PROBABILISTIC SEISMIC HAZARD ANALYSIS IN NORTHERN SUMATRA

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ABSTRACT

Northern Sumatra (NS) is one of Indonesian region that prone to earthquake and has performed a high level of vulnerability due to a large number of population and high economic growth rate. Therefore, the earthquake hazards analysis is crucial in this region. In this study, probabilistic seismic hazard analysis used to quantify the level of the earthquake hazard. Based on the calculated data, the NS region has hazard value between 0.05 – 1.3 g. Moreover, the group of islands in western Sumatera has the maximum hazard value while the eastern coastline of Sumatra presents the minimum amount. Furthermore, Banda Aceh and Padang Sidempuan City have a medium level which influenced by the Sumatran shear fault. Meulaboh and Gunung Sitoli City have a medium level activated from the subduction zone. Meanwhile, Medan and Lhoksuemawe City have a low level of earthquake hazard which associated with the deep and shallow background.

Keywords: Earthquake; Seismic; Hazard

Introduction

North Sumatra is an area with a high degree of disaster vulnerability characterized by a large number of population and the high rate of economic growth. On the other hand, this area is prone to earthquake disaster. There are two active sources of earthquakes in this area: the Indo-Australian Plate subduction zone of the Eurasian Plate and the Slide Fault of Sumatra (Figure 1).

The Australian Indo Plate has undergone its relative plate velocities accounted for 52-60 mm/yr, and the rate of return ha increased over the south of Sumatra.[1] The collision activity of these two plates can trigger an earthquake. In the last two centuries, several earthquake sources have caused quite large earthquakes such as the earthquake occured in 1the 833 (M = 8.3-9.2), in 1861 (M = 8.3-8.5), in 2004 (M = 9.0), in 2005 (M = 8.7).[2]

The Sumatran shear fault (SHF) zone is the boundary between two lithosphere plate blocks, where one of the blocks moves against each other. The SHF zone according to Sieh and Natawidjaja[3] occurs due to the oblique convergent plate meeting between the Eurasian Plate and Indo-Australia plate. The SHF zone stretches for 1900 km and is divided into zones of small segments with slip rate between 11-27 mm/yr. Some of the major earthquakes that have occurred in this zone include the Padang Panjang earthquake of 1926 (Ms = 6.75), the 1933 Liwa earthquake (Ms = 7.5), the 1964 Aceh earthquake (Mb = 6.7), the 1993 Liwa earthquake (Ms = 7.2).[2]

Based on the description above, it is necessary to do hazard seismicity analysis in order to mitigate earthquake disaster. One of the efforts made is to create a hazard map of seismicity, which is useful in planning

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earthquake resistant building. The parameters of earthquake resistant structural earthquake construction study calculations according to Irsyam[4] may be represented by:

1. Maximum ground acceleration, this parameter provides peak earthquake power information.
2. The response of earthquake spectra, this parameter provides additional information about earthquake frequency and possible amplification effect.
3. History of earthquake acceleration time provides the completed information that is a variation of the magnitude of the earthquake load for any time during the duration of the earthquake

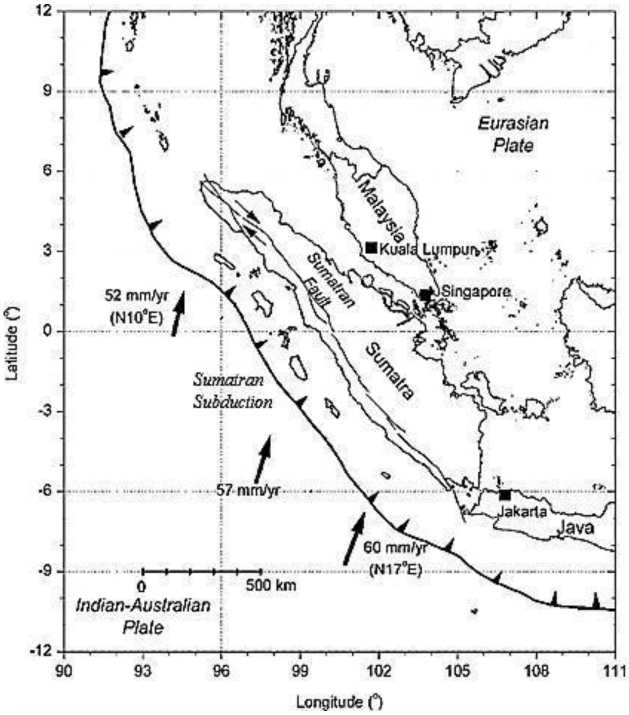

Figure 1.The earthquake source in the northern Sumatran region comes from the subduction zone and the sumatran fault zone that extends along the island of Sumatra. Where the subduction level rises towards the south, from 52-60 mm/yr.[1]

