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Earthquake Risk Area Mapping Based on Probabilistic Seismic Hazard Analysis (PSHA) Method and Microtremor Data in Nias Island

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Abstract

Mapping seismic hazards have been done using Probabilistic Seismic Hazard Analysis (PSHA) and microtremor in Nias Island. This research was purposed to determine seismic Hazards based on peak ground acceleration distribution using software Ez-Frisk 7.52 and the results of microtremor data single station on ten measuring points processed using software geophys. The result of the calculation PSHA value from all sources of the earthquake (Megathrust, Fault, Background, and Local fault Mentawai) obtained distribution hazard value in PGA condition for the return period of 500 years and 2500 years at the base rock with values ranging between 1.0 g – 1.5 g and 1.0 g – 1.5 g. While for hazard value in spectral condition T = 0.2 seconds for the return period of 500 years and 2500 years with the value ranging between 3.0 g – 3.5 g and 6.0 g – 8.0 g. For hazard value in spectral condition T=1.0 second for the return value of 500 years and 2500 years with the value ranging between 1.0 g – 1.5 g and 2.0 g – 2.5 g. The result of processing microtremor shows that North of Nias has local geology characteristics with a dominant frequency range between (0.89 – 6.81) Hz, amplification value between 0.54 – 1.92, index seismic susceptibility value between 0.13 – 4.14, the value of surface peak ground acceleration (0.65 - 185) g, the value of bedrock peak ground acceleration (0.16 – 0.19) g and, thickness of weathering layer between (12.3 – 96) m, the value of ground shear strain 1.5×10^{-5} – 73×10^{-5}.

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Abstrak

Telah dilakukan penelitian mengenai Pemetaan daerah potensi rawan bencana seismik dengan metode Probabilistic Seismic Hazard Analysis (PSHA) dan data mikrotremor di Kepulauan Nias. Penelitian ini bertujuan untuk memperoleh nilai dari percepatan tanah maksimum di batuan dasar dengan kondisi PGA dan spectral acceleration (SA) pada periode 0,2 detik dan 1,0 detik dengan periode ulang 500 tahun dan 2500 tahun. Pemetaan ini dilakukan dengan bantuan software Ez-Frisk 7.52 dan hasil pengolahan data mikrotremor single station pada 10 titik pengukuran diolah dengan bantuan software geopsy. Berdasarkan nilai yang didapatkan dari analisa PSHA dengan menggunakan semua sumber gempa (Megathrust, Fault, Background dan sesar lokal mentawai) diperoleh distribusi nilai hazard pada kondisi PGA dengan periode ulang 500 dan 2500 tahun di Kepulauan Nias yaitu 1,0 g – 1,5 g dan 2,0 g – 2,5 g. Nilai hazard dengan kondisi spektra T = 0.2 detik untuk periode ulang 500 tahun dan 2500 tahun, yaitu 3,0 g – 3,5 g dan 6,0 g – 8,0 g. Nilai hazard di batuan dasar dengan kondisi spektra T = 1,0 detik untuk periode ulang 500 tahun dan 2500 tahun diperoleh nilai, yaitu 1,0 g – 1,5 g dan 2,0 g – 2,5 g. Dari hasil pengolahan data mikrotremor di Nias utara didapatkan karakter geologi lokal dengan nilai frekuensi dominan berkisar antara 0,89 Hz – 6,81 Hz, nilai amplifikasi 0,54 - 1,92, nilai indeks kerentanan seismik 0,13 - 4,14, nilai percepatan getaran tanah di permukaan 0,65 g -1,85 g, nilai percepatan getaran tanah di batuan dasar 0,16 g – 0,19 g, ketebalan lapisan lapuk 12,3 m - 96 m dan nilai ground shear strain $1{,}5 \times 10^{-5}$ – 73×10^{-5}.

