Research Article

Spatial Analysis of Ground Movement Potential, Based on Rock Type and Distance from Active Faults in Ambon City, Indonesia

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Abstract.
Ambon City is one of the most landslide-prone areas in Maluku Province. This study aims to analyze the potential for ground motion in Ambon City, Indonesia, by considering rock types and distance from active faults. This research uses geological data and distance from faults, which are then analyzed using the spatial overlay method. The results showed that the area with high potential for land movement disasters is 8,347.14 ha, medium is 12,157.24 ha, and low is 12,069.09 ha. The predicted built-up area affected in the low class is 2,296.23 ha, in the medium class is 1,470.58 ha, and in the high class is 672.36 ha. These findings highlight the need for special attention to areas with high ground motion potential, as well as the importance of effective mitigation strategies to protect infrastructure and communities. This research is expected to provide useful insights for spatial planning and disaster risk management in Ambon City.

Keywords: Ambon, active faults, land movement, spatial analysis, rock types

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1. Introduction

Indonesia, as an archipelago located between three major tectonic plates, namely the Eurasian Plate, Pacific Plate, and Indo-Australian Plate, has a high vulnerability to various natural disasters (1). One of the frequent disasters is land movement, which can be caused by various factors, including rock type and fault activity (2). Ambon City, as the capital of Maluku Province, Indonesia, is located in an area that has a high vulnerability to geological disasters, including land movement and landslides. With hilly geographical conditions and complex geological structures, Ambon faces great challenges in terms of disaster risk mitigation (3). Land movement can be caused by various factors, including rock type, rainfall, and seismic activity associated with the presence of active faults in the vicinity. In the past five years, Ambon City has experienced several significant landslide events, especially during the rainy season. In June 2024, the Regional Disaster Management Agency (BPBD) recorded 17 landslide points in five sub-districts due to heavy rainfall. Previously, in October 2020, there were 163 landslide points that threatened 120 houses and caused damage in several locations. In addition, in May 2021, landslides also occurred in several areas such as Waiheru and Batu Merah, causing damage to residents' homes (1). These events show that Ambon, with its hilly topography and high rainfall, faces an increasing risk of geological disasters. Mitigation efforts and public awareness of these potential disasters are crucial to reduce their impact. Therefore, it is important to conduct an in-depth spatial analysis to understand the ground movement potential in this area.

One of the main factors affecting soil stability is rock type. Different rock types have different physical and mechanical characteristics, which can affect the soil's ability to retain water and load (4). Softer rocks tend to be more susceptible to weathering and soil movement compared to harder rocks (5). By understanding the distribution of rock types in Ambon, we can identify areas that are more at risk of land movement. In addition, distance from active faults is also an important factor in ground movement risk analysis (6). Active faults are zones where tectonic plate movements occur, which can cause earthquakes (7). Earthquakes, in turn, can trigger ground movements, especially in areas close to faults (8). Therefore, analysis of the distance from active faults can provide valuable insights into the potential for ground movement in Ambon.

In this study, spatial analysis using Geographic Information System (GIS) technology became a very effective and efficient tool for analyzing the potential for ground motion in Ambon City. By using GIS, researchers can map and analyze the relationship between rock types, distance from faults, and ground movement potential (9). This method allows for more accurate identification of landslide-prone zones, which can help in future disaster planning and mitigation in Ambon (4). This research aims to provide a better understanding of the relationship between rock type, distance from active faults, and ground movement potential in Ambon City. By conducting spatial analysis, it is expected to produce risk maps that can be used by local governments and other stakeholders in spatial planning and disaster mitigation. The results of this research are expected to contribute significantly to disaster risk reduction efforts in Ambon. By knowing the high-risk areas, preventive measures can be taken to protect communities and infrastructure. In addition, this information can also be used to increase public awareness about the importance of disaster risk mitigation. Thus, it is expected that the results of this study can be an important reference in sustainable development efforts and disaster risk management in Ambon City.

