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Analysis of Seismotectonic Parameters and Earthquake Return Periods in The Nias Area (1980-2021)

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Abstract

The Nias Islands region is an area prone to earthquakes with a very high level of earthquake activity. One reason is the source of the subduction zone which is in the northwest of the Nias Islands. The aim of this work is to determine the b-value, seismic index, and earthquake return period using probabilistic techniques. For the years 1980 to 2021, the Meteorology, Climatology and Geophysics Agency (BMKG) published data with a magnitude of 3-6.7 and a depth (H) of 10-300 Km. The research results obtained by calculating the highest b-value is 0.791 in South Nias district and the highest a-value is in the South Nias district of 3.97. Calculation of the highest seismicity index with a magnitude of 6.7 in South Nias district with a-value of 7.223191 with an earthquake return period of 14 years.

Keywords: a-value; b-value; likelihood; return period; seismicity index.

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Introduction

Indonesia is a country with a high level of earthquake risk. This is due to the geographical location of Indonesia which is a meeting place Among three the earth's plates which are Eurasian, Australian, and Pacific (Madlazim, 2013; Aslamia & Supardi, 2022).

Geological phenomenon what raises the potential for large earthquakes is the movement of these plates. Earthquakes may occur at the boundary between plates and faults which can occur at any time. Friction between these plates creates pressure and fractures which result in shifting of rocks (Feng et al., 2022).

Geologically, the seismicity of the Sumatra region has a complex rock structure and has experienced collisions from tectonic processes several times. Because its position lies at the confluence of the Eurasian plate to the east and the Australian plate to the west. As a result of the activity of these plates, at any time it can cause earthquakes and tsunamis. In addition, areas that are classified as vulnerable are water areas. Under these conditions, the Sumatra region is very active in seismic activity (Madlazim, 2013; Anwar, 2019).

One of the many small islands to the west of the island of Sumatra is the Nias Archipelago. The cause of the seismicity was due to seismic activity in the Sumatra region based on BMKG monitoring data obtained on the occurrence of a 7.6 Nias seismicity in 1961 (BMKG, 2019). This is most likely caused by the collision of the two plates (BNPB, 2018).

Collision between the two plates produces tectonics that form a subduction zone in the northwest of the island of Sumatra which consists of the Mentawai fault and the Semangko fault which extends from Aceh to Lampung. these tectonic plates will move, collide and rub against each other, so that energy will one day be released to achieve balance, in the form of the 1961 Nias earthquake which had a magnitude of 7.6 (Damayanti et al., 2020; Lubis et al., 2022).

Precautions from earthquakes need to be carried out with a study of seismotectonics in the Nias Islands region. Seismotectonic parameters can be in the form of rock fragility (b-value), seismic activity (a-value), the average number of events earthquake (seismicity index) and earthquake return period based on seismotectonic parameter values by using the relationship between frequency and magnitude of earthquakes by calculating using the likelihood method.

In order to limit infrastructure damage due to large earthquakes, which can even trigger a tsunami, then need for knowing the value of seismotectonic parameters that can be used by local governments as a guideline for building earthquake-resistant infrastructure is very important.

This technique has the benefit of enabling statistical calculations of earthquake parameter values, rock fragility values, and predictions of earthquake return periods. The likelihood method is a statistical approach that is suitable for solving problems involving seismotectonics (Suwandi et al., 2017; Ernandi & Madlazim, 2020).

Based on Geological data for the Nias Islands region (Djamal et al., 1994), most of Nias Island consists of sedimentary rocks of Tertiary age called the Bancuh Complex, which consists of a bed mass of scaly clay and sedimentary rocks such as claystone, marl, sandstone, limestone and alternating sandstone, claystone, siltstone, conglomerate, and tuff. Quarter sediments, on the other hand, consist of alluvial deposits from rivers, swamps, and beaches as well as reef limestone.

The fault, which is in the same direction as the Nias Islands from northwest to southeast, dominates the geological structure of the Nias Islands. Previous tectonic activity has resulted in the formation of this geological structure pattern. There are many active faults in these islands. In conclusion, shallow earthquakes are common. According to Weiss et al. (2018), these faults are located in the accretion wedge zone, which originates at the tertiary start, close to the impact zone. Continuous collisions will result in greater seismic activity.