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1. Introduction

Earthquake damage depends not only on the distance and intensity of the earthquake but also on the local geology of the area, which also contributes to the level of damage (Marjiono, 2010). The location's earthquake disaster level could be known using the PSHA method. PSHA can provide a focused framework by identifying and estimating uncertainty factors, then combined to get a general description of the earthquake hazard level—the hazard level of a site is defined in the PGA form (Kurniawan, 2016). Based on these considerations, this study also analyzed microtremor data using the HVSR method.

PSHA analysis and microtremor observation micro zonation in this study are expected to be able to complement each other to determine earthquake vulnerability areas. This step can be used as a mitigation effort to minimize the impact of the earthquake that will occur in the future. The results of this study expected can provide better information about the vulnerability of the islands of Nias.

1.1 *Probabilistic Seismic Hazard Analysis* (PSHA)

Seismic hazard analysis was conducted to determine the risk of ground motion quantitatively based on the total probability theorem. The PSHA method provides a workspace that can identify uncertainties. The uncertainty factor is measured and combined in a rational relationship to produce a more detailed description of the earthquake risk calculation

1.2 Microtremor

Microseismic is a ground vibration besides earthquake, which can be a vibration due to human activity and natural activity. Microseismic may occur due to the vibrations caused by the ongoing person, the vibration of the car, the vibration of the engine, the vibrations of the wind, the ocean waves, or the natural vibrations of the ground (Tokimatsu, 2004). The vibrations of the soil in waves form are called microtremors.

The Horizontal to Vertical Spectral Ratio (HVSR) method is used to obtain the dominant frequency value of the soil and the amplification factor from microseismic measurement. Microseismic characteristics reflect the characteristics of the rock in a region. The dominant frequency value of the soil and the amplification factor is used to make a vulnerability map. The HVSR method was first described by Nogoshi and Igarashi (Nogoshi & Igarashi, 1971), and was widely introduced by Nakamura (Nakamura, 1989), so this method is commonly known as Nakamura's technique :

$$HVSR = \frac{\sqrt{\left(A_{(hor(east-west))}(f)\right)^2 + \left(A_{(hor(north-south))}(f)\right)^2}}{A_{(vertical)}(f)} \quad (1)$$

With:

$A_{(hor(east-west))}(f)$: Amplitude value of horizontal component frequency (east-west)

$A_{(hor(north-south))}(f)$: Amplitude value of the horizontal component (north-south)

$A_{(vertical)}(f)$: Amplitude value of the vertical component

Some of the parameters which can be obtained from microtremor analysis are:

1. Amplification (A_0), obtained from the HVSR curve
2. Dominant frequency (f_0), obtained from the HVSR curve
3. Seismic vulnerability index (K_g), calculated by:

$$K_g = \frac{A^2}{f_0} \quad (2)$$

4. Peak Ground Acceleration (PGA). The PGA formula used is:
   a. Kanai PGAs use the distance parameter of hypocenter and location, earthquake magnitude M_w, and dominant ground frequency to calculate surface acceleration. Written as:

$$\alpha_s = \frac{5}{\sqrt{T_o}} 10^{0.61M-1.66+\frac{3.6}{R}\log R+0.167-\frac{1.83}{R}} \quad (3)$$

   b. Fukushima and Tanaka PGAs, to calculate bedrock acceleration. written as

$$\log a_b = 0.41Mw - Log(R + 0.032 \times 10^{0.41\,Mw}) - 0.0034 + 1.3 \quad (4)$$

   c. *Ground Shear Strain* (GSS) calculated with:

$$\gamma = K_g 10^{-6} \alpha_b \quad (5)$$

2. Research Methods

2.1. Earthquake data

The earthquake history data used for the last 114 years around Sumatra Island was downloaded from the USGS, ISC, ANSS, EHB, NECEDC, and BMKG catalogs with coordinates -8.23° - 8.76° S and 91.78 ° - 108.27 ° E, From January 1914 to December 2016 with a magnitude of ≥ 5 Mw and depth < 300 km.