Seismic Hazard Analysis

To analyze the above parameters, according to Mc Guire R.K.[5] can be used deterministic or probabilistic seismic hazard analysis. Deterministic seismic hazard analysis (DSHA) is commonly used to estimate seismic hazards based on worst-case scenarios. This method is frequently applied to a building plan such as nuclear power plants, and others.[4]

The probabilistic seismic hazard analysis (PSHA) is a deterministic hazard analysis with the addition of scenarios which accounted for uncertain factors. Uncertainty factors include the size, location or frequency of earthquake events. In addition, this analysis has other advantages of being able to integrate hazards based on a location against various earthquake sources.[6]

The probabilistic seismic hazard analysis (PSHA) according to Irsyam[4] evaluates four stages:

1. Identify the source of seismicity.
2. Characterization, parameterization of earthquake sources.
3. Selection of attenuation function.
4. Calculation of earthquake hazard.

The objective of this research is to develop seismic hazard assesment in The NS area and to know the potential seismic hazard level of big cities in North Sumatera with approach of peak ground acceleration, and earthquake return period.

Methods

The data used in this study is the earthquake occurrence data that occurred in the northern part of Sumatra between 6 LU - 3 LS and 93 BT - 102 BT. Data were extracted from the BMKG and NEIC earthquake catalogs.

Magnitudo Uniformity

The earthquake catalog data has uniform magnitude characteristics which lead to inconsistencies in the hazard analysis. Therefore, the magnitude conversion was done by using a uniform magnitude. In this study, the moment magnitude (Mw) utilized for the good consistency in both large and small magnitudes.[7] The Mw conversion empirically obeyed Irsyam approximations[4]:

Declustering catalogue

The earthquake catalog data is a mixture of both mainshock and aftershock data; if the PSHA analysis is not appropriate, it caused by the probabilistic technique assumed earthquakes involving random and continuous events. Therefore, it is necessary to separate the mainshock earthquake and the other ones.

Separation of major earthquakes and the other ones are done by the method of time and distance windows, Gardner and Knoopof criteria using Zmap software.[8]

$$\text{Mw} = 0.143\ \text{Ms2} - 1.051\text{Ms} + 7.285$$

$$\text{Mw} = 0.114\ \text{mb2} - 0.556\ \text{mb} + 5{,}560$$

$$\text{mb} = 0.125\ \text{ML2} - 0.389\ \text{ML} + 3.513$$

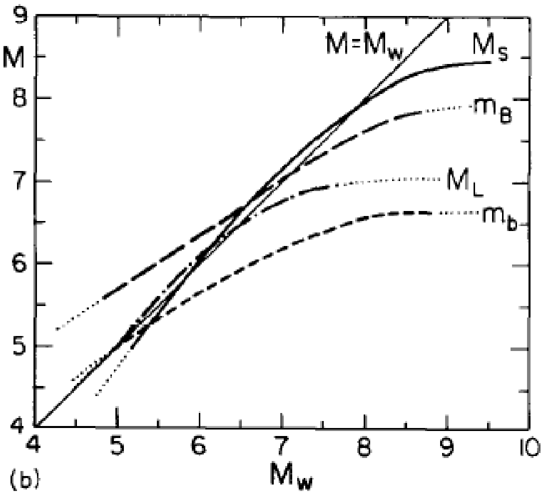

Figure 2. Relations between various magnitudes scales represented the Mw consistency in large and small magnitudes.[7]

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Catalog Completeness Analysis

The earthquake catalog data contains an element of incomplete data on events with small magnitudes and recording in antiquity. This is due to the sensitivity and coverage of the seismograph network. To overcome this, need to be done data completeness analysis, either completeness of magnitude and completeness of year of recording.

