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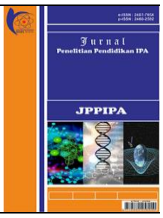

Earthquake Disaster Risk Analysis for Mitigation Efforts in Seram and Buru Islands, Maluku

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Abstract: Earthquakes occur due to the sudden release of energy from within the earth causing seismic waves. Earthquake activity with a magnitude ≥ 3.5 SR is grouped over 21 years from 2000-2020 to determine the level of seismicity in Seram Island, Buru Island, and surrounding areas. The area of seismic activity is clustered over three blocks. The purpose of this research is to determine the seismicity level and mitigation model in each block in the research area. The results showed that seismic activity in the study area with shallow earthquakes was mostly in Block II as many as 1195 times (40.4%) and Block III as many as 1135 times (38.4%). This block is estimated to have the potential for a tsunami to occur. Mitigation efforts to reduce the risk of earthquakes are by implementing a resilient-elastic building system and the location of settlements from the coastline > 100 m with a topography of at least 25 meters.

Keywords: Block method; Earthquake; Mitigation; Seram and Buru islands

Introduction

Active tectonic areas in Indonesia are located on the boundaries of tectonic plates (Souisa, 2018). A number of studies have recently been conducted to better understand Indonesia's tectonics, identifying and imaging sources of seismicity such as subduction zones and crustal faults (Bradley et al., 2017; Fan et al., 2018; Hall, 2019; Irsyam et al., 2020; Patria et al., 2020; Sahara et al., 2021; Souisa et al., 2022, 2021; Supendi et al., 2018). But the impact can be felt at some distance depending on the decay of energy and local geology. When viewed from the peak of the earthquake on the earth's surface, half of Indonesia, including Maluku, has a moderate to high earthquake strength with an epicenter depth of shallow (0-100 km) to a depth of > 300 km (Adii et al., 2021).

Tectonic earthquakes can cause disasters either directly or indirectly, this is very dependent on the magnitude of the magnitude generated when an earthquake occurs. This can explain why major earthquakes that have accompanied each other in the last 21 years in the Maluku region have the potential for tsunamis (Survey, 2020; Watkinson et al., 2017). Maluku is an area that is prone to earthquakes and has earthquake centers centered on the Banda Sea Trench. This must be monitored and periodically given mitigation by the people of Maluku.

To predict whether an earthquake that occurs can cause a tsunami disaster or not, it depends on the magnitude of the earthquake generated and has a shallow depth. Earthquakes are caused by the sudden release of energy from within the earth so that it emits seismic waves. The parameters used to determine the seismicity of the earthquake are the energy scale,

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magnitude scale, intensity scale, distribution of earthquakes, and the history of earthquakes in Maluku. In this case, the intensity scale shows the level of damage and acceleration caused by the earthquake. These parameters can also provide a direct or indirect picture of the impact of each earthquake event in a location.

The results of earthquake monitoring in Maluku conducted by the Meteorology, Climatology and Geophysics Agency (BMKG) Ambon Station show that earthquake activity has been classified as very active since 2000. Thus, tectonic information obtained from BMKG is very helpful for researchers to assess the level of earthquake disaster risk in the region potential tsunami research. BMKG data can determine the level of earthquake risk for 21 years with a magnitude above 3.5 on the Richter Scale (SR). From the earthquake data, an analysis of the level of disaster risk in the research area was carried out whether it triggered a potential tsunami (Hutchings et al., 2021).

Method

Study Area

Geographically, the research location is located at coordinates -2.00°-4.18° South Latitude and 125.77°-127.46° East Longitude (Pula Buru and around) for Block I, the coordinates are at Block II -2.00°-4.18° South Latitude and 127.46°-129.18° East Longitude (West Seram Island and Lease Islands), the coordinates of Block III are -2.00°-4.18° South Latitude and 129.18°-131.05° East Longitude (Figure 1).