The geological features that are likely to be the source of earthquakes in the Nias Islands can be seen in Figure 1. Lithologically, the constituent rocks are dominated by Alluvium (Qa), the Gunungsitoli Formation in blue (Qtgs), the Gomo Formation in brown (Tmpg), the Lolomatua Formation with yellow (Tml), Bancuh Complex Formation in red (Tomm).

The rock type most vulnerable to earthquakes is the Bancuh Complex rock type with red color (Tomm). Where this rock type is composed by the morphology of the coastal plains, rivers, swamp hills, and mountains. The shock effect increases with weathering of Pre and Tertiary rocks and quarterly deposits, which are usually crushed, fragmented and uncompacted. (Djamal et al., 1994).

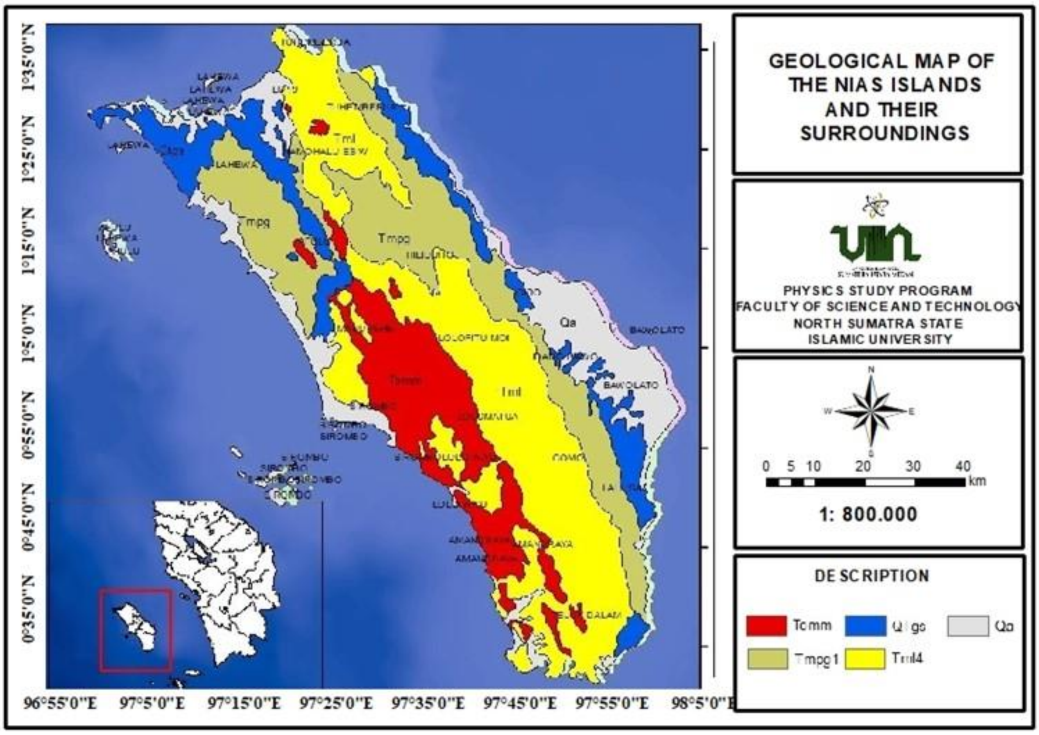

Figure 1. Geological Map of Nias Islands.

Materials and Methods

The research location is located at the location coordinates 0°10’0” - 1°30’0” N and 97°0’3” - 97°0’56” E with an area of 1,004.06 km^2. Nias islands region based on each region as in Figure 2.