The completeness of the recording year can be identified by seismic rate analysis of an independent earthquake event against the cumulative number of earthquakes. Completeness of magnitude or magnitude completeness (mc) is determined by the maximum likelihood method using zmap.[8]

Earthquake Source Modelling

In this analysis three earthquake source models are used, this refers to the PSHA program from USGS, i.e., the source of a fault, subduction, and background earthquake.[9] The origin of the earthquake background itself are categorized into shallow and deep earthquakes.

a. Fault earthquake source

That is the zone of earthquake occurrence that occurs on the fault that has been clearly defined including the mechanisms, the slip rate, the dip, the fault length, and its location. In this study, 9 major segments of Sumatra Fault were modeled, including the segment of Aceh, Seulimeum, Tripa in NAD Province, Renun, Toru, Angkola, Barumun in North Sumatra Province, and Sumani, Sianok in West Sumatra Province.

b. Subduction earthquake

It is an earthquake that occurs at the boundary zone, between the Indo-Australian Plate that plunges into the Eurasian Plate. The seismic events in this source model are limited to a depth of 50 km. This subduction earthquake modeling has a normal or thrust fault mechanism. Meanwhile, seismic events that have depth more than 50 km, represented by deep background model.

c. Background earthquake

That is the source of the earthquake that is not yet known clearly but at that place has been an earthquake event. The source of this earthquake is divided into shallow (< 50 km) and deep (50-300 km) background. This source model used a major earthquake catalog which reduced by earthquakes due to subduction and fault.

Determination of Attenuation Functions

The attenuation function applied the principle of NGA (Next Generation Attenuation) in which the attenuation function is in its manufacture using global earthquake data.[4]

a. Fault and shallow background earthquake source model:

(1) Boore-Atkinson NGA.
(2) Campbell-Bozorgnia NGA.
(3) Chiou-Youngs NGA.

b. Subduction Earthquake Interface Source (Megathrust):

(1) Geomatrix subduction
(2) Atkinson-Boore BC.
(3) Zhao et al., with variable Vs-30.

c. Earthquake source deep background model:

(1) AB intraslab seismicity Cascadia region BC-rock condition.
(2) Geomatrix slab seismicity rock.
(3) AB 2003 intraslab seismicity worldwide data region BC-rock condition.

Probabilistic Seismic Hazard Analysis

The PSHA method was first proposed by Cornell[10]. The models and concepts of this analysis remain in use today. Models and techniques of calculation continue to be developed by experts, such as EERI[11]. This theory assumes the magnitude of the M quake and the distance R as a continuous independent random variable. In this general form the theory of total probability can be expressed as follows:

$$P\,[I \geq i] = \iint P\,[I \geq i \mid m \text{ and } r]\, fM\,(m)\, fR\,(r)\, dm\, dr$$

where,
fM : Magnitude distribution function.
fR : Hyposenter distance distribution function.
P [I ≥ i | m and r] : the conditional probability of intensity I that exceeds the value to a location reviewed for earthquake events with magnitude M and H hypocenter distance.

Results and Discussion

Earthquake Hazard Map

Based on the results of data processing with the help of the USGS PSHA-2007 program, can be generated hazard value for each source earthquake and combined hazard map result of a combination of these sources.

The following seismic hazard map analysis is the maximum ground acceleration at the PGA level (T= 0 s), in bedrock with an opportunity exceeded by 10% within 50 years.

Subduction Hazard Map

The result of processing to the source of earthquake subduction is obtained hazard value of 0.05-1.3 g (Figure 3). The largest value lies in the cluster of islands in the western part of Sumatera Island, such as Simeulue Island, Nias Island and Siberut Island. The value of the hazard is getting to the east getting smaller. This is due to the subduction zone located on the western part of Sumatera Island so that the ground acceleration become shrinking to the east, along with increasing the distance to the source.

Fault hazard map

The result of processing to earthquake source due to a fault has obtained hazard value of 0.0-0.6 g (Figure 4). The largest hazard value is located in the area around the Sumatera fault zone, such as in Banda Aceh, Aceh Besar, Aceh Tengah, Dairi, Tapanuli, and Padang Sidempuan. For hazards in other areas, the hazard value decreases as the distance increases.