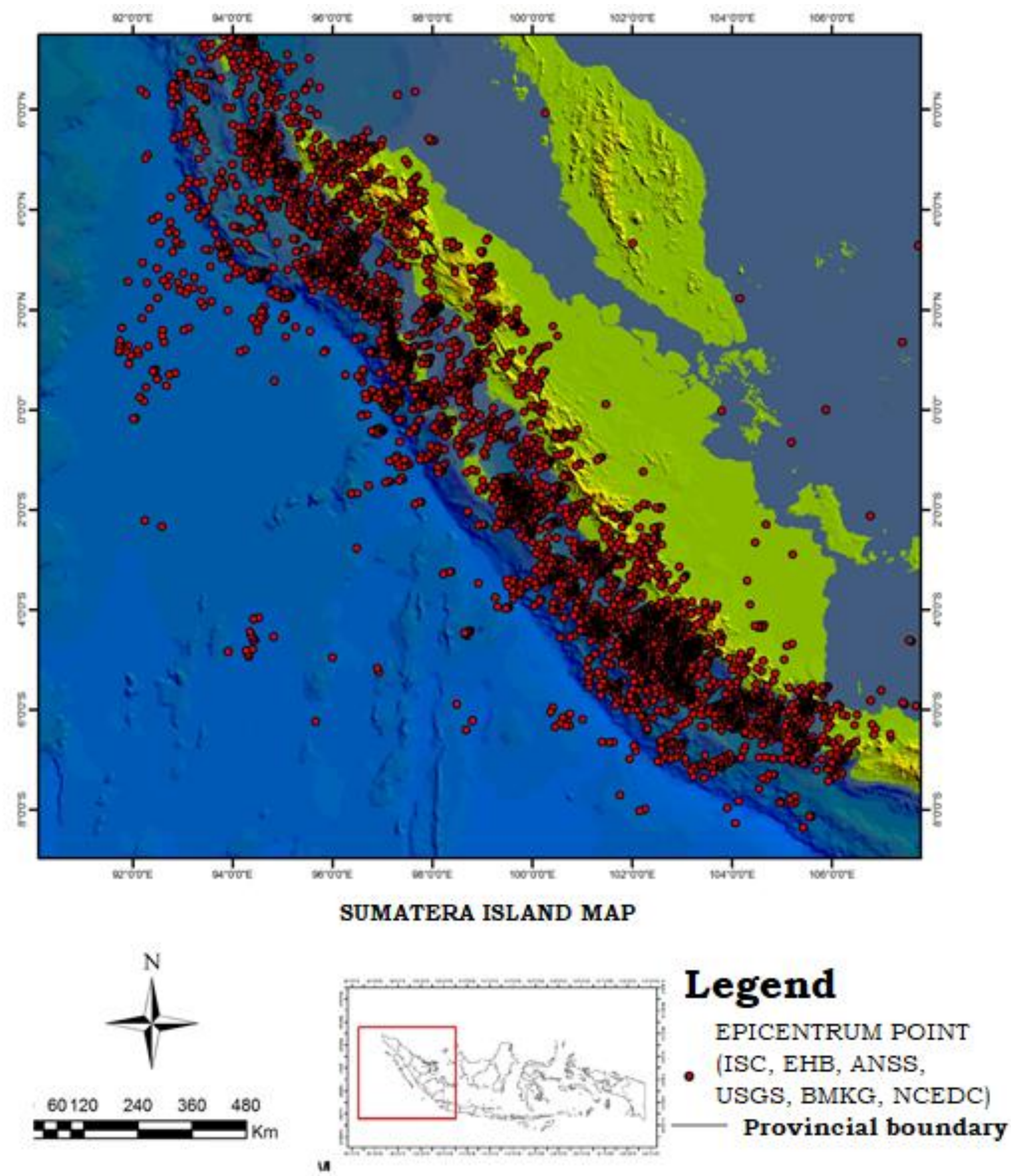

Figure 1. Distribution of epicenter on Sumatera island

2.2 Mikroseismic Data

Microtremor data *single station* North of Nias 1.37° - 1.49° S and 97.12° - 97.54 °E are from PVMBG (Pusat Vulkanologi dan Mitigasi Bencana Geologi) Bandung with ten measurement points.