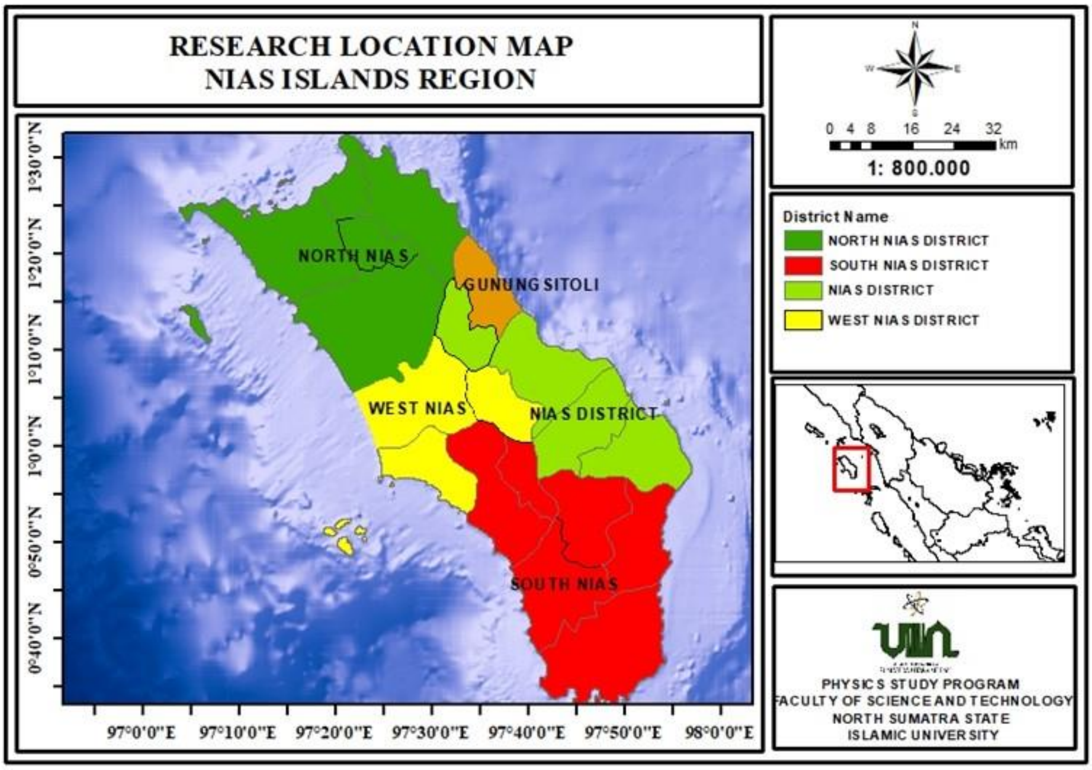

Figure 2. Map of research locations.

The equipment and supplies used were a laptop for data processing, Microsoft Excel software for sorting data, and ArcGIS 10.8 software for making geological maps of the Nias Islands and research location maps.

The data source used is the Deli Serdang Class 1 Geophysics Station which provides earthquake parameter data in the form of area coordinates (latitude and longitude), year, month, date, magnitude, depth, and time of origin with magnitude 3–10 and depth (H) 1– 300 km, which is a shallow to deep depth with a high damage potential. The 41-year period covered by the study's seismic data spanned from January 1, 1980 to December 31, 2021.

Data processing is carried out using Microsoft Excel software for sorting data such as coordinates (latitude and longitude), year, month, date, magnitude and depth in each area. After that, the data processing is done manually. The steps in processing earthquake data include:

1. Examining the literature that supports the study of b-value and a-value seismotectonic analysis on the Nias Islands is known as a literature review .
2. By dividing the five regencies in the study area into equal parts, the b-value, a-value, seismic index, and earthquake return period were determined.
3. Mapping was carried out using the seismicity index level mapping using Arcgis 10.8 software .
4. Equations (1) and (2) are used to calculate b-values and a-values using the maximum likelihood method (Kijko et al., 2022; Zaccagnino et al., 2022):

$$b = \frac{\log e}{\bar{M} - M_0} \quad (1)$$

$$a = \log N + (b \ln 10) + M_0 . b \quad (2)$$

5. Furthermore, according to Welkner (1965) the calculation of the seismicity index to describe the number of earthquakes per year with a magnitude greater than the smallest magnitude. According to Welkner (1965) with a seismicity index of "N (M ≥ 3)" using equation (3).

$$N_1\,(\bar{M} \geq 3.0) = 10^{a_1' - 3.b} \quad (3)$$

Divide the a-value by the study period (T) to determine the number of earthquakes each year.

$$a_1 = a - \log T$$

$$a' = a_1 - (\text{logb}) . (\text{lan } 10)$$

$$a_1' = a' - \log T \quad (4)$$

6. The determination of the return period of an earthquake uses equations (5) and (6) to see the possibility of damaging earthquakes occurring in the future. Where the maximum magnitude of the earthquake return period has the highest annual average cumulative frequency (T) (Fidia et al., 2018; Septiani & Pujiastuti, 2021):

$$N_1^{(M>6.7)} = N_1^{(M>3)} . 10^{-2.b} \quad (5)$$

$$\theta = \frac{1}{N_1\,(\bar{M} \geq M_0)} \quad (6)$$

Research Result

Results of manual calculation of b-value and a-value

If the b-value is reached, the calculation results used to determine the degree of fragility of the rock (b-value) shows a relatively high indicator of rock fragility and relatively low association with fractures. Meanwhile, relatively strong assertiveness correlates with a relatively low b-value.