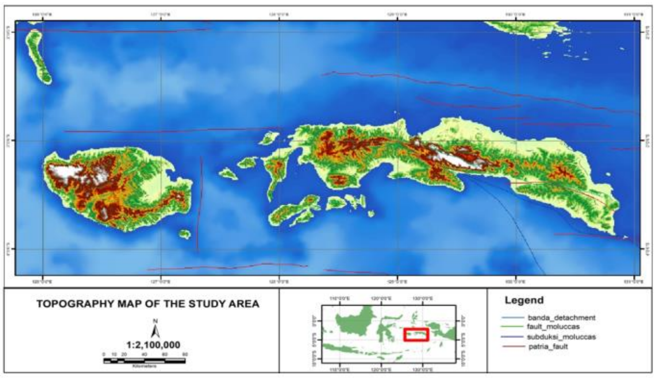

Figure 1. Topographic map of the study area

Block Method

The method used to classify an object of observation based on data is called the Block method. This method is almost the same as clustering (Febriani et al., 2015). What distinguishes the Block and Clustering methods, among others, is that the Cluster method's main objective is to group several data or subjects into clusters (groups) so that each cluster will contain data that is as similar as possible. In clustering, try to determine objects that are close or similar in the same cluster, and make the distance between clusters as far as possible, meaning that objects in a cluster are very similar to each other and different from objects in other clusters (Rujasiri et al., 2009), while the Block method is a method that aims to reduce an object of observation so that it is easier to observe based on the available data without comparing between each block.

Thought Construction and Data Processing Process

The method used to examine the problems in this research is the Block method using a computer to obtain a seismicity map with a grouping of magnitudes from small to large and depths from the shallowest to the deepest. The research was conducted using secondary data, in the form of earthquake data in the Maluku region with an earthquake magnitude of 3.5 SR, the depth of the earthquake center, positions based on latitude and longitude, and the area felt based on the MMI scale that occurred. Maluku earthquake data collection from 2000-2020. The data is downloaded from the BMKG and USGS catalogs (U.S. Geological Survey, 2020), then processed using software to create seismicity maps at predetermined locations. Topography and bathymetry data are plotted as a global relief grid (Tozer et al., 2019) and accessed via GMT (Wessel et al., 2019). Furthermore, an analysis is carried out to determine the percentage of seismicity in each block, and to determine the highest level of earthquake risk based on the frequency of the three predetermined blocks. The groups of magnitudes in the three seismicity blocks are the same, with magnitude stretches of (3.5 – 4.5) SR, (4.5 – 5.5) SR, and > 5.5 SR. From this seismic block, it is possible to estimate areas with the potential for a tsunami. After that, mitigation of the tsunami caused by the earthquake was carried out.

Result and Discussion

Seram Island, Buru, and its surroundings are geographically located at the confluence of three tectonic plates, namely the Indo-Australian plate, the Pacific-Carolina plate, and the Philippine Ocean plate (Souisa, 2018; Supendi et al., 2020; Souisa et al, 2021). These three plates move relative to each other so that the Seram and Buru regions experience moderate to high earthquake activity, resulting in the emergence of many faults (Wattimanela et al., 2023). These faults act as generators of earthquake activity.

Earthquake Epicenter Distribution Mapping

At this stage, earthquake data is input for 21 years into the computer. The input data is earthquake parameter data in the form of coordinates, depth, and magnitude. After the data input process, the earthquake epicenter distribution mapping was carried out (Figure 2). The info picture shows the distribution pattern of the earthquake epicenter very much with an earthquake strength of 3.5 SR–6.5 SR. The distribution of earthquakes or seismicity of earthquakes that occurred in this area was a type of shallow earthquake (0.0–100) km, a moderate earthquake type at a depth of (100.1–300.0 km), and a deep earthquake type that was at a depth of > 300 km.

