Journal of Selvicoltura Asean, 1(3) - June 2024 105-119

Integration of Remote Sensing Data and Geographic Information System for Mapping Landslide Risk Areas in Ambon City, Indonesia

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Received: July 26, 2024	Revised: Sep 04, 2024	Accepted: Sep 04, 2024	Online: Sep 04, 2024

ABSTRACT
This research investigates the integration of remote sensing data and Geographic Information Systems (GIS) to map landslide risk areas in Ambon City, Indonesia, a region characterized by its hilly terrain and susceptibility to landslides. Utilizing various environmental variables such as slope gradient, land use, and rainfall patterns, the study employs a multi-criteria approach to assess landslide vulnerability and distribution. The findings reveal significant correlations between anthropogenic factors, such as urbanization, and increased landslide risk, highlighting the urgent need for sustainable urban planning and disaster risk management strategies. By providing a comprehensive landslide risk map, this study aims to support local authorities in making informed decisions to enhance community resilience and mitigate the impacts of landslides in Ambon City.

Keywords: *Ambon, Hazard, Vulnerability*

Journal Homepage https://journal.ypidathu.or.id/index.php/ijnis

How to cite: Hehanussa, S, F., Latuem, C, P., Rakuasa, H & Somae, G. (2024). Integration of Remote Sensing Data and Geographic Information System for Mapping Landslide Risk Areas in Ambon City, Indonesia. *Journal of Selvicoltura Asean*, 1(3), 105-119. https://doi.org/10.70177/jsa.v1i3.1185
Published by: Yayasan Pedidikan Islam Daarut Thufulah

INTRODUCTION

Landslides pose a significant threat to communities in mountainous regions, causing loss of life, property damage, and economic disruption (Aditian et al., 2018). In Indonesia, the city of Ambon faces particularly high landslide risks due to its topography and climate. This study aims to integrate remote sensing data and Geographic Information System (GIS) technologies to map landslide risk areas in Ambon City, providing crucial information for disaster mitigation and urban planning (Rakuasa & Rifai, 2021; Rakuasa et al., 2022). Ambon City, located on Ambon Island in the Maluku province of Indonesia, is characterized by its hilly terrain and tropical climate. Approximately 89% of the city's area consists of mountainous landscapes, making it highly susceptible to landslides

(Somae et al., 2022; Sugandhi et al., 2023). The combination of steep slopes, intense rainfall, and increasing urbanization has led to a higher frequency of landslide events in recent years (Muin & Rakuasa, 2023).

Remote sensing techniques have proven invaluable for landslide risk assessment, offering a cost-effective and efficient means of gathering data over large areas. Satellite imagery and aerial photography can provide detailed information on land cover, topography, and geological features that influence landslide susceptibility (Aditian et al., 2018). These technologies allow researchers to identify and monitor potential landslide-prone areas without the need for extensive field surveys. Geographic Information Systems (GIS) complement remote sensing data by enabling the integration, analysis, and visualization of multiple spatial datasets (Ullah et al., 2022). GIS tools facilitate the creation of landslide hazard inventory and zoning maps, which are essential for risk assessment and management (Chen & Li, 2020; Bai et al., 2021). The ability to overlay various thematic layers and perform complex spatial analyses makes GIS an indispensable tool for landslide risk mapping (Skilodimou et al., 2018; Van Phong et al., 2022).

Previous studies have demonstrated the effectiveness of integrating remote sensing and GIS for landslide risk assessment in various geographical contexts. For instance, Abay et al., (2019), utilized remote sensing and GIS alongside the Analytical Hierarchy Process (AHP) to assess landslide susceptibility. Their approach achieved high accuracy in predicting landslide-prone areas, highlighting the potential of these integrated technologies for risk assessment. In the context of Ambon City, limited research has been conducted on comprehensive landslide risk mapping using advanced geospatial technologies. While Latue & Rakuasa, (2023), analyzed landscape suitability for settlement development in Ambon using GIS, their study did not specifically focus on landslide risk. The present research aims to address this gap by integrating up-to-date remote sensing data and GIS analysis to create a city-wide landslide risk map.