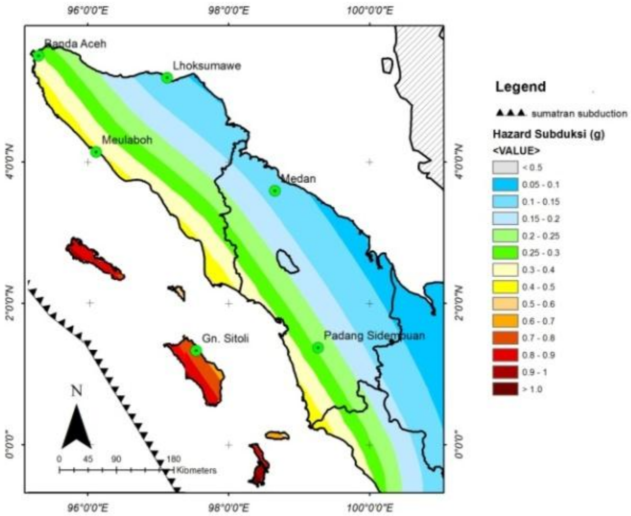

Figure 3. Earthquake hazard map due to subduction source

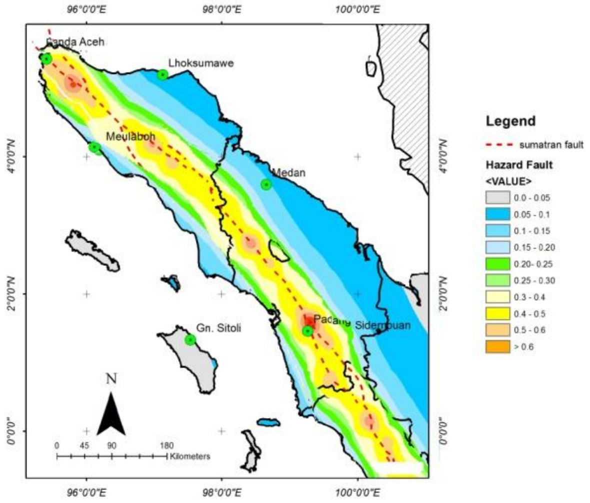

Figure 4. Earthquake Hazard Map due to fault source

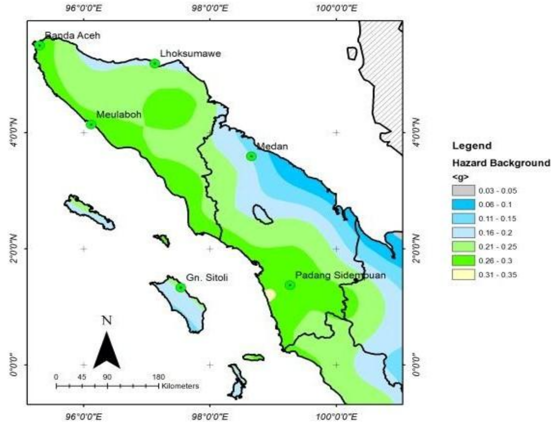

Figure 5. Earthquake hazard map due to background souce

Background Hazard Map

The result of the processing due to background earthquake has resulted in a hazard value of 0.05 - 0.35 g (Figure 5). The largest hazard value is located on the west coast of Sumatera such as Aceh Jaya, South Aceh, East Aceh in the Nangroe Aceh Darussalam Province and Tapanuli Tengah to Mandailing Natal in North Sumatera Province.

Hazard Map of Combine Source

From the combined hazard processing of the three sources, the northern part of Sumatera has a hazard value of 0.05 - 1.3 g (Figure 6). Areas with the greatest hazard potential are the islands in the western part of Sumatera Island namely Simeulue Island, Nias Island, Siberut Island with hazards greater than 0.6 g. Meanwhile, areas with low hazard potential are on the coast east of Sumatra Island such as Medan City and Lhokseumawe City with hazard value is less than 0.2 g.

Compared with national earthquake hazard map 2017 from PUSGEN[12] (Figure 7) found that hazard map of Northern Sumatera (Figure 6) has the same relative hazard ranges, ranging from 0.05 g to more than 0.6 g.

