



[Research Article]



Application of GIS Technology for Landslide Prone Area Analysis in Ambon Island, Indonesia

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Article Info:	Abstract
<p>Received: 4 November 2024</p> <p>Accepted: 29 January 2025</p> <p>Published: 3 March 2025</p> <hr/> <p>Keywords: Ambon; GIS; landslide; Storie Index.</p>	<p><i>The application of Geographic Information System (GIS) technology in analyzing landslide-prone areas in Ambon Island, Indonesia, is becoming increasingly important given the hilly geographical conditions of Ambon Island and its slopes, making landslides a frequent occurrence. This study used slope, soil type, rainfall, and land cover variables. This research used the Storie Index Method to analyze landslide prone areas in Ambon Island. The results showed that Ambon Island has a medium vulnerability level of 38,282.53 ha, a high class of 23,922.00 ha, and a low landslide prone level with an area of 21,676.08 ha. The results of this study are expected to be used as a policy recommendation for future landslide mitigation in Ambon Island.</i></p>
Informasi Artikel:	Abstrak
<p>Diterima: 4 November 2024</p> <p>Disetujui: 29 Januari 2025</p> <p>Dipublikasi: 3 Maret 2025</p> <hr/> <p>Kata kunci: Ambon; SIG; longsor; Storie Index.</p>	<p><i>Penerapan teknologi Sistem Informasi Geografis (SIG) dalam analisis daerah rawan longsor di Pulau Ambon, Indonesia, menjadi semakin penting mengingat kondisi geografis Pulau Ambon yang berbukit serta memiliki lereng yang terjadi membuatnya sering terjadi bencana longsor. Penelitian ini menggunakan variabel kemiringan lereng, jenis tanah, curah hujan dan tutupan lahan. Penelitian ini menggunakan metode Metode Indeks Storie untuk menganalisis daerah rawan longsor di Pulau Ambon. Hasil penelitian menunjukkan bahwa Pulau Ambon memiliki tingkat kerawanan sedang seluas 38.282,53 ha, kelas tinggi seluas 23.922,00 ha dan tingkat rawan longsor rendah memiliki luas 21.676,08 ha. Hasil penelitian ini diharapkan dapat menjadi bahan sebagai rekomendasi kebijakan untuk mtigasi bencana longsor kedepanya di Pulau Ambon.</i></p>

INTRODUCTION

Landslides are a natural phenomenon controlled by geological conditions, rainfall, and land use on slopes. In recent years, the intensity of landslide disasters in Indonesia has increased, with the distribution of disaster areas getting wider (Ram & Gupta, 2022). This is due to the increase in land use that is not environmentally sound in areas prone to land movement, as well as high rainfall intensity with a long duration, or due to the increasing frequency of earthquakes. The National Disaster Management Agency recorded 608 land movement disasters throughout 2023, with the locations of the incidents spread across various regions in Indonesia including Ambon Island (BNPB, 2023b).

Maluku Province is an area with a high disaster risk index with a score of 179. Based on BNPB's disaster classification, Maluku Province has 12 types of disaster threats, namely floods, flash floods, landslides, extreme waves and abrasion, earthquakes, tsunamis, volcanic eruptions, droughts, epidemics and disease outbreaks, forest and land fires, extreme weather, and technological failures (BNPB, 2023a). Potential hazards are dominated by hydrometeorological hazards, such as floods, landslides, extreme waves, abrasion, and extreme weather. The most recurrent disasters in the last five years are floods and landslides.

Administratively, Ambon Island consists of Central Maluku Regency and Ambon City. Based on data from the Maluku Province National Disaster Risk Assessment 2022 - 2026, Ambon City has a medium landslide hazard potential with a score of 572,402, while Central Maluku Regency has a high landslide hazard potential with a score of 24,503. In 2024, there were 140 landslide incidents on Ambon Island. The disaster affected 147 families, 284 male individuals, and 307 female individuals, resulted in 2 fatalities, and caused light to moderate damage to 14 houses (BNPB, 2023a).