The rapid urbanization of Ambon City has led to increased development in hilly areas, exacerbating the landslide risk (Rakuasa & Latue, 2023). Rakuasa et al., (2024), found that a significant portion of the city's built-up areas falls under high landslide vulnerability categories. This underscores the urgent need for accurate risk mapping to inform urban planning decisions and protect vulnerable communities. Climate change is expected to further intensify the landslide risk in Ambon City by altering rainfall patterns and increasing the frequency of extreme weather events. As such, developing robust methods for landslide risk assessment and monitoring is crucial for enhancing the city's resilience to climate-related disasters (Manakane et al., 2023)

This study employs a multi-criteria approach to landslide risk mapping, integrating various factors such as slope, lithology, land use/land cover, rainfall, and historical landslide occurrences (Rakuasa, 2024). By leveraging the capabilities of remote sensing and GIS, we aim to produce a comprehensive and up-to-date landslide risk map for Ambon City that can serve as a valuable tool for disaster risk reduction and sustainable urban development (Salakory & Rakuasa, 2022).

The results of this research will not only contribute to the scientific understanding of landslide risks in Ambon City but also provide practical insights for local authorities and urban planners. By identifying high-risk areas and potential triggering factors, this study aims to support evidence-based decision-making in land use planning, infrastructure development, and disaster preparedness strategies for the city.

RESEARCH METHODOLOGY

Research Location

This research was conducted in June 2024 in Ambon City, which is the capital of Maluku Province, Indonesia.

Materials and Tools

The materials and tools used in this study are:

Materials;

1) Ambon City Adiminstrasi Map-BAPEKOT Ambon
2) Soil Type Map of Ambon City- BAPEKOT Ambon
3) Elevation Map - DEM Analysis
4) Slope Map - DEM Analysis
5) River Buffer Map - RBI Analysis
6) Land Cover Map 2024- Landsat 8 Image Analysis
7) Rainfall Data - BMKG Class II Pattimura Ambon
8) History of Landslide Events in Ambon City in 2019-2024 - BPBD Ambon City
9) Ambon City in Figures 2020 - BPS

Tools

1) Computer
2) GPS
3) Arc GIS 10.6 software
4) ENVI 4.5 software
5) Microsoft Office 2016

Workflows

The landslide risk map consists of three mappings, namely landslide hazard mapping, vulnerability mapping and capacity mapping. The three maps were then analyzed to produce a landslide risk map of Ambon City. The methodology is described in Figure 1 as follows.

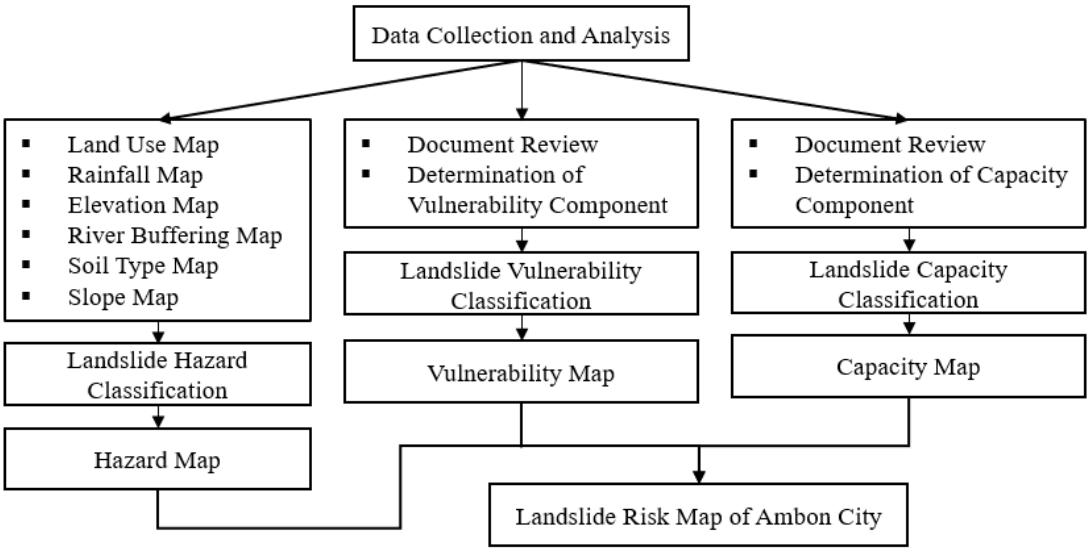

Figure 1. Research Flow

Landslide Hazard Mapping

Landslide hazard map making is done first by compiling and arranging various types of data whose units and functions are not yet organized into systematic and detailed data in accordance with their functions, classifications and uses, so that the data is easy to be analyzed further. The determination of landslide hazard level is done by combining and weighting the parameters of slope, soil type, rainfall, land use, elevation and river buffer. Below are details of the weighting of each parameter:

1. Soil Type

The soil type or erodibility parameter (the level of soil sensitivity to erosion) is categorized into three categories: high, medium and low. This classification qualitatively refers to the soil type of the Center for Agricultural Land Resources (2009). Soil erodibility is classified into three: high erodibility, medium erodibility, and low erodibility. Soil types have different levels of sensitivity to landslide potential, depending on the criteria of soil type and its classification see Table 1.

Table 1. Soil type parameter formula

Class	Soil Type	Score
I. Sensitivity to landslides Low	Alluvial, Gelisol, Planosol, Hydromorphic Gray, Groundwater Lateric, Latosol	1-2
II. Moderate landslide sensitivity	Alluvial, Gelisol, Planosol, Gray Hydromorph, Groundwater Lateric, Latosol	2-3
III.High landslide sensitivity	Alluvial, Gelisol. Planosol, Hydromorphic Gray, Groundwater Lateric, Latosol	3-5

Source: (Rakuasa, 2021; Ullah et al., 2022; Latue et al., 2023)

2. Land Cover

Land Cover is one of the parameters used to determine landslide potential in an area. This factor is related to land stability. Land covered by dense vegetation such as forests and plantations has less potential for landslides than land without dense vegetation. The Land Cover parameter score can be seen in Table 2.

Table 2. Land Cover Parameter Formula

Class	Land Cover Type	Score
I	Agriculture	5
II	Built-up Land	4
III	Open Land	3
IV	Forest	2
V	Water Body	1

Source: (Rakuasa , 2021; Ullah et al., 2022; Latue et al., 2023)

3. Rainfall

Rainfall is one of the factors that determine the level of landslides, because during the rainy season the soil becomes looser and makes it easy to landslide. Processing rainfall data from observation stations into rainfall maps. The data used is the amount of daily rainfall in Ambon City. Rainfall class scoring can be seen in Table 3.

Table 3. Rainfall Parameter Formula

Class	Rainfall (mm/year)	Score
Very wet	> 4000	5
Wet	>3001- 4000	4
Medium	2001-3000	3
Dry	1001-2000	2
Very Dry	<1000	1

Source: (Rakuasa , 2021; Ullah et al., 2022; Latue et al., 2023)

4. Elevation

Elevation is the height of an object from a certain point. Elevation affects the occurrence of landslides, this is because the height of the slope depends on the slope of the slope or the size of the slope angle. The elevation in the research area is around 0 meters to > 300 meters (Table 4).

Table 4. Elevation parameter formula

Class/ mdpl	Score
0-20	1
20-50	2
50-100	3
100-300	4
>300	5

Source: (Rakuasa , 2021; Ullah et al., 2022; Latue et al., 2023)

5. Slope

The classification of slope class is according to BAPEDA (Regional Planning and Development Agency) of Ambon City, but the weighting refers to (Rakuasa & Rifai, 2021) Slope weighting can be seen in Table 5.

Table 5. Slope Gradient Parameter Formula

Class/ %	Score
0-2	1
2-15	2
15-25	3
25-40	4
>40	5

Source: (Rakuasa , 2021; Ullah et al., 2022; Latue et al., 2023)

6. Distance from River

Classification and weighting of distance from river refers to Government Regulation of the Republic of Indonesia No. 38/2011. Weighting of Distance from River can be seen in Table 6.