2. Research Methodology

This research was conducted in Ambon City, Maluku Province, Indonesia. This research uses geological data and active fault data obtained from the Regional Development Agency of Ambon City and built-up land data of Ambon City obtained from the analysis of Landsat 8 satellite image data in 2024 obtained from the official website of the United States Geological Survey USGS. This research uses variables of rock or geology and distance from active faults. The use of rock or geology variables and distance from active faults in making maps of ground motion potential in Ambon City greatly affects the accuracy and effectiveness of risk analysis. Rock types have different physical characteristics, such as strength, density, and permeability, which affect soil stability and its ability to retain water (10). Softer or fragmented rocks tend to be more susceptible to weathering and ground movement, while harder rocks can provide better stability (11). On the other hand, distance from active faults is an important factor, as seismic activity around faults can trigger ground motion, especially in areas close to faults (12),(13),(2). By integrating these two variables, maps of ground motion potential can provide a more comprehensive picture of high-risk areas, thereby assisting the government and stakeholders in planning appropriate mitigation measures and improving community preparedness for disasters.

The distance from active faults was analyzed using the bufer technique that refers to previous research (14). Rock data and distance from active faults were scored and analyzed in ArcGIS 10.8 software using the overlay method to obtain a map of potential ground motion in Ambon City (Table 1). The potential ground motion areas in Ambon City were then classified into three classes: low, medium and high. These results were then overlaid with data on the distribution of built-up land in 2024 to determine the built-up land potentially affected by land movement disasters.

Table 1: Research Variables.

No	Variables	Classification	Score
1	Geology	Batuan Ultramafik (JKu)	4
		Terumbu Koral Terangkat (Q)	2
		Aluvium (Qa)	5
		Granit Ambon (Ti)	3
		Batuan Gunungapi Ambon (Tpav)	4
		TRJK.Formasi Kanikeh	3
2	Distance from Fault	0 - 500 m	5
		501 – 1500 m	4
		1501 - 3000 m	3
		3000 - 5000 m	2
		>5000 m	1

Source: (14), (15), (2)

3. Research Result and Discussion

3.1. Geologic Influence on Ground Motion Potential in Ambon

Ambon City, as part of Ambon Island, was formed from a geosynchronization that caused deformation, such as valleys, which were then buried by Upper Triassic sedimentary materials from pre-existing rocks such as gneiss and schists, sandstones, radiolarite rocks, and limestones with thicknesses varying between 500 and 1000 meters, which experienced folding until they turned into diabases. Verbeek (1905) argued that the first formation in Ambon City, known as the Leihitu peninsula, had a tectonic phase that caused the intrusion of granite rocks along with eruptions that formed volcanic formations that are then known as ambonite rocks, consisting of liparite rocks, andesite, dacite, and basalt (16).

Based on the geological map of the Ambon City sheet, Maluku, the type of Ambon City consists of Ambon volcanic rocks (Tpav), uplifted coral reef rocks (Q), ultramafic rocks (JKu), Kanikeh formation (TRJK), alluvium (Qa), and Ambon granite (Ti). The analysis shows that Ambon volcanic rocks (Tpav) dominate the area with an area of 22,812.82 hectares, followed by uplifted coral reefs (Q), which cover 4,996.54 hectares. Volcanic rocks, known for their easily weathered characteristics, have a high potential for landslides, especially when exposed to high rainfall. Meanwhile, ultramafic rocks (JKu) and the Kanikeh formation (TRJK) also contribute to the potential for land movement, albeit with smaller areas of 1,915.25 hectares and 1,316.34 hectares, respectively. Aluvium (Qa) and Ambon granite (Ti) have a more limited area of 1,338.25 hectares and 194.26 hectares, respectively, but are still important to consider in the context of soil stability (Figure 1).