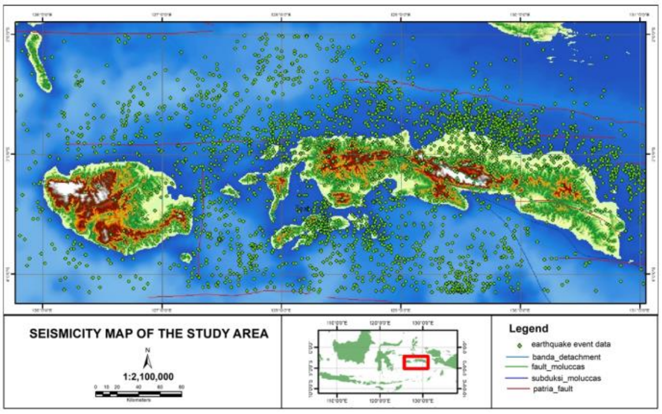

Figure 2. Seismicity map of the research area

Seismicity on Each Block

The main earthquake and aftershocks > 3.5 on the Richter scale that occurred in 2000-2020 caused two fault parameters according to the data obtained from the USGS calculations which were then verified with BMKG data. Seismic data grouped in one block is carried out randomly and accumulates automatically. Likewise, the distance between seismic data is shown to be cumulatively irregular.

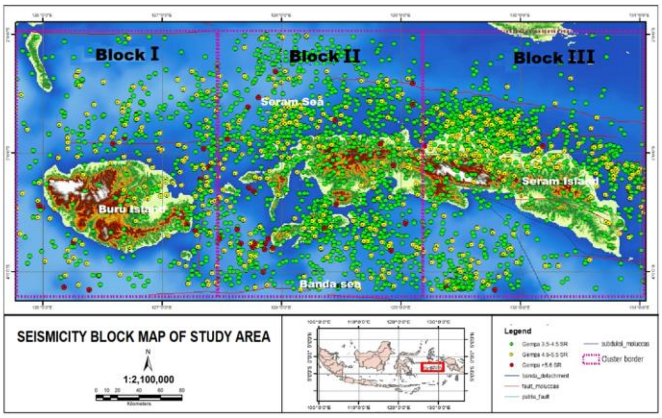

Figure 3. Seismicity Block Map of the research area

Earthquake epicenters found in each block are used to see an overview of the classification of earthquake risk levels over 21 years (Figure 3). Figure 3 shows the distribution of tectonic earthquake centers in several research areas. Earthquake activity contained in each block is referred to as the active zone. Even if the earthquake activity is only a moderate magnitude ≤ 6.5 on the Richter scale, it is necessary to monitor its movements. Blocks of activity for moderate earthquakes or active zones that have existed for 21 years could be in the following years, and there could even be blocks that have turned inactive or shifted to other zones.

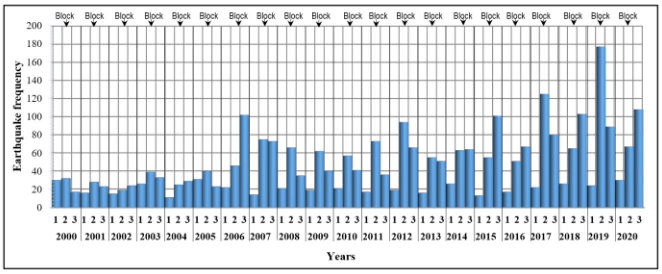

Figure 4. Earthquake frequency every year in each block

Based on Figure 4 shows the number of earthquake events as much as 2955 times. In 2019, the highest frequency of earthquakes was in Block II with a magnitude (4.6 - 5.5) SR of 177 events (5.99%), followed in 2017 in Block II with a magnitude (4.6 - 5.5) SR of 125 incidents (4.23%), and in 2020 in Block III with a magnitude > 5.5 on the Richter scale, there were 108 incidents (3.65%). Whereas in 2004, the lowest earthquake frequency was in Block I with a magnitude (3.5 - 4.5) on the Richter scale of 11 events (0.37%).

The recap of earthquake events from 2000–2020 in Figure 5 shows that Block II has high seismic activity, followed by Block III, and the lowest seismicity is in Block I. This is caused by the movement of the Pacific-Carolina and Indo-Australia plates through the fault. Sorong and Banda. This is due to the existence of strike-slip and thrust structures around Seram Island as a form of accommodation for complex deformations (Watkinson et al., 2017). This fault is also parallel to the Buru strike-slip fault, and the Banda strike-slip fault.

