

GIS-based Spatial Modeling of Flood Prone Areas in Ambon City Center, Indonesia

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ABSTRACT

This research aims to model flood-prone areas in Ambon's downtown area, given the increasing disaster potential due to climate change and urbanization. The method used includes geographic information system (GIS) technology and remote sensing, namely the multicriteria evaluation method, where the data analyzed includes elevation, slope, soil type, land use, distance from the river, and rainfall. The results showed that low vulnerability has an area of 1,589.91 ha or 73.30%, medium vulnerability has an area of 238.59 ha or 11%, and high vulnerability has an area of 340.49 ha or 15.70%. Flood-affected settlements in the low class are 827.15 ha or 60.68%, in the medium class are 214.51 ha or 15.74%, and in the high class are 321.46 ha or 23.58%. The increase in flood risk in the study area is due to land use change and limited drainage capacity that requires serious attention. The results of this study provide a basis for more effective mitigation planning and policies in reducing flood impacts, as well as increasing community resilience in Ambon City against disaster threats.

Keywords: *ambon, flood, GIS, multicriteria evaluation*

1. INTRODUCTION

Flooding is one of the natural disasters that often occur in various urban areas, including in the downtown area of Ambon (Hermawan et al., 2021). This phenomenon is influenced by natural and anthropogenic factors, such as land cover change, high rainfall intensity, and inadequate drainage systems (Liu et al., 2021; Hossain & Mumu, 2024). Spatial modeling of flood-prone areas is important to identify areas at risk and design effective mitigation strategies. Previous studies have shown that geographic information systems (GIS) and remote sensing-based approaches can provide accurate analysis in mapping flood vulnerability (Osei et al., 2021).

The Central Area of Ambon City, which serves as the governmental and socioeconomic activity hub, is located on gentle topography with elevations >20 meters above sea level (BPS, 2024; Rakuasa, 2024). The change of land use, especially due to urbanization, has increased the risk of flooding in the region (Hermawan et al., 2021; Rakuasa et al., 2022). In addition, heavy rainfall during the wet season often causes waterlogging in low-lying areas, which is

exacerbated by limited drainage capacity (Rakuasa & Latue, 2024). Therefore, an in-depth understanding of the factors that influence flooding in Ambon's downtown area is needed.

Spatial modeling using GIS and remote sensing technologies has proven effective in predicting and mapping flood-prone areas in various regions (Demissie et al., 2024). This method allows the integration of spatial and non-spatial data, such as topography, land cover, soil type, distance from rivers, and rainfall, to produce comprehensive flood risk maps (Hossain & Mumu, 2024). In Ambon's downtown area, this approach can be used to identify areas most vulnerable to flooding and formulate research-based policy recommendations.

In addition to physical factors, socio-economic factors also play an important role in determining the vulnerability of an area to flooding. People living in flood-prone areas often face the risk of property loss, health problems, and a reduced quality of life (Riaz & Mohiuddin, 2025). In Ambon's downtown area, densely populated settlements and inadequate infrastructure exacerbate the impact of flooding, so a holistic analysis is needed to reduce risk in this area (Rakuasa et al., 2024).

Previous studies on flood modeling in Indonesia have provided valuable insights, but there are still gaps in the context of Ambon's downtown area. This research aims to fill this gap by developing a spatial model that is accurate and relevant to local conditions. By combining field data, satellite imagery, and statistical analysis, this research is expected to make a significant contribution to flood mitigation efforts in the area.

In addition, the results of this research can serve as a basis for the government and stakeholders in designing more effective disaster risk reduction policies. The resulting flood risk maps can be used for spatial planning, infrastructure development, and the preparation of emergency response plans. Thus, this research not only has academic value but also practical applications that can increase community resilience to flood disasters. Based on the above background, this research aims to spatially model flood-prone areas in the central area of Ambon City.

2. METHODS

2.1. Research Data Collection

This research was conducted in the Ambon City Center Area, Maluku Province, Indonesia. The data used in the research included a map of the Ambon City Center Area sourced from the Detailed Spatial Plan for the Ambon City Center Area for 2021-2041, the Indonesian Rupa Bumi Map (RBI) of Ambon City at a scale of 1:50.000 - Geospatial Information Agency to process data on distance from rivers, National DEM data of Ambon City Sheet 2612-23 - Geospatial Information Agency to analyze land height or elevation and slope, rainfall data obtained from BMKG Ambon City, soil type map data of Ambon City scale 1:50,000 obtained from the Ambon City Development Agency, and land use data for the year 2025 obtained from the results of interpretation and classification of PlanetScope 3 meter resolution images downloaded from the official planet website: <https://www.planet.com>.

