectonic earthquakes in the NTB region using the Zhao attenuation method, when compared with the intensity scale mapping based on data released by the BMKG in 2019, are similar. However, the data verification of field facts in some areas does not always show the maximum intensity value. This is what distinguishes why Zhao et al. [21] is different from the map of the results of field fact verification. Although the two maps are different, there are similarities in intensity patterns to each other [37]. The implications of the results of this study are useful in the development of geophysics in relation to earthquake modeling. The results of the mapping are useful as a reference for disaster mitigation so that disaster risk reduction is expected [38-39].

The limitations of this research are that the data collected on shallow earthquakes, with a depth of ≤ 60 km and a magnitude M≥5 SR, knowing that there is still a possibility of an earthquake from a subduction or deep source that can be damaging. It is recommended that future researchers do a comprehensive mapping of destructive earthquakes from both shallow and deep earthquake sources that occurred in the NTB region. In addition, further research can do mapping after relocating the source of the earthquake so that the results are more accurate.

CONCLUSION

The NTB islands have tectonic earthquake characteristics with a scale of 5.0-5.5 SR and 5.5-6.0 SR, with the highest frequency of occurrence and only a small frequency of occurrence on a scale of 6.0 SR and above. The distribution of earthquake epicenters in the NTB region is clustered in four places, namely the plate subduction zone in the southern waters of the NTB islands, the non-volcanic and volcanic zones in the eastern NTB islands, and the Back Arc Thrust zone in the northern waters of the archipelago. Meanwhile, the distribution of the hypocenter is spread over the Eurasian plate. Only a small part of the distribution of the earthquake hypocenter on the Indo-Australian plate. The tectonic earthquake hazard level is significantly destructive in the NTB region based on the analysis using the Zhao attenuation function. This is characterized by the value of the V-VIII MMI intensity scale. Most of the islands of NTB are characterized on the VII-VIII MMI scale and only a small part is characterized on the V-VI MMI scale.

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AUTHOR CONTRIBUTIONS

Ahmad Luthfin: Conceptualization, edit article, Formal Analysis, Resources, Project Administration and Validation; Irjan: Conceptualization, Methodology and validation; and Septiana Nur Hidayati: Data Curation and Writing - Original Manuscripts, Methodology and validation

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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