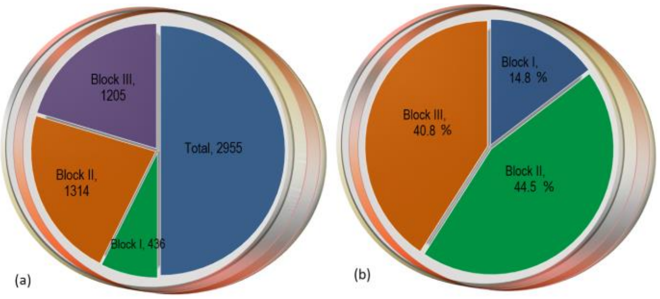

Figure 5. (a) Recap of earthquake occurrences, and (b) percentage of earthquake occurrences in each block

The high seismic activity occurring in small to moderate earthquakes indicates that the rock conditions in the Seram and Buru segments are generally solid

(Figure 6) and do not break easily but store large amounts of energy.

After the earthquake on September 26, 2019 (6.5 Mw), there were no aftershocks in the Seram and Buru segments with a magnitude of M > 6.5. Nearly the last three years in the area of this segment there are still expectations of energy storage that have not moved.

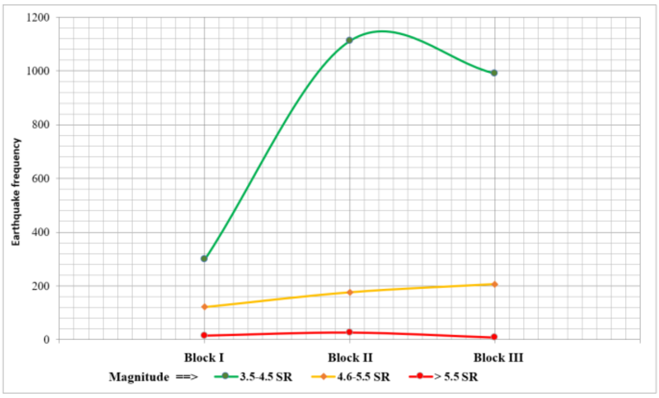

Figure 6. Graph of the relationship between earthquake frequency and block

Other supporting data are changes in the shape of microatoll coral reefs in the Seram and Buru areas and their surroundings indicating that there has been a change in the deformation of the earth's crust in the area in the last few decades. This decrease, which only occurs around Seram and Buru Islands, could indicate that energy has been accumulating for a long time and has not been released around Buru Island. The lock that occurs around the subduction zone has caused the Buru and Seram islands which are in the front of the subduction zone to be pulled down due to the movement of the Indo-Australian plate subducting under the Eurasian plate and to the right of the Carolina Pacific plate. This locking process is still going on and there has been no release of energy in the Seram and Buru segments with strength > 7.0 Ms.

Tectonic Seismicity Analysis

From the frequency of earthquakes over the past 21 years, a relationship is made to the depth of the hypocenter in multiples of 10 km (Figure 7). The frequency of earthquakes is at a depth of the hypocenter (3-10) km. In this hypocenter depth range, it can be estimated as an area that can cause a tsunami.

In Figure 7, the highest frequency of earthquakes is at depths between 0-10 km 1171 times, followed by depths between 31-40 km 442 times, and there are no earthquakes with frequencies (0 - 5) at depths above (201 - 780) km. Thus, there are three types of earthquakes based on depth, namely: depth (0 - 100) km is a type of shallow earthquake with 2735 earthquakes (92.55%), depth (100.1 - 300) km is a type of moderate earthquake with a total of 201 earthquakes (6.80%), and a depth of > 300 km is a type of deep earthquake with a total of 19 earthquakes (0.64%).