The software used for data processing and analysis in this research is Microsoft Office Office365 and ArcGIS 10.8. Based on the results of the literature study and direct observation in the field, it is known that there are 6 basic variables that affect flooding in the Ambon City

Center Area. The six variables include elevation, slope, soil type, land use, distance from the river, and rainfall.

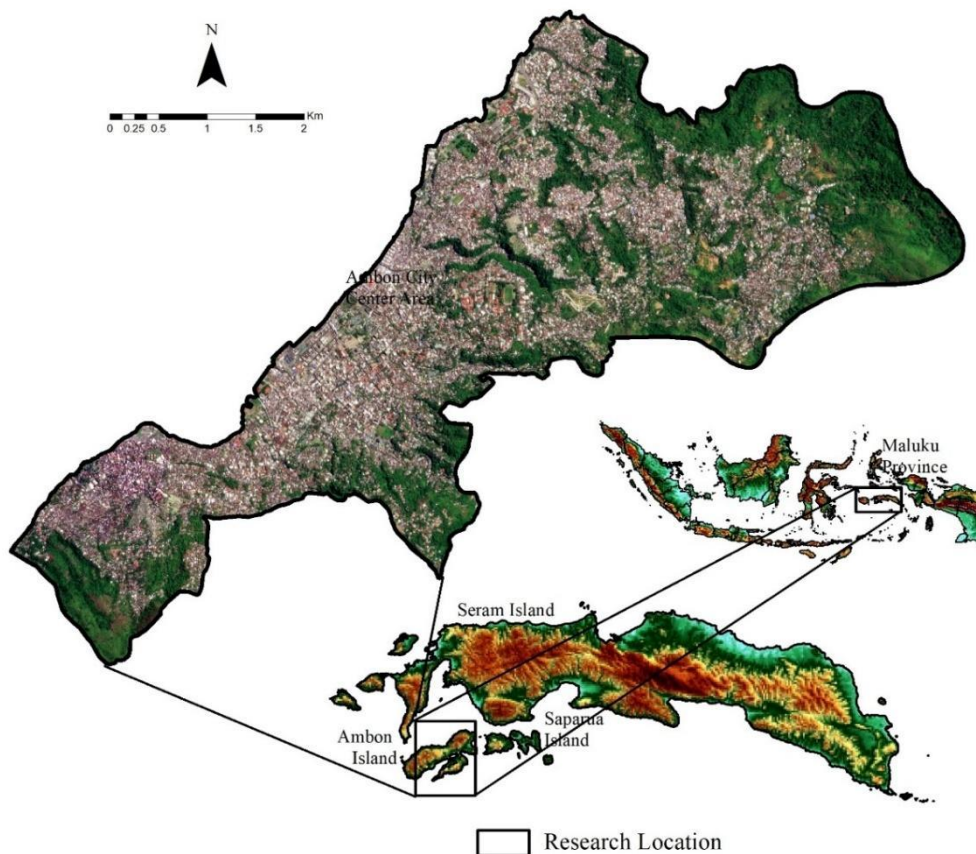


Figure 1. Research Location

2.2.Data Processing and Analysis

The process of creating a flood hazard model requires weights for each flood variable, and each flood variable has a criterion class. Based on the calculation of the mean spatial of each flood variable, the weight of each flood variable can subsequently be calculated with the assumption that flood potential is caused by several factors with equal weight, and the ranking and score of each criterion and each factor refer to the research (Maulita et al., 2024). The weight calculation for creating a flood hazard model using Composite Mapping Analysis (CMA) is as follows: Determination of the flood event map based on the location position and the frequency of floods occurring in the field with the assumption: (a) The potential for flooding is caused by several factors with equal weight. (b) The ranking and score of each criterion and each factor refer to previous research. (c) The first point is generated by the distribution of flood areas and the extent of flood areas. (d) Next, the flood distribution map is overlaid with each flood variable, where the flood variables include elevation, slope gradient, soil type, land use, distance from the river, and rainfall. The overlay process conducted with each flood variable results in a tabulation of the overlay results for each flood variable. (e) Calculation of the flood ratio for each criterion for all variables and criteria. (f) The result obtained is a relative weight called the spatial mean. (g) Next, a composite of all variables is performed, resulting in

the weight of each flood-causing variable. The weighting of flood vulnerability in the Central Ambon City area was modified from previous studies and can be seen in Table 1.