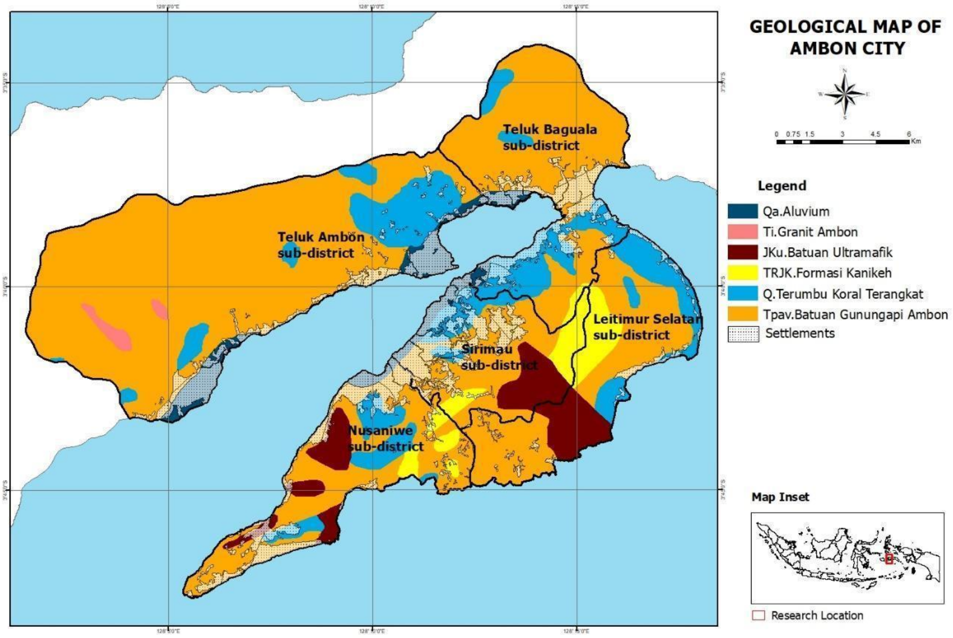

Figure 1: Geological Map of Ambon City.

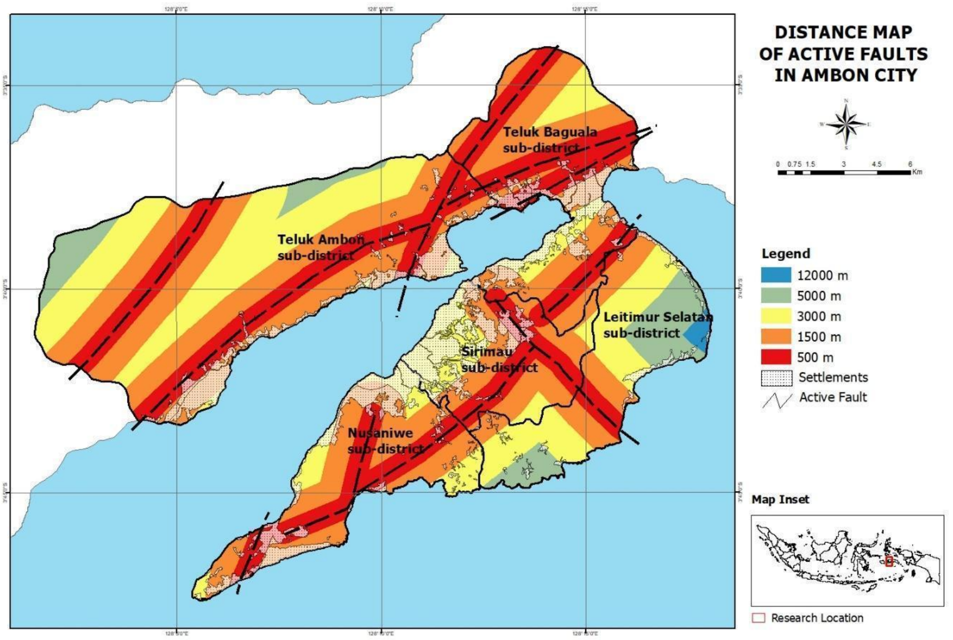

Figure 2: Map of distance from active faults.