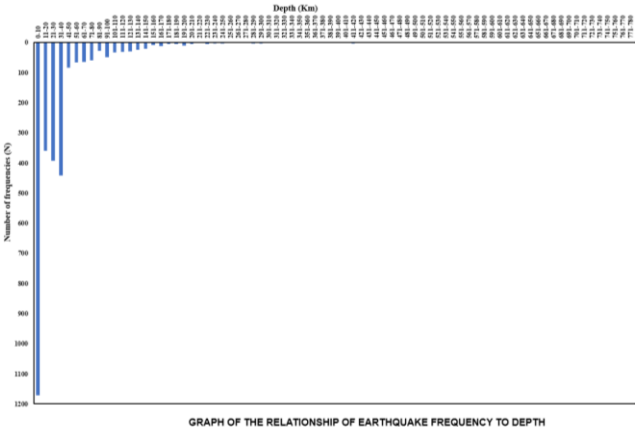

Figure 7. Graph of the relationship between earthquake frequency and depth

The infographic shows that the research area has different types of earthquakes, so based on the hypocenter with the highest frequency of earthquakes, this type of earthquake can be shallow, so it can be predicted that this area has the potential for a tsunami. Likewise, from the recapitulation of the percentage of earthquake occurrences based on the depth range, the research area is an area that has the highest frequency of shallow earthquakes, so it has the potential to cause a tsunami.

Determination of Tsunami Risk Level by Block

There are three types of Blocks to determine the level of earthquake risk referred to in Figure 3. The level of tsunami risk can be identified from the division of research areas using the Block method.

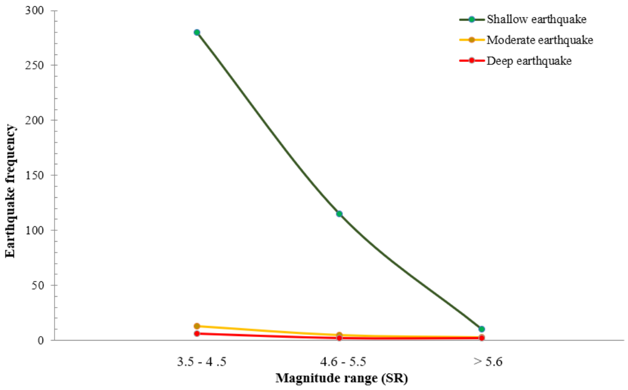

Figure 8. Graph of earthquake frequency and magnitude in Block I

The tsunami risk level in Block I (Figure 3) is found in the Buru Island area and its surroundings with an earthquake frequency that has occurred in 21 years of 436 times (Figure 8). The infographic shows that within 21 years, Block I have the highest type of earthquake categorized as shallow earthquakes with a total frequency of 405 times (13.7%), followed by moderate earthquakes with a frequency of 21 times (4.8%) and deep earthquakes with a frequency of 10 times (2.3 %).

The tsunami risk level in Block II is in the area of West Seram Island and Lease Islands with a frequency of earthquakes that have occurred in 21 years of 1314 times (Figure 9). The infographic shows that for 21 years Block II has had the highest type of earthquake categorized as shallow earthquakes with a frequency of 1195 times (90.9%), followed by moderate earthquakes with a frequency of 115 times (8.8%) and deep earthquakes with a frequency of 4 times (0.3%).

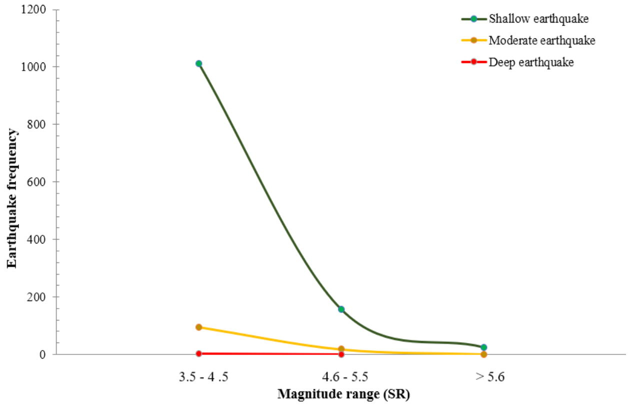

Figure 9. Graph of earthquake frequency and magnitude in Block II

The tsunami risk level in Block III is in the East Seram Island region and its surroundings with an earthquake frequency that has occurred in 21 years of 1205 times (Figure 10). The infographic shows that for 21 years Block II has the highest type of earthquake categorized as shallow earthquakes with a frequency of 1135 times (94.2%), followed by moderate earthquakes with a frequency of 65 times (5.4%) and deep earthquakes with a frequency of 5 times (0.4%).