Geomorphologically, the island has a diversity of hills, old volcanoes, denudational mountains, and many alluvium plains, but the area is not very large compared to other landscapes (Aditian et al., 2018; Latue et al., 2023a). These physical conditions indicate that Ambon Island is vulnerable to natural disasters, and the most recorded natural disaster in Ambon

Island is landslides (Souisa et al., 2016; Rakuasa & Rifai, 2021).

The application of Geographic Information System (GIS) technology in the analysis of landslide-prone areas in Ambon Island, Indonesia, is becoming increasingly important given the geographical and climatic conditions that can trigger natural disasters (Kalmar et al., 2024). Ambon Island, located in the eastern region of Indonesia, has diverse topographic characteristics, with many mountainous areas prone to landslides. According to previous research, the use of GIS can assist in the mapping and analysis of disaster risks, including landslides, by utilizing spatial and attribute data to identify areas most at risk (Muin & Rakuasa, 2023).

One of the methods used to assess the landslide potential of an area is the modified Storie Index method. The Storie Index method is a technique used to predict the vulnerability level of land movement by utilizing GIS analysis (Ristya et al., 2019). This method involves data processing by overlaying several important parameters, such as slope, land use, soil type, and rainfall. By integrating these factors, the storie index method can determine the level of ground motion susceptibility in low, medium, or high categories. The results of this analysis are very useful for disaster mitigation planning and risk management in landslide-prone areas.

METHOD

This research was conducted in Ambon Island, Maluku Province, Ambon City (Figure 1). In this study, landslide prone areas were classified using Storie Method factors with predetermined weight criteria (Table 1). This research also reviews the physical characteristics that affect the classification results. The variables used are slope, soil type, rainfall, and land cover. This research uses SPOT 6 satellite image data to analyze the land cover of Ambon City in 2024. DEMNAS data was obtained from the Indonesian Geospatial Information Agency, soil type map was obtained from the FAO-UNESCO Soil Map of the World. Monthly rainfall data for 2024 was obtained from the Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS).