Ambon City is composed of volcanic rocks (Tpav), which generally have a weaker structure and are prone to weathering, thus increasing the risk of ground movement,

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especially in areas with steep slopes. In addition, uplifted coral reef rocks (Q) and alluvium (Qa) that often have softer properties and are easily eroded also contribute to landslide potential (14). On the other hand, ultramafic rocks (JKu) and Ambon granite (Ti) tend to be more stable and have better resistance to land movement. The Kanikeh Formation (TRJK), which has certain geological characteristics, can also affect drainage patterns and water accumulation, which in turn can trigger ground movements (14). Thus, an understanding of the distribution and properties of these geologies is essential to identify areas at high risk of ground motion in Ambon City.

3.2. Effect of Distance from Active Faults on Ground Motion Potential

The results of the analysis show that distance from active faults has a significant influence on the potential for ground motion in Ambon City. The data obtained shows that the area with a distance of 500 meters from the active fault covers 8,599.82 hectares, while at a distance of 1,500 meters, the area increases to 12,887.61 hectares. However, as the distance increases to 3,000 meters, the area of potential ground motion decreases to 8,820.65 hectares. A further decrease is seen at distances of 5,000 meters and 12,000 meters, where the area affected is only 2,127.89 hectares and 137.49 hectares, respectively (Figure 2). This finding indicates that the further away an area is from an active fault, the potential for ground motion tends to decrease, although other factors such as rock type and topographic conditions also need to be considered. The effect of distance from active faults shows that proximity to faults is directly related to seismic activity that can trigger ground movement (14). Areas close to active faults are more susceptible to earthquakes and ground movements due to the resulting tremors (14). This is important to understand in the context of spatial planning and disaster mitigation in Ambon City. With this information, local governments can develop more effective mitigation strategies to protect communities and infrastructure from geological disaster risks that increase along with seismic activity in the region.

3.3. Land Movement Hazard Zone in Ambon City

The results of the ground motion hazard zonation analysis in Ambon City show that there are three main categories, namely low, medium and high, based on the potential for ground motion influenced by rock type and distance from active faults. The area under the low risk category reaches 12,069.09 hectares, indicating that most areas in Ambon City have relatively good stability against ground movement. These areas generally consist of more stable rock types and are located far from active faults, so the risk of landslides or ground movements in these areas can be considered minimal (17). Meanwhile, areas with a moderate risk category cover 12,157.24 hectares. These areas may have a more varied combination of rock types and are in closer proximity to active faults, increasing the potential for ground movement. Although the risk in these areas is not as high as in the high category, attention is still needed to monitor geological and weather conditions, especially during times of heavy rainfall or seismic activity. Proper management of these areas can help reduce the risk and impact of ground movement. Areas categorized as high risk cover 8,347.14 hectares, indicating that these areas are highly susceptible to ground movement. Factors such as easily weathered rock types and proximity to active faults contribute to the high potential for ground movement in these areas (18). Therefore, it is important for the government and community to implement effective mitigation measures, such as geological monitoring, wise spatial planning, and public education on the risks of ground motion. Thus, efforts to reduce the impact of disasters can be carried out more effectively in Ambon City.