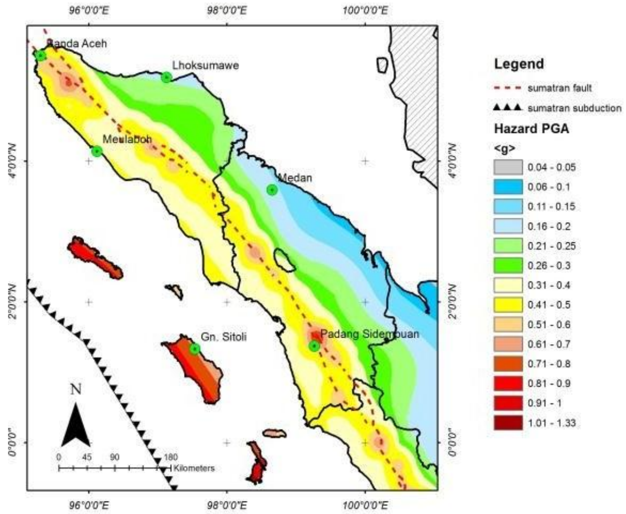

Figure 6. Earthquake hazard map from source combination (NS hazard map)

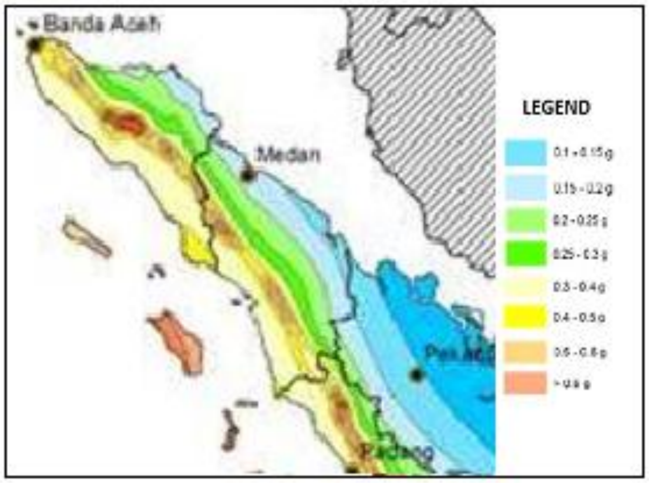

Figure 7. PUSGEN earthquake hazard map[14]

Table 1. Comparison of Earthquake Hazard results in several cities in Northern Sumatra

Province	Cities	PUSGEN Hazard Map	NS Hazard Map	Difference
NAD	Banda Aceh	0.4-0.5	0.4-0.5	± 0.0
NAD	Meulaboh	0.3-0.4	0.4-0.5	± 0.1
NAD	Lhokseumawe	0.15-0.2	0.15-0.2	± 0.0
North Sumatra	Medan	0.15-0.2	0.15-0.2	± 0.0
North Sumatra	Padang Sidempuan	0.5-0.6	0.5-0.6	± 0.0
North Sumatra	Gn. Sitoli	> 0.6	0.6-0.7	≥ 0.0

From the sample at Table 1, most of the sample cities in Northern Sumatera also show that the earthquake hazard results relatively same, except Meulaboh city that has difference around 0.1 g.

In this analysis, there are several aspects that distinguish the national earthquake hazard map 2017 with the earthquake hazard map of Northern Sumatera. The difference in earthquake catalogue has implied the difference in total numbers of earthquake and parameter result. It affects the difference of the earthquake background source.[7]

The difference in source modelling especially in Sumatran Fault (fault source, slip rate) has altered the total stress, and strain resulted in the little difference in seismicity and fault hazard map.

Earthquake hazard curve

This curve describes the relationship between the repeated periods of earthquakes and the peak acceleration of the ground against each source of the earthquake. Thus, through this curve can be identified how an earthquake source can affect a region. The following discussion provides an analysis of seismic potential from several big cities in northern Sumatera.

a. Banda Aceh

Banda Aceh is a city with the dominant hazard of the fault (Figure 8). This is because the city is quite close, even flanked by two segments of the Sumatera shear fault, the Aceh and Seulimeum segments. Then for other sources, it also has a significant influence both between subduction, deep background and shallow background.