Table 1. Flood Vulnerability Variables

No	Variables	Class	Score	Weight
1	Elevation	0-20 masl	5	20
		21-50 masl	4	
		51-100 masl	3	
		101-300 masl	2	
		>300 masl	1	
2	Slope	0-8 %	5	10
		8-15 %	4	
		15- 25 %	3	
		25-45 %	2	
		>45%	1	
3	Soil Type	Lithosols	4	10
		Cambisols	3	
		Renzina	2	
4	Land Use	Water Body	5	25
		Open Land	4	
		Built-up land	3	
		Mixed Farm	2	
		Forest	1	
5	Distance from river	20 m	5	20
		50 m	4	
		100 m	3	
		300 m	2	
		>300 m	1	
6	Rainfall	>3000 mm/month	5	15

Source: (Rakuasa et al., 2022); (Kabenla et al., 2024)

This research uses the Multicriteria Evaluation (MCE) method. The Multicriteria Evaluation (MCE) method shows the importance of decision makers in determining the right weights and methods (Kabenla et al., 2024). MCE is used to calculate the weight of each factor. In addition to the MCE method, weighted linear combination (WLC) is also used to reorganize flood-prone areas. The weights and values of the criteria can change according to the research area (Kabenla et al., 2024). If the characteristics change, the results will show different conditions. Mathematically, the calculation of flood hazards can be seen in formula 1, adapted from previous research.

$$FH = Es \times Ew + Ss \times Sw + STs \times STw + LUs \times LUw + DFRs \times DFRw + Rs \times Rw \quad (1)$$

Where: FH= Flood Hazard, s= score, w= weight, E= Elevation, Sl= Slope, ST= Soil Type, LU= Land Use, Dfr= Distance from the river, R= Rainfall

The interval of flood vulnerability level in Ambon City Center Area is classified using formula 2;

$$I = R/K \quad (2)$$

Where: I = Width of interval, R = Range or the difference between the highest data value minus the lowest data, and K = Number of class intervals. Flood vulnerability areas in the study area are classified into 3 classes consisting of low, medium, and high. The flood vulnerability map was then overlaid with built-up land to identify built-up land affected by flooding.

3. RESULT AND DISCUSSION

3.1. Flood Vulnerability Variables

The elevation analysis results show that 36.13% of the central area of Ambon City is at an elevation of 51-100 meters above sea level (masl), meaning this region is relatively safe from flood disasters, whereas low-lying areas tend to be more prone to inundation. Areas with an elevation of 0-20 meters above sea level cover 23.49%, reinforcing the flood risk given that low-lying areas have limited drainage capacity, such as in the sub-districts of Honipopu, Silale, Uritetu, and Ahusen. In contrast, only 0.22% of the area is above 300 masl and remains unaffected by flooding, such as in the villages of Soya, Waihoka, and Karang Panjang, indicating that most of the central area of Ambon City is vulnerable to flooding due to its relatively gentle topography

The slope distribution shows that 28.86% of the area has a slope of 25-45%, which can accelerate surface flow and increase the risk of flooding in downstream areas. Slopes of 0-8% cover 15.55%, indicating a flat zone vulnerable to water accumulation. The combination of steep slopes and lowlands exacerbates flood vulnerability, as water flow is not evenly distributed. The dominance of lithosols, covering 69.54%, indicates that this soil type dominates the study area and has low permeability, reducing infiltration ability. Cambisols cover only 3.55%, while rendzina reaches 26.91%, which also has poor drainage characteristics when exposed to heavy rains. These soil characteristics increase the risk of flooding as rainwater is not easily absorbed into the soil.