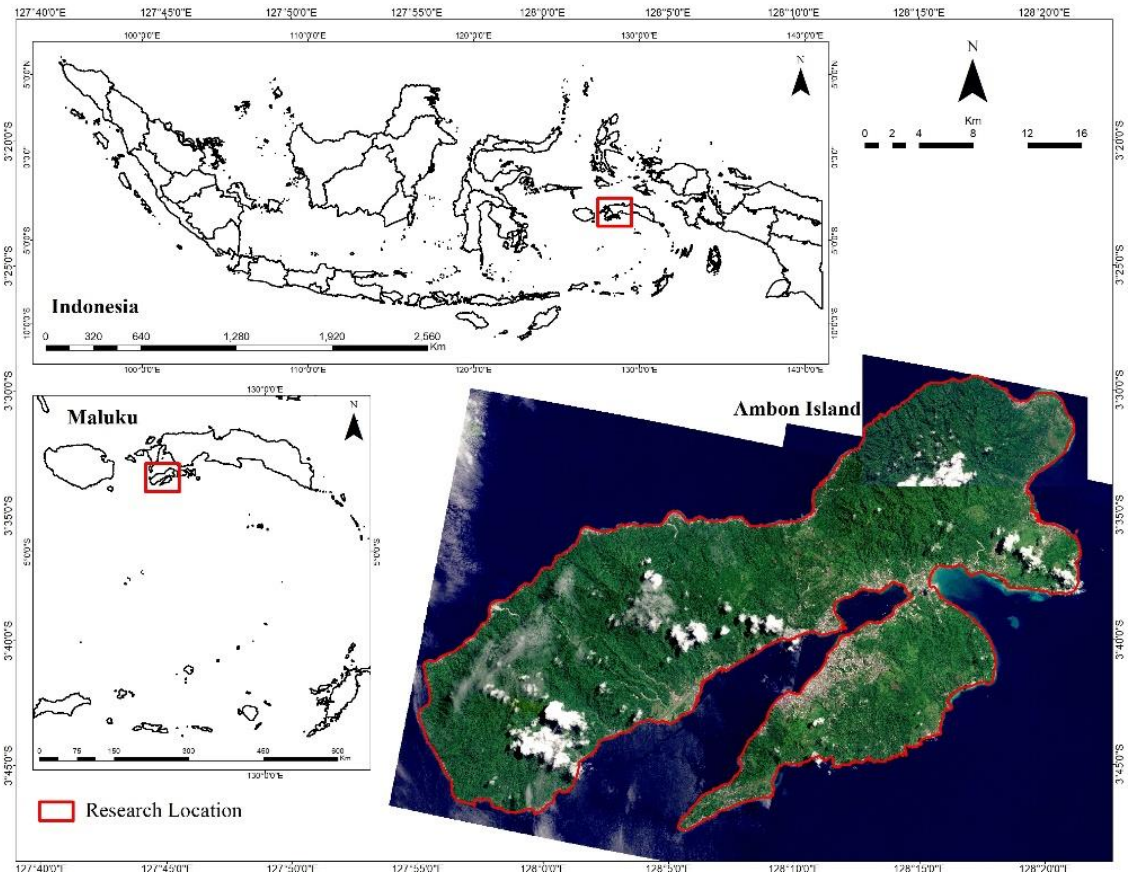


Figure 1. Research Location

Table 1. Research Variables

No	Variables	Classification	Weight
1	Slope	0-8%	1
		8-15%	2
		15-25%	3
		25-45%	4
		>45%	5
2	Soil Type	Orthic Acrisols	4
		Readiness	3
3	Rainfall	>3000 mm	2
		3000-4000 mm	3
		>4000 mm	5
4	Land Cover	Forest	1
		Built-up Land	3
		Open Land	4
		Agriculture	3
		Shrubs	2

Source : Sugianti et al., 2014; Santoso et al., 2022; Manakane et al., 2023.

Data on slope, soil type, rainfall, and land cover were then overlaid by referring to the modified storie index method. The equations used are as follows:

$$L = A \times B/10 \times C/10 \times D/10 \quad (1)$$

where L is vulnerability level, A is land cover, B is slope, C is soil type, and D is rainfall.

The equation above contains two types of variables, namely (1) factors that can be changed by humans such as vegetation growing on the ground (factor A); topographic elements such as slope length (factor B); and (2) factors that cannot be changed by humans such as soil type (factor C); slope steepness (factor B); and climate (factor D). The amount of vulnerability of an area is classified based on Table 2.

Table 2. Classification of Landslide Hazard Level

Weight	Weight Analysis	Weight Class Value	Vulnerability Level
1	0,016	< 0,016	Low
2	0,081	0,017-0,081	Medium
3	0,256	> 0,082	High

Source : Sugianti et al., 2014; Aditian et al., 2018; Santoso et al., 2022; Manakane et al., 2023.