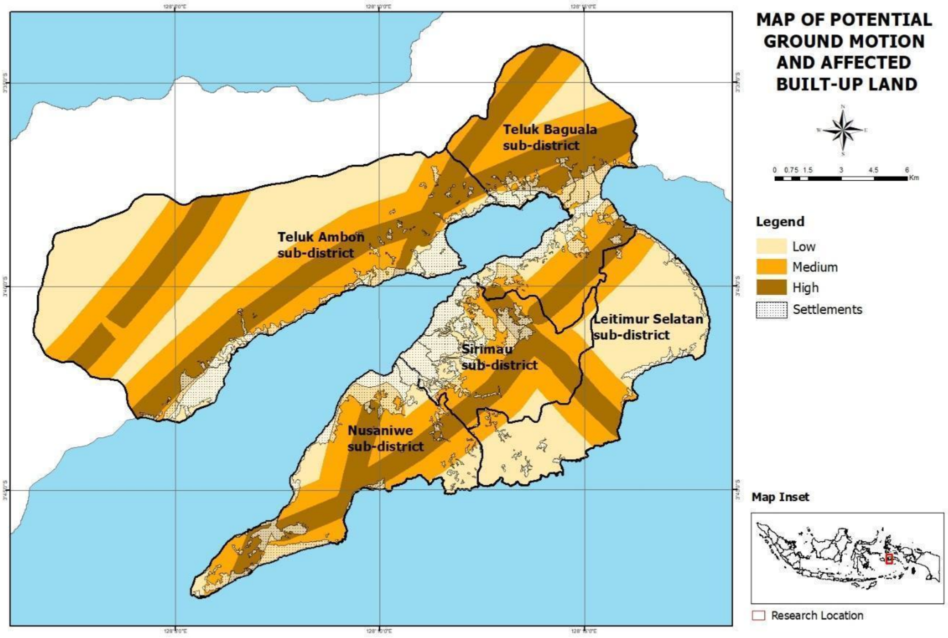

Figure 3: Map of Potential Ground Motion and Affected Build up land.

The results of the analysis of built-up land located in potential ground motion-prone areas in Ambon City show that there is significant variation in the distribution of land by risk category. Areas in the low-risk category cover 2,296.23 hectares, indicating that most of the built-up land in this area has better stability against potential ground motion. Built-up land in this category is generally located further away from active faults and has more stable rock types, which minimizes the risk of landslides or ground movements. On the other hand, the moderate risk category covers 1,470.58 hectares. Built-up land in this category indicates that although it still has a lower potential for ground movement compared to the high category, attention is still needed. These areas may have a more varied combination of rock types and are in closer proximity to active faults, increasing the potential for ground motion. Therefore, it is important to conduct regular monitoring and evaluation of the geological conditions and infrastructure in these areas to reduce the risk (19). The high-risk category area covers 672.36 hectares, indicating that the built-up land in this area is highly susceptible to ground motion. Factors such as weathered rock types and proximity to active faults contribute to the high potential for ground movement in this area (Figure 2).

In terms of disaster mitigation, several recommendations can be proposed to reduce the risk of land movement in Ambon. First, the local government needs to develop a more comprehensive risk map that integrates geological and seismic data, so as to provide clear information on high-risk areas. Second, public education on the potential risk of ground movement is essential, especially in areas adjacent to active faults. This education can include training on actions to take in the event of a disaster. Third, infrastructure development should consider rock type and distance from active faults to reduce the impact of disasters. Finally, further research is needed to monitor changes in geological and seismic conditions in Ambon, and to develop more effective mitigation strategies. With these measures, it is expected to improve community preparedness and reduce the impact of future ground motion disasters.

4. Conclusion

The potential for ground movement in Ambon City is strongly influenced by two main factors, namely rock type and distance from active faults. The analysis shows that areas with soft rocks, such as alluvium and volcanic rocks, have a higher risk of experiencing ground motion compared to areas dominated by hard rocks such as granite. In addition, proximity to active faults also contributes significantly to the increased potential for ground movement, especially in areas less than 500 meters from the fault. These findings provide a clear picture of areas that need more attention in terms of disaster mitigation. Based on the results of this study, it is recommended that the government and stakeholders develop a more comprehensive risk map that integrates geological and seismic data. Socialization to the community regarding the potential risk of land movement is also very important to increase awareness and preparedness. In addition, spatial planning and infrastructure development should consider the geological characteristics of the area to reduce disaster impacts. With appropriate and sustainable mitigation measures, it is expected that the impact of land movement can be minimized, thus protecting the community and infrastructure in Ambon City from increasing disaster risks.

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