Table 6. Formula for distance parameters from rivers

Distance from River (m)	Score
0-50	1
51-100	2
>100	3

Source: (Rakuasa , 2021; Ullah et al., 2022; Latue et al., 2023)

The class of landslide disaster threat level is based on the Regulation of the Head of the National Disaster Management Agency Number 02 of 2012 concerning General Guidelines for Disaster Risk Assessment. Calculation of class intervel = Maximum value-Minimum value/Class value

Landslide Vulnerability Mapping

Vulnerability mapping is done by document review, the first thing to do is to determine and classify vulnerability components. In determining the appropriate components and variables of landslide vulnerability of Ambon City, the existing conditions can be seen, then the classification of assessment and weighting of each vulnerability component is done. The group of landslide vulnerability components are:

1. Physical Vulnerability

   Physical vulnerability is a component selected based on the spatial arrangement of an area that requires physical development in the form of infrastructure.
2. Demographic, Social and Cultural Vulnerability

   This vulnerability was chosen because an area will experience the development of the population living in the area. The development and interaction of a region's population will form a social community and cultural development. This makes this vulnerability component important for an area in facing the threat of landslides.
3. Economic Vulnerability

   Economic Vulnerability is a component that is selected based on the economic activities of the population in an area. These activities can be in the form of several things, namely the efforts of residents in utilizing land for production, and also the development of economic infrastructure with economic activities in it. The economic component is a component that is prone to disasters.
4. Environmental Vulnerability

   The environment plays an important role in maintaining the quality and natural balance of an area. The environmental vulnerability component was chosen to determine how much the environment is damaged by the threat of landslides. The variables are forest land area, paddy land area, swamp land area, garden land area, grassland land area.

Landslide Disaster Capacity Mapping

The determination and assessment of landslide disaster capacity components of Ambon City is based on PERKA BNPB No. 2 Year 2012 by using data from interviews and direct surveys in several villages as well as secondary data obtained from BPBD Ambon City. In determining the components of capacity parameters, the level of capacity of a neighborhood is seen based on the ability of the area. Capacity in landslide disaster consists of 5 variables which are as follows:

1. Number of health workers

   This component is based on disaster risk reduction which is a national and local priority with a strong institutional basis for its implementation. The selection of this component is because the placement of health workers must be in accordance with the demographic and social conditions of the population of an area determined by an institutional rule.
2. Number of health facilities

The number of health facilities on the basis of the same capacity component, namely disaster risk reduction, is a national and local priority with a strong institutional basis for implementation.

3. Landslide disaster socialization
   This component is based on the use of knowledge, innovation and education to build a culture of safety and resilience at all levels.
4. Acquisition of assistance
   The component of obtaining assistance as a reflection of reducing risk factors. The data in this component is secondary data from BPBD Ambon City and the results of interviews in several villages.
5. Disaster anticipation efforts
   This component is based on efforts to strengthen disaster preparedness for effective response at all levels.

Landslide Disaster Risk Mapping

Risk mapping is processed through the calculation of risk score and classification of the results of threat, vulnerability and capacity mapping of landslides. The calculation of score and classification uses two methods. The two methods of score calculation and classification are as follows:

1. Classification using matrix multiplication according to VCA (Vulnerability Capacity Analysis) formula.
2. Mathematical calculation using the formulation in the modified PERKA BNPB No. 2 Year 2012.

$$R = \sqrt[6]{H^2 \times V^2 \times (1-C)^2} \quad ....(1)$$

Description: R = Risk Score H = Threat Score V = Vulnerability Score C = Capacity Score

The results of the above calculations were validated by comparing the mapping results with the results in the field conducted through the interview process with officials in the Ambon City urban village, assuming that the classification in the field is the actual condition.

RESULT AND DISCUSSION

Landslide Hazard Mapping Analysis

Landslide hazard map of Ambon City was made in 2021. By using data from 2020, 2019 and 2018, a landslide hazard map for 2021 was produced. This is used as a reference for making the landslide risk map. In accordance with PERKA BNPB No. 2 of 2012 concerning General Guidelines for Disaster Risk Assessment, the disaster risk map is about 5 years ahead. The following recapitulation of landslide hazard area and hazard map results can be seen in Table10 and Figure 2.

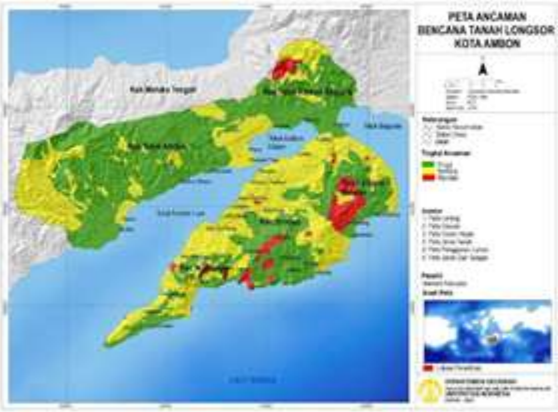

Figure 2. Landslide hazard Map in Ambon City

Table 7. Recapitulation of the Extent of the Landslide Disaster hazard in Ambon City