Land use is dominated by built-up land (62.85%), which reduces water infiltration and increases surface runoff. Forests cover only 9.91%, even though vegetation plays an important role in retaining water flow. Mixed gardens (22.96%) and open land (3.19%) also contribute to increased flood discharge if not managed properly. Annual rainfall reaches 3000-4000 mm, which is very high and can trigger flooding if not balanced with an adequate drainage system. The distance from water bodies shows that 50.95% of the area is within a radius of 4000 meters, increasing the risk of flooding due to river runoff. The combination of these factors emphasizes the need for spatial modeling to accurately identify flood-prone zones.

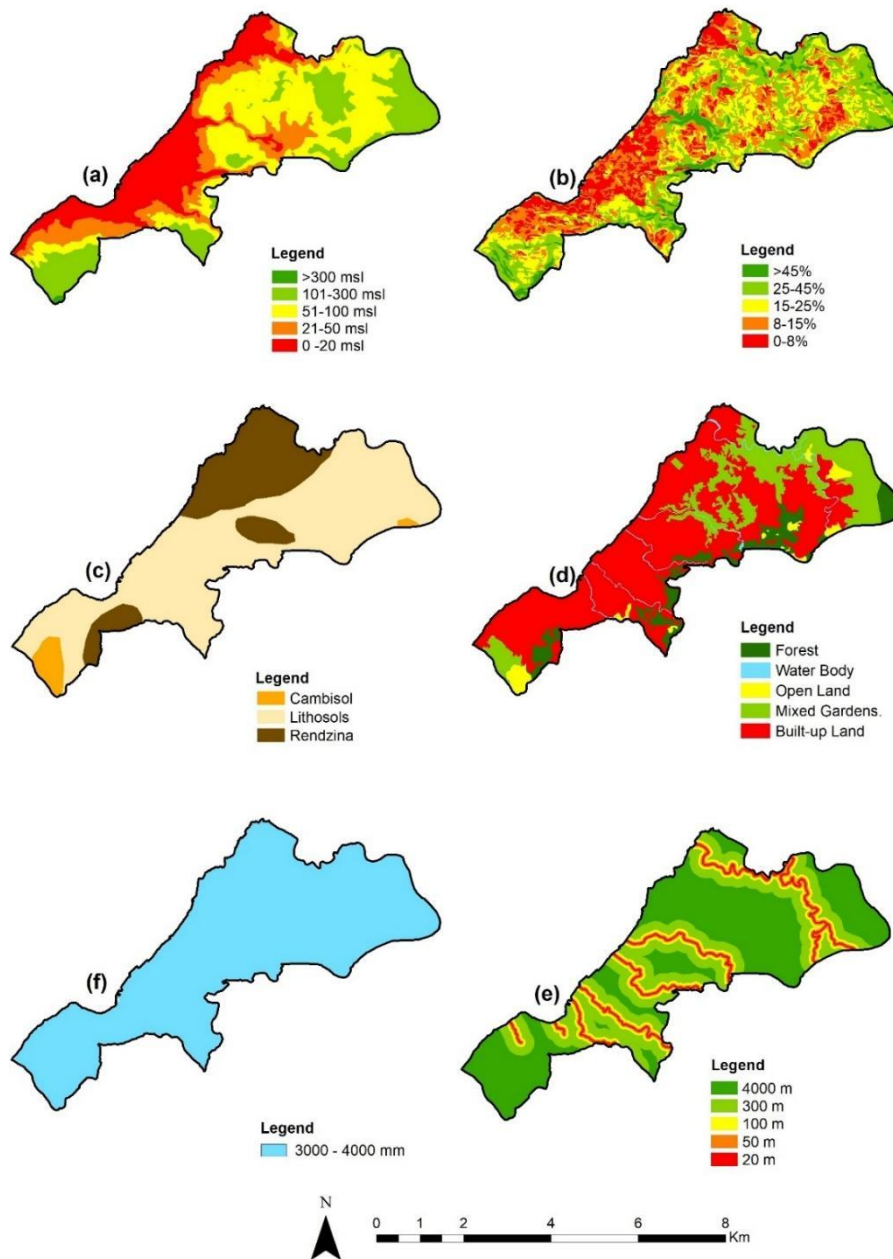


Figure 2. Variables of Flood-Prone Areas(a) elevation, (b) slope gradient, (c) soil type, (d) land use, (e) distance from the river, (e) rainfall

3.2.Flood Vulnerability Level

The results of flood vulnerability mapping show that 73.30% of the study area falls into the low category, indicating that most of the central area of Ambon City has a relatively manageable flood risk. However, the large area of low vulnerability should not reduce vigilance, as changes in land use can significantly increase flood risk. Areas with low vulnerability are generally located in areas with higher topography and adequate drainage systems. The spatial extent of flood vulnerability in the central area of Ambon City can be seen in Figure 3.