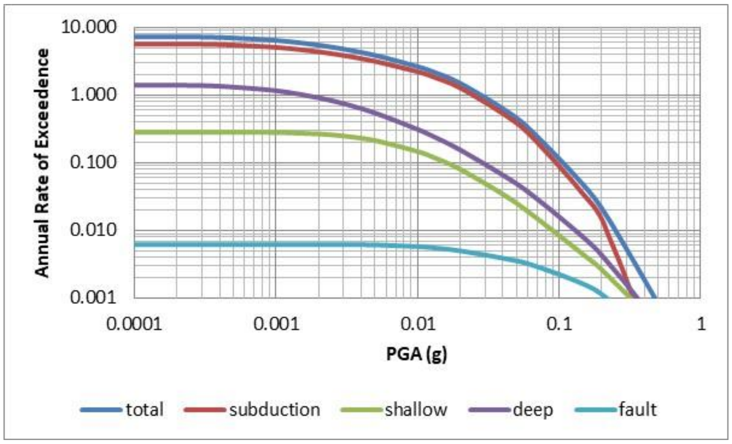

Figure 8. Banda Aceh Hazard Curve

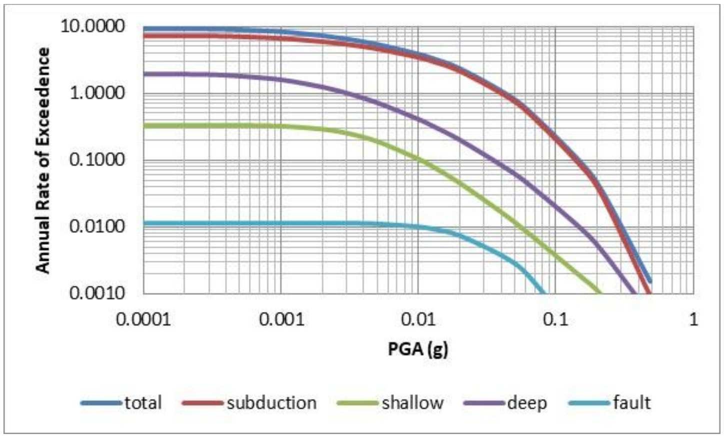

Figure 9. Meulaboh Hazard Curve

Then another influential source of earthquakes is the source of the earthquake due to the deep background (50-300 km), whereas shallow background (0-50 km), and fault have not a significant influence.

c. Lhokseumawe

Lhokseumawe is a city with dominant hazard influences derived from shallow earthquakes (Figure 10). The other one is deep background earthquake also has a significant influence, while the effect of earthquake due to fault and subduction is not significant because the distance of these two sources is quite far with this city.

d. Medan

Medan City is a city with the dominant hazard from deep background earthquakes (Figure 11). This is because the city of Medan is quite far from the source of the fault and subduction earthquakes, so the source of the earthquake is not significant and most of the earthquakes that affect are the earthquakes that coming from the subduction slab. Although the largest number of earthquakes occur caused by megathrust subduction, where the effect is not significant in this city.