Of the three blocks for 21 years (2000-2020), the ones that have had the shallowest earthquakes are in Block II with an earthquake frequency of 1195 times (90.9%) and Block III with an earthquake frequency of 1135 times (94.2%). Because of this, the Block II and Block III areas are estimated to have the potential for a tsunami. The frequency of shallow earthquakes is 405 times (92.9%) in block I, and at any time there can be a potential for a tsunami if there is a large change in rock stress at the fault with a high energy release which triggers a large earthquake. The presence of stress loads on the south and north Seram fault zones have reached or even exceeded the threshold for triggering aftershocks (Parsons et al., 2006; Toda, 2005) and caused a fault shift of the earthquake main earthquake.

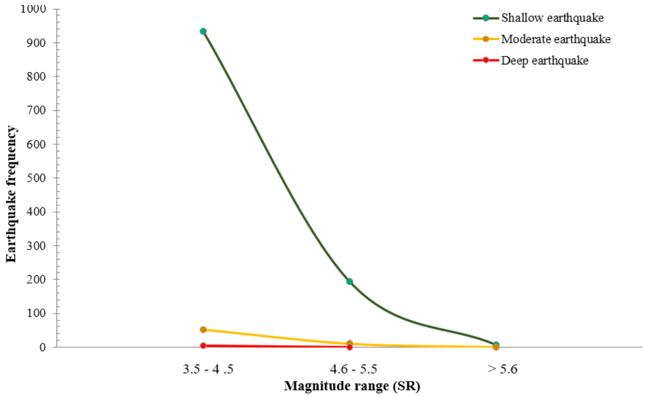

Figure 10. Graph of earthquake frequency and magnitude in Block III

Mitigation models in research areas with the highest level of earthquake risk are carried out to reduce or minimize the destructive power of threats caused by earthquake disasters by applying structural methods such as layout of settlements, designing resilient-elastic buildings, and non-structural methods such as vulnerability analysis, community education, the location of settlements from the coastline > 100 m with a topography of at least 25 meters, and dissemination of earthquake occurrence updates.

Conclusion

Seismic activity in the study area (Seram Island, Buru Island, and its surroundings) within 21 years (2000-2020) in Block I with a magnitude range of (3.5 – 4.5) SR of 299 times (68.6%), magnitude (4.6 – 5.5)) SR 122 times (28.0 %), and magnitude > 5.5 SR 15 times (3.4 %). For Block II with a magnitude range of (3.5 – 4.5) SR is 1112 times (84.6%), magnitude (4.6 – 5.5) SR is 176 times (13.4%), and magnitude > 5.5 SR is 26 times (2.0%), and Block III with a magnitude range of (3.5 – 4.5) SR 991 times (82.2 %), magnitude (4.6 – 5.5) SR 206 times (17.1 %), and magnitude > 5.5 SR 8 times (0.7 %). Blocks that have a high risk of earthquake disaster based on the frequency of earthquakes in the study area (Seram Island, Buru Island, and its surroundings) with more shallow earthquake types are in Block II with an earthquake frequency of 1195 times (90.9%) and Block III with an earthquake frequency of 1135 times (94.2%), so that the area in this Block is estimated to have the potential for a tsunami. Mitigation efforts to reduce the risk of earthquakes are by implementing a resilient-elastic building system and the location of settlements from the coastline > 100 m with a topography of at least 25 meters.

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Author Contribution

Conceptualization and methodology, Matheus Souisa (M.S); formal analysis, M.S., S.M.S. (Sisca M.Sapulete), and L.A.S. (Learsi A. Siahaya); investigation, M.S., and L.A.S.; writing—original draft preparation, M.S., and L.A.S.; writing—review and editing, M.S., S.M.S. and L.A.S.; funding acquisition, M.S., S.M.S. and L.A.S. All authors have agreed to the published version of the manuscript.

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Conflicts of Interest

In writing this article, we sincerely declare that there are no relevant conflicts of interest that could affect the objectivity and integrity of the results.

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