District	Hazard Area (ha)		
	Low	Medium	High
Teluk Ambon Baguala	3.927,93	2.620,54	290,74
Teluk Ambon	10.204,65	4.354,41	-
Leitimur Selatan	2.842,40	1.611,15	821,49
Serimau	2.088,25	2.113,29	158,41
Nusaniwe	2.363,44	2.687,74	270,06
Total Area	21.408,67	13.387	1.540,70

Based on Figure 2 and Table 7 above, the sub-district that has the highest hazard area is Leitimur Selatan sub-district with an area of 821.49 ha, while Teluk Ambon Baguala sub-district has the lowest hazard area of 3.927.93 ha.

Landslide Vulnerability Mapping Analysis

There are four components in landslide vulnerability mapping. The results of the assessment, parameter classification and mapping can be seen in Table 7 and Figure 3.

Table 8. Recapitulation of Landslide Vulnerability Area in Ambon City

District	Vulnerability Area (ha)		
	Low	Medium	High
Teluk Ambon Baguala	4.093,53	1.981,51	-
Teluk Ambon	10.958,55	2.401,31	-
Leitimur Selatan	4.750,92	-	-
Serimau	230,26	3.471,98	-
Nusaniwe	4.417,73	265,99	-
Total Area	4.093,53	1.981,51	-

Figure 3. Landslide Vulnerability Map in Ambon City

Based on Figure 3 and Table 8 above, the sub-district that has the largest Medium Vulnerability is Serimau Sub-district with an area of 3471.98 ha, while Nusaniwe Sub-district has the lowest vulnerability with an area of 265.99 ha.

Landslide Disaster Capacity Mapping Analysis

The basis of the determination of landslide disaster capacity component is PERKA BNPB No. 2 Year 2012. The results of the assessment and classification of capacity parameters of the villages with high capacity level, 6 villages with medium capacity level and the rest with low capacity level. Landslide capacity map of Ambon City can be seen in Figure 4.

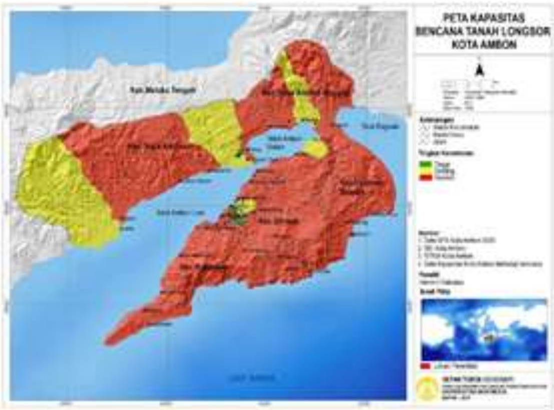

Figure 4. Landslide Capacity Map in Ambon City

Table 9. Recapitulation of Ambon City Landslide Disaster Capacity

District	Area Capacity (ha)		
	Low	Medium	High
Teluk Ambon Baguala	4.963,29	1.111,75	-
Teluk Ambon	6.945,76	6.377,05	37,04
Leitimur Selatan	4.750,92	-	-
Serimau	3.384,42	177,29	140,54
Nusaniwe	4.683,73		-

Total Area	4.963,29	1.111,75	-

Based on Figure 4 and Table 9 above. The sub-district with the widest high capacity is Serimau Sub-district with an area of 140.54 ha, and also has the widest lowest capacity, namely 3384.42 ha.

Landslide Disaster Risk Mapping Analysis

Landslide risk map of Ambon City is generated from the analysis of threat, vulnerability and capacity mapping using the two methods mentioned earlier, with the following results: Landslide Risk Map of Ambon City and its area table can be seen in Table 10 and Figure 5 below.