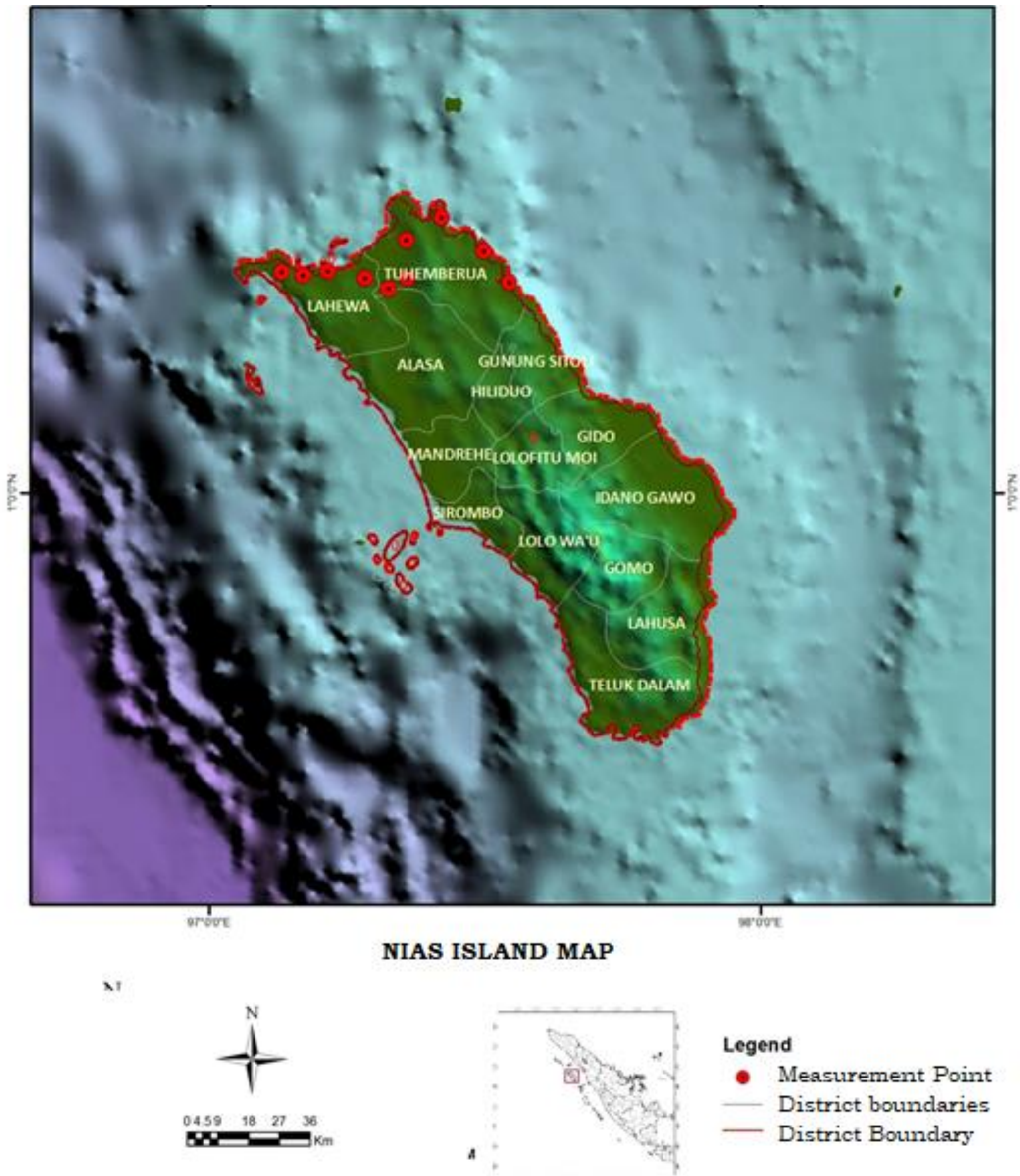

Figure 2. Location of Microtremor area

2.2. Workflow

The whole process of data processing for PSHA and Microtremor analysis is shown in the following figure:

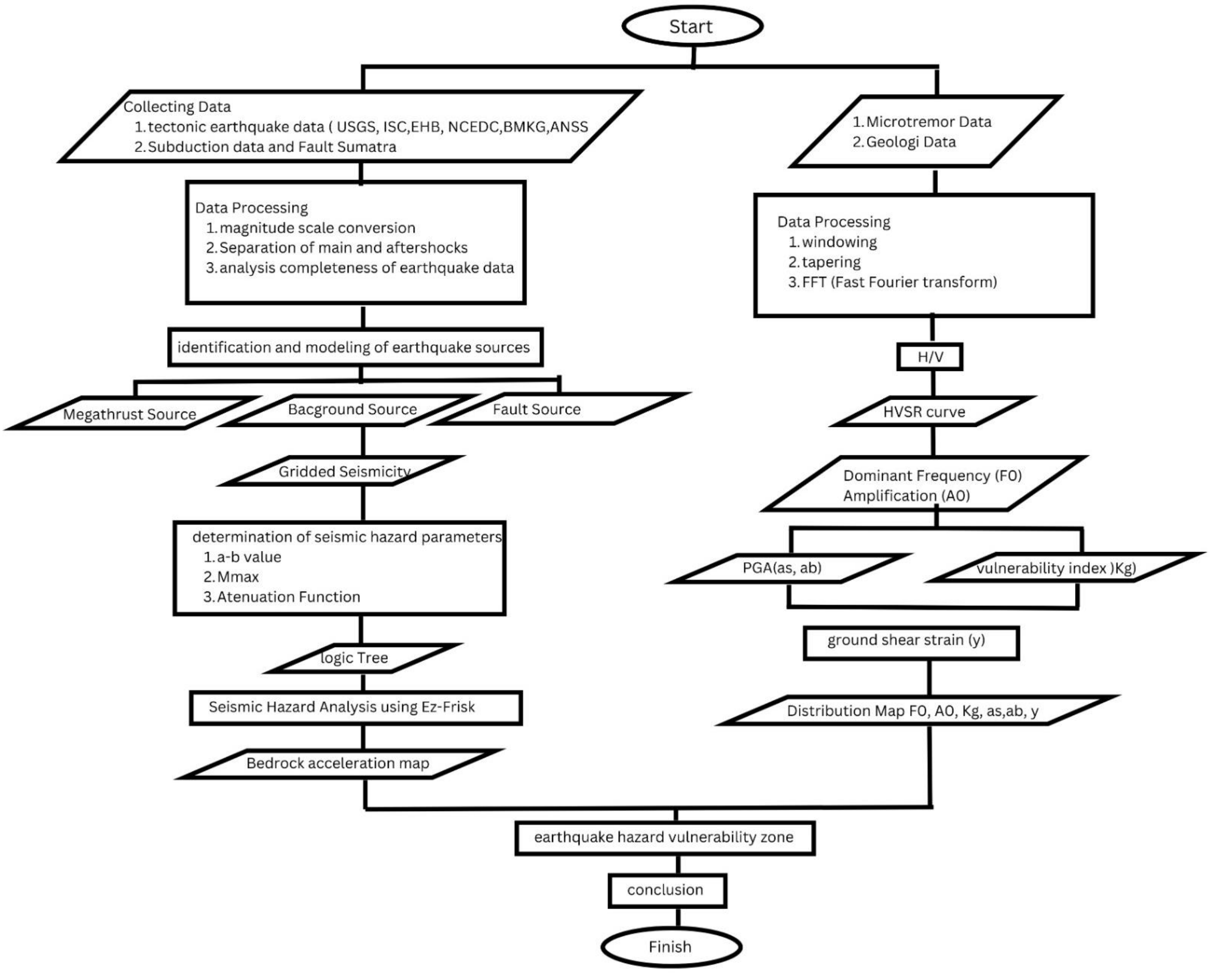

Figure 3. Research flow chart

3. Results and discussion

3.1. PSHA Analysis

The maximum vibration distribution value of each earthquake source model using the PSHA method gives the different values on each earthquake source. The influence of the Megathrust earthquake source contributed the most significant PGA value. It is because the Nias is located in the Megathrust area at a reasonably close distance. The Mentawai fault that divides the island of Nias also contributes to the value of the Hazard obtained. Based on the distribution of maximum acceleration values obtained, Nias island has a maximum acceleration because the area is located in the seismic source zone and the subduction and active fault zone. The value obtained highly correlates with the historical earthquake that ever happened. The earthquake source zone significantly affects the seismic activity and the acceleration value of ground movement in Nias.