The results of calculating the level of earthquake activity (a-value) show that if the a-value is reached, the higher the a-value, the more frequent earthquakes occur in that location, and the lower the a-value, the more frequent earthquakes occur in that area.

The seismic parameters b-value and a-value are combined for the analysis because they can help predict the likelihood of major earthquakes in a given area. Where the a-value is a seismicity constant and the b-value is a fracture distribution constant whose value is directly proportional to the a-value.

Based on the results of manual calculations (Table 1), the highest b-value results were found in South Nias district of 0.791. While the lowest b-value of 0.446 is found in North Nias district. The results of the highest a-value were found in the South Nias district of 3.97. While the lowest a-value is in North Nias district with a-value of 2.67.

Table 1. A-value and b-value based on the five districts in the Nias Islands using manual calculations.

No	Research Area	b-values	a-values
1	Nias Regency	0.555	2.83
2	South Nias Regency	0.791	3.97
3	North Nias Regency	0.446	2.67
4	West Nias Regency	0.517	2.79
5	Mount Sitoli	0.740	3.09

Seismicity index value results

The seismicity index is needed to determine the typical number of earthquakes per year with a certain magnitude. Where the magnitude is greater than the smallest magnitude ($M \geq 3$) If the earthquake seismicity index value is N (($M \geq 3$) in a period of 41 years in each region, with a high seismicity index value, then the area is classified as prone to earthquakes.

The results of calculating the seismicity index for five areas in the Nias archipelago and its surroundings with $M \geq 3$ range from 0.09677 to 7.22319.

Whereas for the South Nias region it is 7.22319 which has a greater seismic index than other regions. In other words, the South Nias region has a lot of earthquake activity and is vulnerable to earthquake-related disasters. Statistics on the occurrence of earthquakes in South Nias Regency, which is higher than other locations, is proof of this claim. Meanwhile, Nias Regency has a low seismicity index compared to other values, which is 0.09677. Based on previous research by Nfingrum et al. (2022) the results of a high seismic vulnerability index value will be vulnerable to earthquake disasters and alluvium type factors consisting of gravel, sand can also affect disasters in the area.

As a result, the selected earthquake data is very helpful for various tasks such as designing earthquake resistant structures or preparing areas for potential earthquakes. Table 2 displays the results of manually calculating the seismic index values as follows.

Table 2. Seismicity index calculation.

Area	A value	a_1	a'	a'_1	$N_1 = (M \geq 3)$
Nias Regency	2.83	1.21953	1.80823	0.19544	0.09677
South Nias Regency	3.97	2.36147	2.59498	0.98220	7.22319
North Nias Regency	2.67	1.06079	1.866888	0.25410	0.45536
West Nias Regency	2.79	1.18551	1.84369	0.23090	0.14840
Mount Sitoli	3.09	1.48344	1.784171	0.17138	0.73701

Earthquake return period

The probability of a destructive earthquake occurring is based on five areas in the Nias Islands and its surroundings. Based on Table 3. The highest destructive earthquake index value with the fastest repetition rate with a magnitude (M) of 6.7, which is in the South Nias Regency area of 0.0571 for 14 years. While the index value of the lowest destructive earthquake with the longest earthquake repetition rate was 5.8, which is in the Nias district of 0.0005 for 1861 years.

Table 3. Destructive earthquake index value and return period.

Area	Destructive earthquake index value	Return Period Value	Magnitude (M)
Nias Regency	0.0005	1861 year	5.8
South Nias Regency	0.0571	14 years	6.7
North Nias Regency	0.0020	491 years	6
West Nias Regency	0.0007	1301 years	5.6
Mount Sitoli	0.0054	183 years	5.3

Discussion

B-value which describes the level of fragility of rocks is one of the benchmarks of tectonic conditions in a region. Areas that have large rock characteristics will easily experience cracks and are relatively unable to withstand the weak level of rock fragility. Meanwhile, the relatively low b-value parameter correlates with relatively high fractures (Naimi-Ghassabian et al., 2016). Where is the area with a high level of rock fragility, which is in South Nias Regency with a b-value of 0.791.