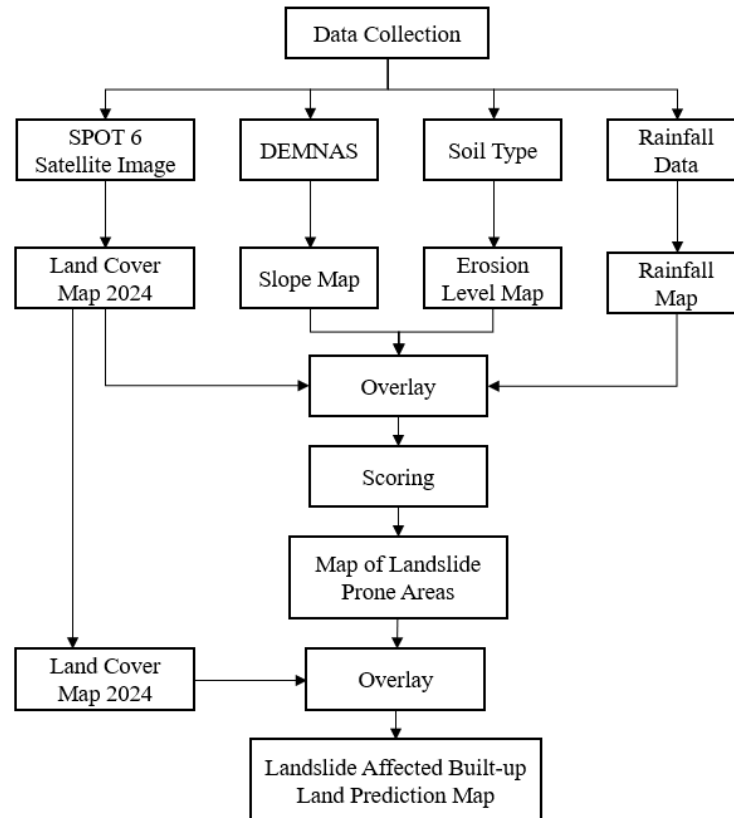


Figure 2. Workflow of Methodology

Spatial analysis was conducted by analyzing the distribution of landslide potential areas on Ambon Island. The resulting map of landslide prone areas is analyzed spatially descriptively. After the analysis, an overlay with built-up land data in 2024 was conducted to predict built-up land affected by landslides in Ambon Island. Details of the research workflow can be seen in Figure 2.

RESULT AND DISCUSSION

Landslide Variables

The slope is one of the important variables for landslide vulnerability analysis. There are 5,838.15 ha of areas with 0-8% slope, 7,228.58 ha of areas with 8-15% slope, 14,431.01 ha of areas with 15-25% slope, 31,154.44 ha of areas with 25-45% slope and 18,225.05 ha of slope >45%. The slope has a significant influence on landslides, where the

steeper the slope, the greater the potential for movement of soil or rock masses. Slopes with a slope of more than >25% tend to have an increased risk of landslides due to the stronger gravitational force acting on the material on the slope, reducing the frictional force that holds the material in place (Goswami et al., 2024). In addition, steep slopes also increase erosion rates and surface runoff, which can erode the soil layers that support slope stability.

Based on soil type map data obtained from FAO-UNESCO Soil Map of the World, there are two soil types in Ambon Island, namely orthic Acrisols and Rendzinas. Soil types in Ambon Island, especially orthic Acrisols and Rendzinas, have a significant influence on the potential for landslides. Orthic Acrisols, which are generally acidic and low in fertility, can increase susceptibility to erosion, especially in areas with steep slopes (Puturuhu et al., 2022).

The 15,976.76 ha of orthic Acrisols suggests that these areas may be more susceptible to landslides if not managed properly. On the other hand, Rendzinas, which are more fertile and rich in organic matter, covering an area of 60,936.20 ha, may provide better stability to the slopes but are still risky in case of heavy rains that cause soil saturation. Therefore, proper management of these two soil types is essential to reduce the risk of landslides on Ambon Island, especially in areas with high slopes (Arshid et al., 2024).

Based on monthly rainfall data for 2024 (January-October) obtained from Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS), rainfall on Ambon Island consists of 3 areas: areas with rainfall 2000 - 3000 mm/month covering 12,446.95 ha, 3000 - 4000 mm/month covering 63,402.92 ha and areas with rainfall >4000 mm covering 602.26 ha. Rainfall has a significant influence on the occurrence of landslides, where high rainfall intensity and duration can cause the soil to become saturated with water, reducing its stability. As rainfall increases, water will seep into the soil, causing the initially unsaturated surface layer to become saturated, increasing the weight of the soil mass and reducing the frictional force holding the material on the slope (Ristya et al., 2019). This can trigger ground mass movement, especially in areas with steep slopes. In addition, high rainfall can also

increase surface flow, which has the potential to erode soil and worsen slope stability conditions (Rakuasa et al., 2022). Thus, high rainfall is one of the key factors in landslide risk analysis, especially in areas prone to land movement.