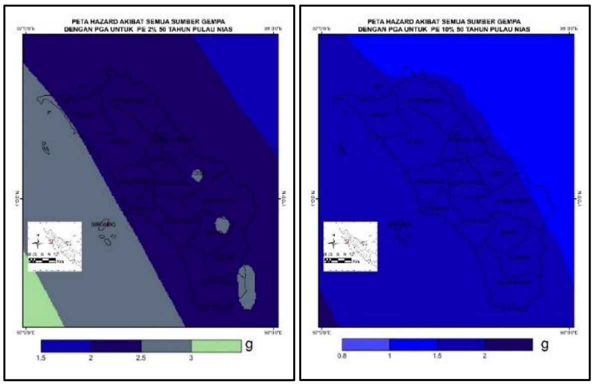

Figure 4. Hazard map of all earthquake sources with PGA, return period 500 (left) and 2500 (right) years

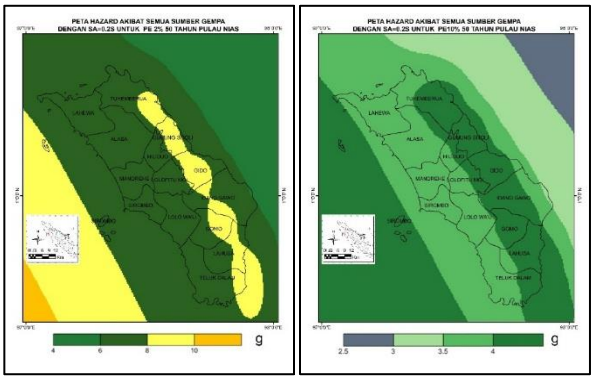

Figure 5. Hazard map of all earthquake sources with SA= 0.2 S, return period 500 (left) and 2500 (right) years

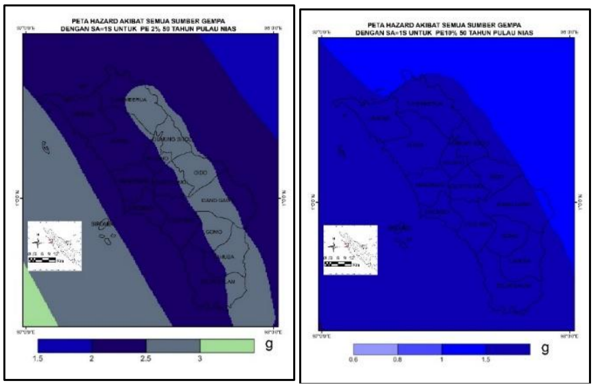

Figure 6. Hazard map of all earthquake sources with SA= 1 S, return period 500 (left) and 2500 (right) years

3.2. Microtremor Analysis

3.2.1. Dominant Frequency and Amplification

Data was obtained from PVMBG has as many as ten measurement points, but it can be processed only 9 points because one of the data (point 8) needs better record data. The dominant frequency value at point 9 needs to be more reliable. The results obtained from the data processing are shown in table 2. The distribution of dominant frequency and amplification values in North Nias is shown in Figure 7.