The Bancuh rock complex (Tomm) which is composed of the morphology of the coastal plains, valleys and hills dominates the geology of this area. Pre-tertiary (metamorphic and metasedimentary rocks) and quaternary deposits form these rock conditions (alluvial, coastal, riverine, and marshy). The pre-tertiary rock has been weathered, and the quarterly deposits in the south Nias region have been decomposed, loose and not yet compacted, which amplifies the effects of the shaking.

In addition to the level of rock fragility, the level of seismic activity also affects this area where the value of the level of seismic activity (a-value) in this area is 3.97 which means this area is very active in seismicity. The Australian plate immigrates from the northwest and subducts into the European continental plate, and the South Nias Regency area is close to this convergence point (megathrust zone). Where this area stretches from the northwest-southeast region of Nias Island.

Based on Damayanti et al. (2020) and Lubis et al. (2022) the main fault line that cuts through Nias Island in a northwest-southeast direction, known as the Nias fault line, is the main contributor to earthquakes in South Nias Regency apart from the megathrust zone. The Nias-Ordi-Bahorok fault line, which originates from the western part of Pini Island and crosses Sumatra, is another important fault line in the southern part of Nias Island. The potential for earthquakes in this region is quite large due to the causes of earthquakes which can also result in disasters such as tsunamis and landslides.

If it is associated with the seismicity index which describes the number of annual earthquakes the highest occurs in the South Nias Region, which is 7.223191. When planning earthquake-resistant buildings or preparing an area for possible earthquakes, for example, this value is very helpful.

While the return period shows the possibility of damaging earthquakes in the future. The return period of this seismicity is seen by determining the magnitude of the greatest seismicity, which is the magnitude (M) 6.7. Where the shortest area of repetition is South Nias Regency for 14 years.

In the previous study, Daiana et al. (2021) conducted research using seismicity analysis of b-value studies using earthquake data from 1914 to 2020 (Case study: Bengkulu Province). The results show that the environment closest to the coast has the largest a- and b-values, which is in the range of 3.05 – 3.2. The mainland area of Bengkulu Province has a high level of seismicity, according to the variation in the b-value. This is possible because the rocks that make up Pre-Tertiary and Tertiary rocks, as well as quarterly deposits, are usually decomposed, loose, and soft in coastal areas, which can increase the impact of earthquake shocks.

Conclusion

From the results of the analysis of seismotectonic parameters and earthquake return periods in the Nias region in 1980-2021 it can be concluded that: first, the calculated b-value for Nias district is 0.555, South Nias district is 0.791, North Nias district is 0.446, West Nias district is 0.517, and Gunung Sitoli is 0.740. While the results of the calculation of the a-value for Nias district is 2.83, South Nias district is 3.97, North Nias district is 2.67, West Nias district is 2.79, and Gunungsitoli is 3.09. The second, the Seismicity Index value in each region with a magnitude greater than the smallest magnitude ($M \geq 3$) Nias district is 0.096770, South Nias district is 7.223191, North Nias is 0.455368, West Nias is 0.148408, and Gunungsitoli is 0.73701. The last, the return period value for each region is Nias district of 0.0005 with destructive earthquakes (M) 5.8 with a predicted return period of 1861 years, South Nias District of 0.0571 with destructive earthquakes (M) 6.7 for 14 years, North Nias of 0, 0020 with destructive earthquakes (M) 6 for 491 years, West Nias for 0.0007 for destructive earthquakes (M) 5.6 for 1301 years, and Gunungsitoli for 0.0054 with destructive earthquakes (M) 5.3 for 183 years.

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Author Contribution

In the preparation of this research journal, each author contributed to several parts, which are for data processing and library resources by Riski Efrina, journal compilation by Lailatul Husna Lubis while observers and supervisors in compiling this journal were Ratni Sirait and Novita Sari.

Conflict of Interest

In this study there were no funds or finances issued, either between the authors or the parties involved in this research. so that the author can account for it with the rules in the Journal of Geocelebes.

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