The results of SPOT 6 satellite image interpretation show the classification of land cover in an area divided into five classes, namely Forest, Built-up Land, Open Land, Agriculture, and Shrubs. The forest covers 30,578.04 ha, which functions as an ecosystem buffer and plays an important role in maintaining soil stability and reducing the risk of landslides. Meanwhile, built-up land of 6,034.00 ha shows the presence of settlements and infrastructure that can increase vulnerability to landslides if not managed properly. Open land of only 204.61 ha has a high potential for landslides. The agricultural sector covering 25,268.38 ha has the potential to increase the risk of landslides, especially if agricultural practices do not pay attention to soil conservation. Finally, bushes covering an area of 15,200.25 ha can function as a soil barrier but also require good management to prevent damage. This classification is important to understand the dynamics of land use and potential landslide risk in the area (Hehanussa et al., 2024). The variables map can be seen in Figure 3.

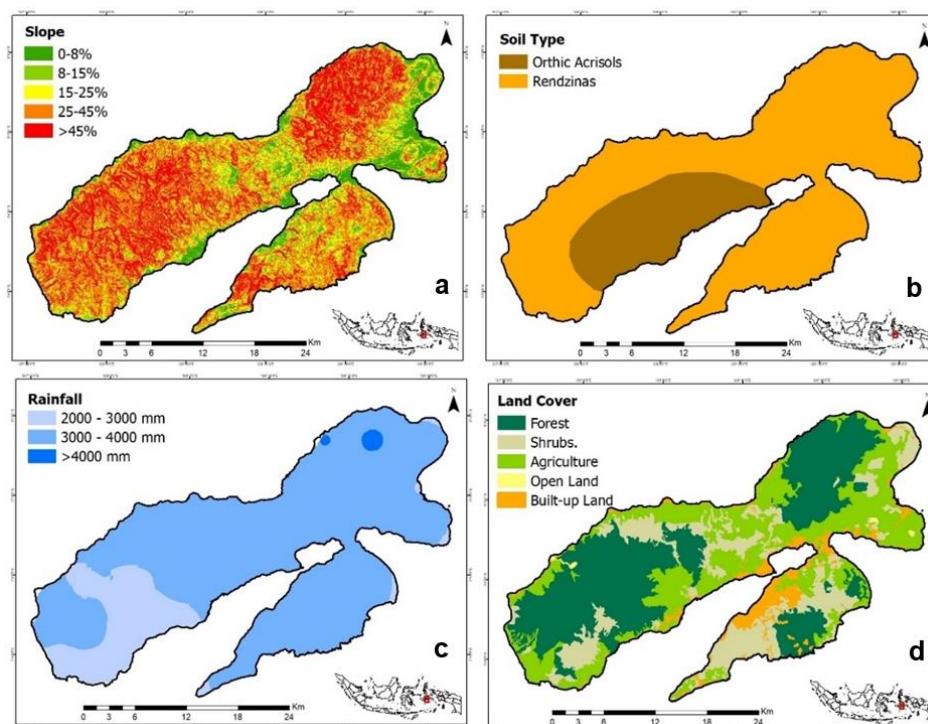


Figure 3. Research Variables: a) Slope, b) Soil Type, c) Rainfall, and d) Land Cover 2024

Landslide Prone Areas

The landslide prone areas map of Ambon Island was generated by calculating the variables affecting land use assessment in the storie index method. The map was created by overlapping four variables that cause landslides, namely land use, slope, soil type, and rainfall. The calculation of landslide vulnerability is done by multiplying the class values of the variables that have been classified and weighted according to the influence of the variables on landslides.