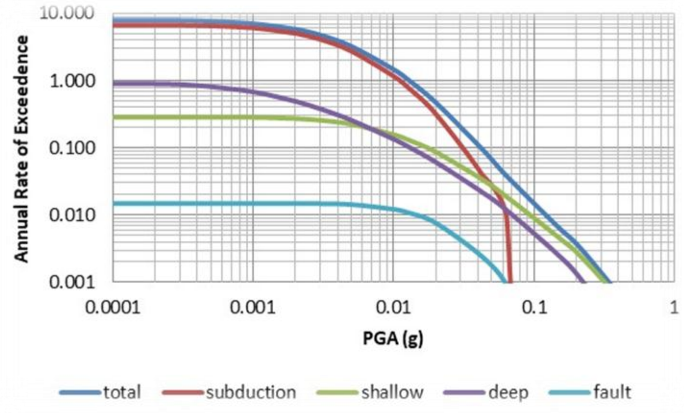

Figure 10. Lhokseumawe Hazard Curve

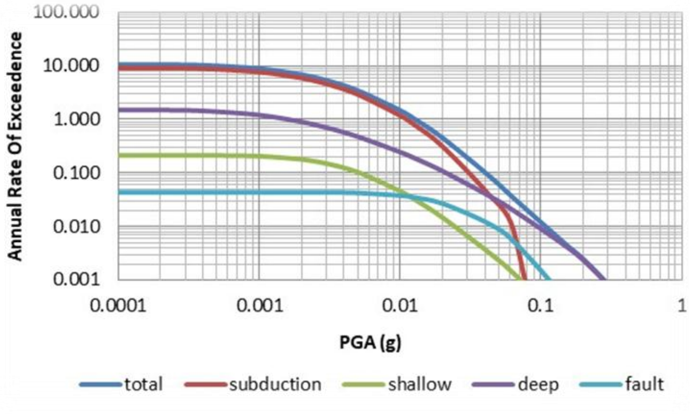

Figure 11. Medan Hazard Curve

e. Padang Sidempuan

Padang Sidempuan has a dominant hazard effect that originates from the fault (Figure 12). This is because the city is located close to the zone of the Sumatera shear fault. Although the highest frequency of earthquakes that occur is caused by megathrust earthquakes, the resulting shock is very small (<0.2 g) so it does not have a significant effect.

f. Gunung Sitoli

From hazard curve analysis it is found that Gunung Sitoli City (Figure 13) is a city with dominant hazard effect due to subduction. This corresponds to the geographical location of the city directly adjacent to the subduction zone.

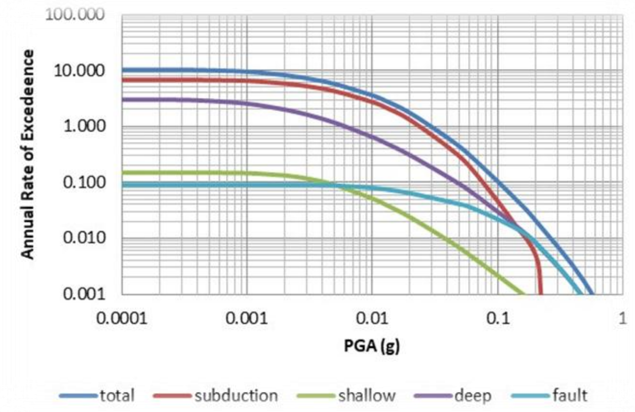

Figure 12. Padang Sidempuan Hazard Curve

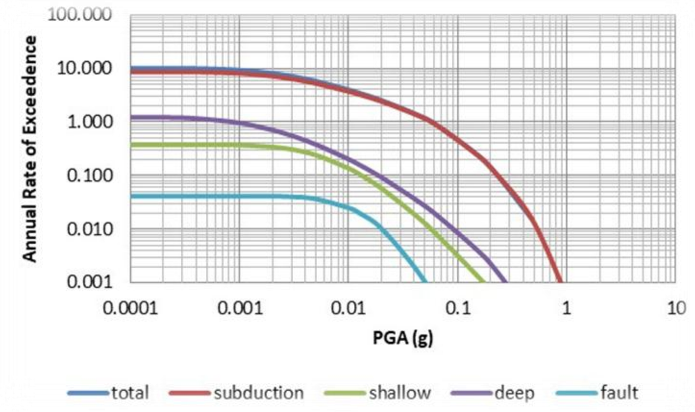

Figure 13. Gunung Sitoli Hazard Curve

Earthquake Threats Level

The National Disaster Management Agency has classified the earthquake threat level based on the ground acceleration.[13] This threat level is divided into three classes including, low (<0.26 g), moderate (0.26 -0.70 g), and high (> 0.70 g).

Based on the calculations, the hazard for Meulaboh and Gunung Sitoli cities is 0.488 g and 0.688 g, which is included in the category of moderate threat levels. Lhokseumawe and Medan each have a low threat potential level, with hazards of 0.171 and 0.199 g. Padang Sidempuan and Banda Aceh had a moderate threat level with a hazard of 0.578 g and 0.405 g (Table 4).

Conclusion

Hazard seismicity in the PGA level (T = 0 s) in northern Sumatra ranges from 0.05-1.3 g, with the highest hazard lying on the west coast, while the smallest on the east coast of Sumatera Island. Banda Aceh, Padang Sidempuan, Meulaboh, and Gunung Sitoli have moderate threats level of earthquakes. Meanwhile, Medan and Lhokseumawe have low threats level of earthquake. Banda Aceh and Padang Sidempuan have hazard with dominant influence from fault activity, Meulaboh and Gunung Sitoli come from subduction activities, while Lhokseumawe and Medan come from earthquake background. There is a little difference with National hazard map 2017 between 0.0-0.1 g; this difference is caused by catalogue data factor and earthquake source modelling.

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