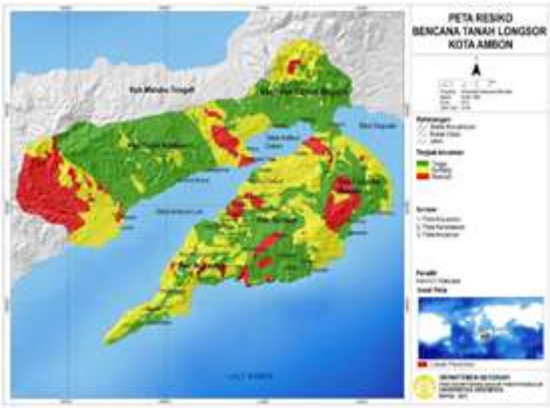

Figure 5. Landslide Risk Map in Ambon City

Table 10. Recapitulation of Landslide Disaster Risk Area Results of Ambon City

District	Risk Area (ha) (ha)		
	Low	Medium	High
Teluk Ambon Baguala	3.927,93	2.620,54	290,74
Teluk Ambon	8.189,56	3.803,63	3.061,14
Leitimur Selatan	2.631,00	1.481,58	880,72
Serimau	1.828,81	1.578,77	397,17
Nusaniwe	2.204,84	2.494,50	269,06
Total Area	3.927,93	2.620,54	290,74

Based on Figure 5 and Table 10, the sub-district with the highest risk is Teluk Ambon with an area of 3061.14 ha, while Nusaniwe sub-district has the lowest risk with an area of 2204.84 ha. The research conducted on landslide risk mapping in Ambon City, Indonesia, highlights the critical need for comprehensive assessments of natural hazards in urban areas. The integration of remote sensing data and Geographic Information Systems (GIS) has proven to be an effective approach in identifying landslide-prone areas. This study builds upon previous works that have utilized similar methodologies, such as the study by Aditian et al. (2018), which compared various GIS-based landslide susceptibility models. Their findings underscore the importance of employing advanced geospatial technologies to enhance the accuracy of landslide risk assessments (Aditian et al., 2018).

The results indicate that slope gradient, distance from rivers, and land use patterns are significant factors influencing landslide susceptibility in Ambon City. The classification of slope gradients, as referenced from BAPEDA (Regional Planning and Development Agency), aligns with the findings of Ullah et al. (2022), who emphasized the role of topography in landslide occurrences. The study's slope weighting system effectively categorized areas based on their vulnerability, providing a clear framework for understanding the relationship between slope and landslide risk (Harist et al., 2018; Rakuasa & Somae, 2022).

Moreover, the research highlights the impact of anthropogenic factors on landslide susceptibility. Urbanization and land-use changes have exacerbated the risk of landslides, as noted by Rakuasa et al. (2022). Their analysis of spatial data revealed that areas with significant human activity are more prone to landslides, reinforcing the need for sustainable urban planning practices. The findings of this study contribute to the growing body of literature that advocates for integrating environmental considerations into urban development strategies (Rakuasa et al., 2022; Pakniany et al., 2023).

The study also emphasizes the importance of community awareness and preparedness in mitigating landslide risks. As highlighted by Van Phong et al. (2022), effective communication of risk information to local communities is essential for enhancing resilience against natural disasters. The research suggests that local governments should prioritize public education initiatives to inform residents about landslide risks and appropriate response measures. This aligns with the recommendations of the National Disaster Management Agency, which advocates for community engagement in disaster risk reduction efforts (Van Phong et al., 2022; Latue et al.,2023).

In conclusion, the integration of remote sensing and GIS in assessing landslide risk in Ambon City provides valuable insights for disaster management and urban planning. The study's findings underscore the need for a multi-faceted approach that considers both natural and anthropogenic factors in landslide susceptibility assessments. Future research should focus on refining these methodologies and exploring additional variables that may influence landslide occurrences, such as climate change impacts and geological conditions. By continuing to build on this research, stakeholders can develop more effective strategies for mitigating landslide risks and enhancing community resilience.

CONCLUSION

In conclusion, the research on landslide risk mapping in Ambon City demonstrates the effectiveness of integrating remote sensing and Geographic Information Systems (GIS) to identify and assess landslide-prone areas. The findings reveal that both natural factors, such as slope gradient and rainfall, and anthropogenic influences, including urbanization and land use changes, significantly contribute to landslide susceptibility. This comprehensive approach not only enhances the understanding of landslide dynamics in the region but also provides critical insights for urban planners and local authorities to implement informed disaster risk reduction strategies. By prioritizing sustainable development and community awareness, stakeholders can better mitigate the impacts of landslides and enhance the resilience of vulnerable populations in Ambon City.

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