Based on the results of data processing of landslide prone areas in Ambon Island, the study shows that this area has a moderate level of vulnerability with a percentage of 45.64%. This means that almost half of the studied area, which is 38,282.53 hectares, is in the category of moderate landslide vulnerability. This category indicates that although the risk of landslides exists, the influencing factors such as slope, soil type, and rainfall are not at the most critical level (Latue et al., 2023a). Knowledge of this level of vulnerability is crucial for disaster mitigation planning and risk management in the area, especially in the context of increased land use that is not environmentally sound (Rakuasa et al., 2024).

Furthermore, the high vulnerability level was recorded at 28.52% with an area of

23,922.00 hectares. These areas show a greater potential to experience landslides, which can be caused by a combination of factors such as steep slopes, vulnerable soil types, and high rainfall (Rakuasa et al., 2022). In this context, it is important to conduct stricter prevention and management measures, such as planting of soil retaining vegetation, and regulating land use, to reduce the risk of landslides in these areas. Previous studies have also shown that areas with slopes greater than 25% tend to have a higher risk of landslides, so special attention should be paid to such areas (Mirdda et al., 2022; Rif'ah et al., 2024).

The low vulnerability level has an area percentage of 25.84%, covering 21,676.08 hectares. Although these areas are considered to have a lower risk, good monitoring and management is still required to prevent changes in conditions that could increase vulnerability. The use of Geographic Information System technology in this analysis enables the identification of the most at-risk areas and assists in more effective disaster mitigation planning (Abay et al., 2019). Thus, an in-depth understanding of landslide vulnerability in Ambon Island can contribute to overall disaster risk reduction efforts. Landslide classes in Ambon Island can be seen in Figure 4.