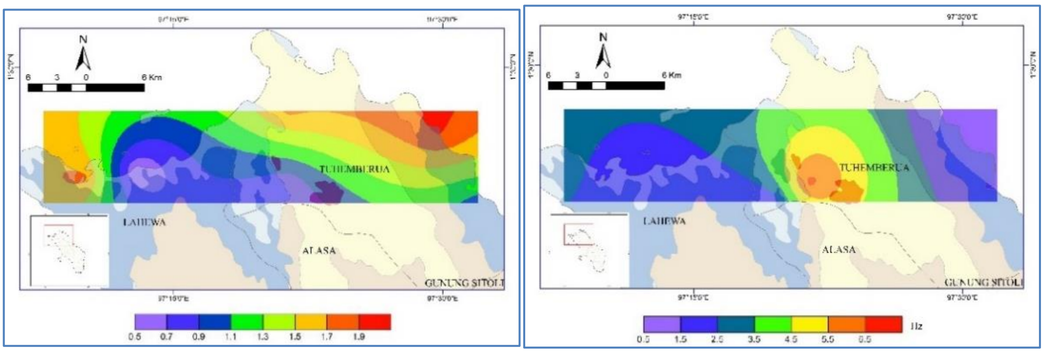

Figure 7. Amplification Distribution (Left) and Dominant Frequency (Right).

3.2.2. *k Ground Acceleration* (PGA)

The earthquake source calculated on the PGA calculation is the largest earthquake that ever occurred on 28 March 2005, with magnitude 8.6 at a depth of 30 km. The Kanai PGAs are used to calculate the PGA on the surface. The earthquake risk level table [9] indicates the area has a substantial (very high-risk second) earthquake risk level. Fukushima and Tanaka PGAs are used to calculate PGA values in bedrock. Based on the earthquake risk level table [9] with it indicates the area has a significant earthquake risk level (high-risk second).

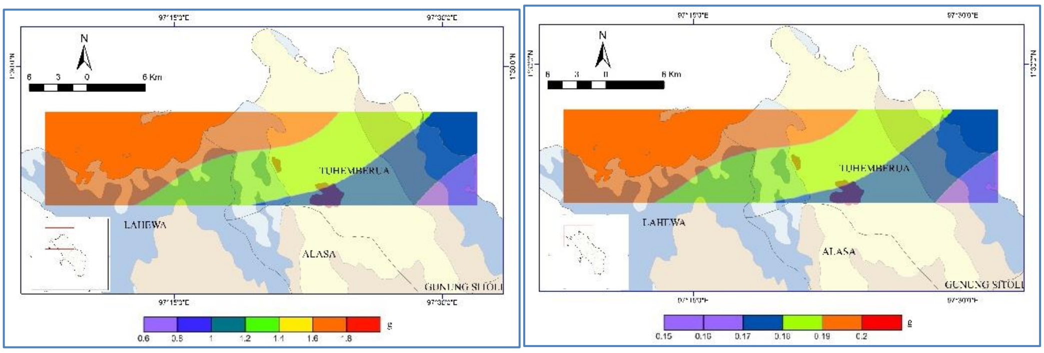

Figure 8. PGA surface (left) and PGA bedrock Distribution (right)

3.3. Analysis of the Relation of earthquake hazard level in Nias Island with PSHA and microtremor method.

The processing results on each earthquake source can be seen in table 1. Based on the distribution of maximum acceleration value obtained, Nias islands areas have a significant maximum ground acceleration value. It is because the area is located in the seismic source zone and the subduction zone, and the active fault zone. The value obtained highly correlates with the historical earthquake that ever happened. The earthquake source zone significantly affects the seismic activity and the acceleration value of ground movement in Nias.

Table 1. The results of processing each source of earthquake

Num	Source of earthquake	Return Period	
		500 yr	2500 yr
1	Megathrust	(1 - 1,5) g	(2,0 - 2,5) g
2	Fault Sumatera	(0,25 - 0,3) g	0,6 g
3	Fault Sumatera and Fault Mentawai	(0,4 - 1,0) g	(0,6 - 2,0) g
4	Deep Background	(0,1 - 0,4) g	(0,1 - 0,6) g
5	Shallow Background	(1,0 - 1,5) g	(2,0 - 2,5)
6	Background and Fault Mentawai	(0,4 - 1,0) g	(0,8 - 2,0) g
7	All sources of the earthquake with PGA	(1,0 - 1,5) g	(2 - 2,5) g
8	All sources of the earthquake with SA= 0,2 s	(3,0 - 3,5) g	(6,0 - 8,0) g
9	All sources of the earthquake with SA= 1 s	(1,0 - 1,5) g	(2,0 - 2,5) g