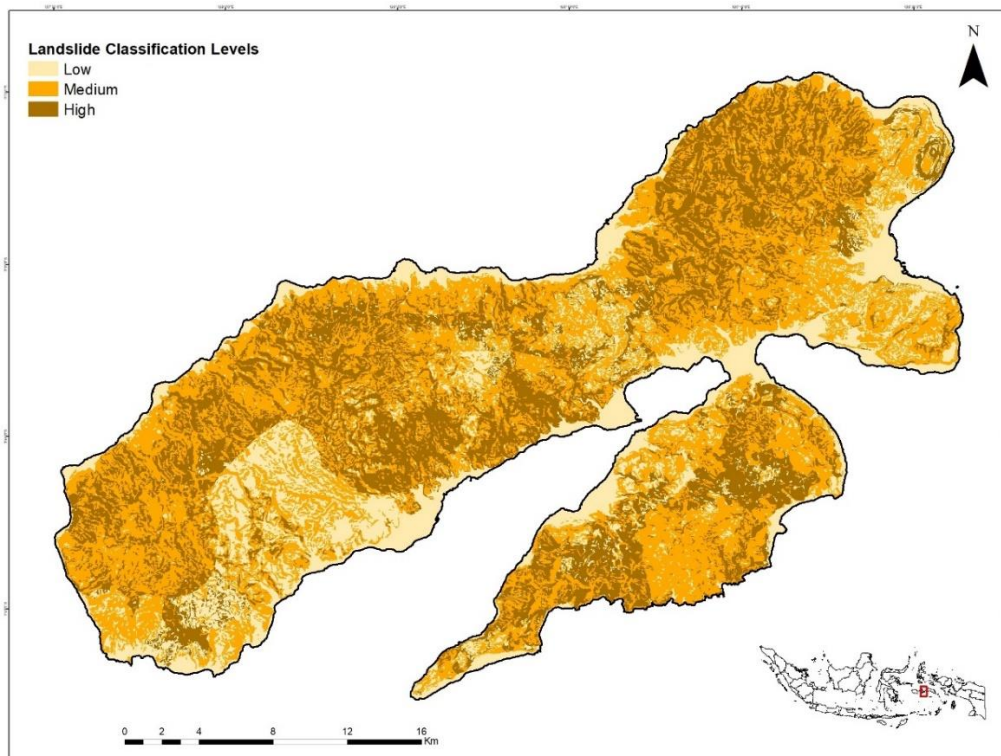


Figure 4. Landslide Classification Levels

Prediction of Built-up Land Affected by Landslides

According to Rahmad et al. (2018), one form of mitigation and anticipation of landslides in Ambon Island is by predicting how much built-up land/settlements are located in landslide prone areas. The distribution of residential land located in flood-prone areas can be seen in Figure 4. Built-up land on Ambon Island shows significant variations in its distribution based on the level of landslide vulnerability (Aditian et al., 2018). In areas with high landslide vulnerability, built-up land covers an area of 163.75 hectares, which is equivalent to 1.74% of the total built-up area. Although this percentage is relatively small, the presence of infrastructure in high landslide prone areas is of great concern as it can increase the risk of damage and casualties in the event of a landslide (Harist et al., 2018).

Therefore, it is important to implement appropriate mitigation measures, such as strengthening of building structures and good drainage management, to protect infrastructure and residents in these areas (Wang et al., 2017).

Meanwhile, built-up land located in moderate landslide prone areas reached 2,205.41 hectares, or 23.46% of the total built-up land. This area shows a greater potential risk compared to built-up land in low areas, thus requiring special attention in spatial planning and risk management (Figure 5). Infrastructure development in these areas should take into account geological and hydrological factors that can affect soil stability (Chen & Li, 2020). Research shows that good management of land use and implementation of sustainable development practices can help reduce landslide risk in these areas (Kalmar et al., 2024).

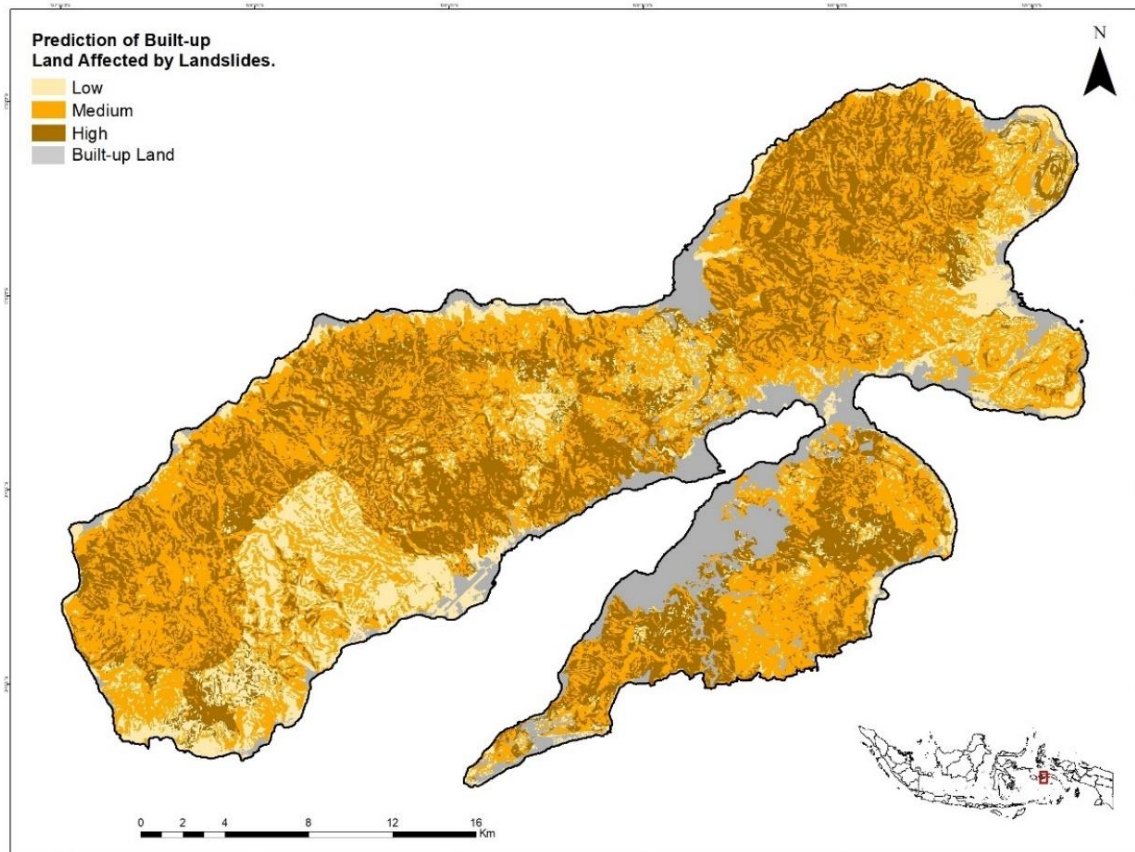


Figure 5. Prediction of Built-up Land Affected by Landslides

On the other hand, built-up land located in low landslide prone areas covers 7,031.03 hectares, or 74.80% of the total built-up land. This high percentage indicates that most of the infrastructure on Ambon Island is in areas that are relatively safe from landslide risk. However, despite the lower risk in these areas, it is still

important to conduct good monitoring and management to prevent changes in conditions that could increase vulnerability (Somae et al., 2022). By utilizing technologies such as Geographic Information Systems, stakeholders can more effectively plan and manage land use,

as well as identify potential risks that may arise in the future (Latue et al., 2023b).

The GIS technology plays an important role in landslide analysis by providing tools for the collection, mapping, and analysis of geospatial data related to factors that cause landslides (Fatiatun et al., 2019). The GIS allows the integration of various data, such as slope, soil type, land use, and rainfall, to accurately identify landslide-prone areas. Using methods such as modified Storie Index, GIS can generate landslide susceptibility maps that assist in spatial planning and disaster risk management (Sugianti et al., 2014). In addition, GIS also supports real-time monitoring of environmental conditions, which is important for providing early warning to communities in risky areas, thereby improving the effectiveness of disaster mitigation.

In addition to structural aspects, non-structural inequalities also play a significant role in the prediction and management of built-up land affected by landslides in Ambon City. Policy inequalities, such as uneven enforcement of land use regulations and the lack of integration of disaster risk reduction into spatial planning, can exacerbate the risks faced by communities in landslide-prone areas (Asmare, 2022). Overlapping interests among stakeholders, including government agencies, private developers, and local communities, often lead to conflicting priorities, hindering effective risk mitigation (Ram & Gupta, 2022). For instance, economic interests in developing high-value land may take precedence over safety considerations, resulting in inadequate protective measures in vulnerable areas (Latue et al., 2023c). Addressing these non-structural challenges requires a coordinated approach that promotes equitable policies, transparent decision-making processes, and active involvement of all stakeholders to ensure sustainable and inclusive spatial planning.

CONCLUSION

The conclusion of this study shows that Ambon Island has varying levels of landslide vulnerability, with 25.84% of the area classified as low, 45.64% as moderate, and 28.52% as high. The use of Geographic Information System (GIS) technology in this analysis enables the identification of risk areas and supports more effective disaster mitigation planning. The proposed policy recommendations, such as

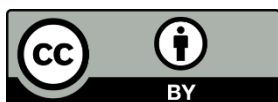
strengthening infrastructure, sustainable land use management, and improving early warning systems, are expected to reduce landslide risk and enhance community resilience to disasters. In the context of built-up land affected by landslides, it is crucial to conduct a comprehensive evaluation of high-risk locations, particularly those near residential areas. Recommendations include reorganizing land use to avoid development in landslide-prone areas and implementing strict zoning policies to protect these regions. Additionally, increasing public awareness about landslide risks and the importance of maintaining vegetation on slopes is essential to minimize the impact of future disasters.

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