The hazard results of the research have a more excellent value than the value Hazard PGA earthquake zoning map based on the study results from Irsyam et al. and SNI 1726: 2012. Differences in the value obtained due to this research study using the data of the latest large earthquakes that occurred in the study area of research that may have previously not been used.

The value of PGA calculated by microtremor using two methods differs where the PGA value with the Kanai method has a more significant value. It is because the Kanai method counts the dominant period's magnitude, distance, and value. While the methods of Fukushima and Tanaka only count the magnitude and distance of the hypocenter only.

With the PGA value PSHA varying results and value PGA microtremor measurement results (**Table 2**), it is challenging to correlate the two relationships because the microtremor has a few data points. However, in general, it can be concluded that the value of PGA in research is relatively high. The risk level by each earthquake source's contribution was arranged based on the previous classification (Fauzi et al., 2005) and obtained from **Table 3**.

Table 2. Results of microtremor data processing

Num	Parameter	Value
1	Dominant frequency (f_0)	(0,89- 6,81) Hz
2	Amplification factor (A_0)	0,54 -1,92
3	Dominant period (T_0)	(0,1 – 1,1) s
4	Seismic vulnerability index (Kg)	0,13 - 4,14
5	Surface PGA (a_s)	(0,65 – 1,85) g
6	Bedrock PGA (a_b)	(0,16 - 0,19) g
7	Ground shear strain (γ)	(1,5-73) x10^{-5}
8	Weathered layer thickness (h)	(12,3 - 96) m

Table 1. The level of risk in the study area.

Num	Source of earthquake	Return Period (Year)	PGA value (g)	Level of Risk
1	Megathrust	500	1 - 1,5	considerable risks II
		2500	2,0 - 2,5	considerable risks II
2	Fault Sumatera	500	0,25 - 0,3	big risks III
		2500	0,6	considerable risks I
3	Fault Sumatera dan Fault Mentawai	500	0,4 - 1,0	considerable risks II
		2500	0,6 - 2,0	considerable risks II
4	Deep Background	500	0,1 - 0,4	Big risks
		2500	0,1 - 0,6	Big risks
5	Shallow Background	500	1,0 - 1,5	considerable risks II
		2500	2 - 2,5	considerable risks II
6	Background and Fault Mentawai	500	0,4 - 1,0	considerable risks I
		2500	0,8 - 2,0	considerable risks I
7	All sources of the earthquake with PGA	500	1,0 - 1,5	considerable risks II
		2500	2 - 2,5	considerable risks II
8	All sources of the earthquake with SA= 0,2 s	500	3,0 - 3,5	considerable risks II
		2500	6,0 - 8,0	considerable risks II
9	All sources of the earthquake with SA= 1 s	500	1,0 - 1,5	considerable risks II
		2500	2,0 - 2,5	considerable risks II

Contributions by local fault Mentawai provide a more dominant spread of values for each source of earthquakes. The area passed by the fault has a high ground acceleration value. This condition is similar to the mapping of the damage zone done by Naryanto (Naryanto, 2005). The sub-districts of the Nias that have been traversed by fault and have high hazard values are Tuhemberua, Gunungsitoli, Gido, Idanogawo, Lahusa, and Telukdalam.

4. Conclusion

From the results of PSHA and Microtremor, the islands of Nias generally have a high PGA value. So that when an earthquake happens, it can cause damage. However, the characteristics and parameters have yet to be discovered. For a more detailed analysis, it is necessary to conduct further study to obtain data and parameters, mainly geological data for the Nias Islands area in the form of Fractures suspected to be active. It also needs to measure more specifically by microtremor measurement in more points area to improve further analysis.

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