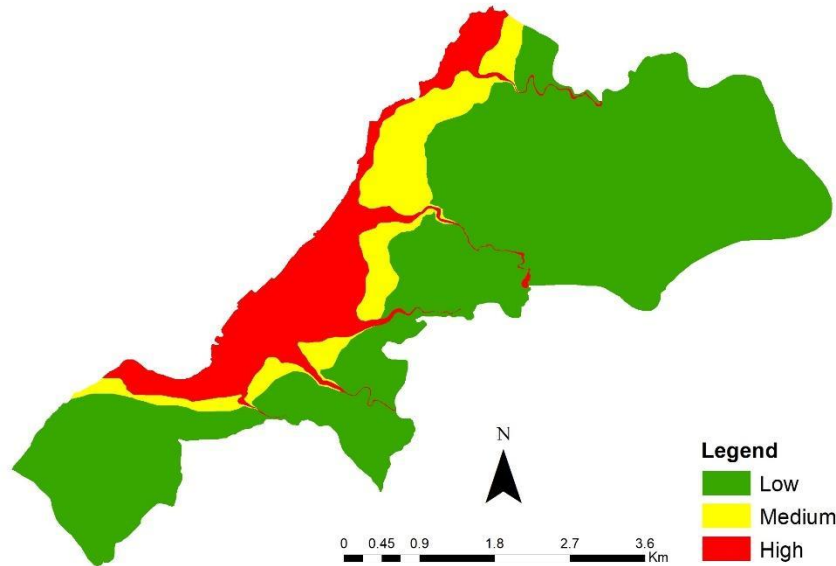


Figure 2. Map of Flood Vulnerability Level in Ambon City Center Area

A total of 11.00% of areas fall into the medium vulnerability category (Table 2), indicating the potential for flooding in the event of extreme rainfall or sudden environmental changes. Moderately vulnerable areas are often located in the transition zone between lowlands and steep slopes, making them susceptible to water accumulation (Latue et al., 2023). Factors such as soil permeability and land cover contribute to this level of vulnerability.

Table 2. Area of Flood Vulnerability Levels

Flood Vulnerability Level	Area (ha)	%
Low	1.589,91	73,30
Medium	238,59	11,00
High	340,49	15,70
Total area	2.168,99	100.00

High vulnerability covers 15.70% of the study area, indicating that parts of the central area of Ambon City are highly vulnerable to flooding. These areas are generally located in the lowlands with elevations below 50 meters above sea level and are dominated by lithosol soils that have low water absorption capacity. The built-up land use that dominates this zone also worsens the condition as it reduces the water absorption capacity (Muin & Rakuasa, 2023). The spatial distribution of flood vulnerability shows a pattern consistent with the physical characteristics of the watershed, where downstream areas tend to be more vulnerable than upstream areas (Rakuasa & Latue, 2023). The high annual rainfall in Ambon City, which reaches 3000-4000 mm, further increases the threat of flooding in the high vulnerability zone. This modeling is in line with other research findings that state that a combination of topographic, soil, and anthropogenic factors determines the level of flood vulnerability.

This finding confirms the importance of flood risk management based on vulnerability zoning to reduce disaster impacts in urban areas. High vulnerability areas require structural interventions such as the construction of drainage systems and river normalization. Meanwhile,

medium- and low-vulnerability zones can be managed through non-structural approaches such as sustainable spatial planning.

3.3. Prediction of Built-Up Land Affected by Floods

The analysis of the prediction of built-up land affected by flooding shows that 60.68% of the area falls into the low-impact category, indicating that most built-up areas have limited risk of flooding. This finding is consistent with the characteristics of areas with higher elevations and relatively good drainage systems. However, it should be noted that land use changes can significantly alter this level of vulnerability. The spatial extent of settlements affected by flood vulnerability in Ambon City Center can be seen in Figure 4.

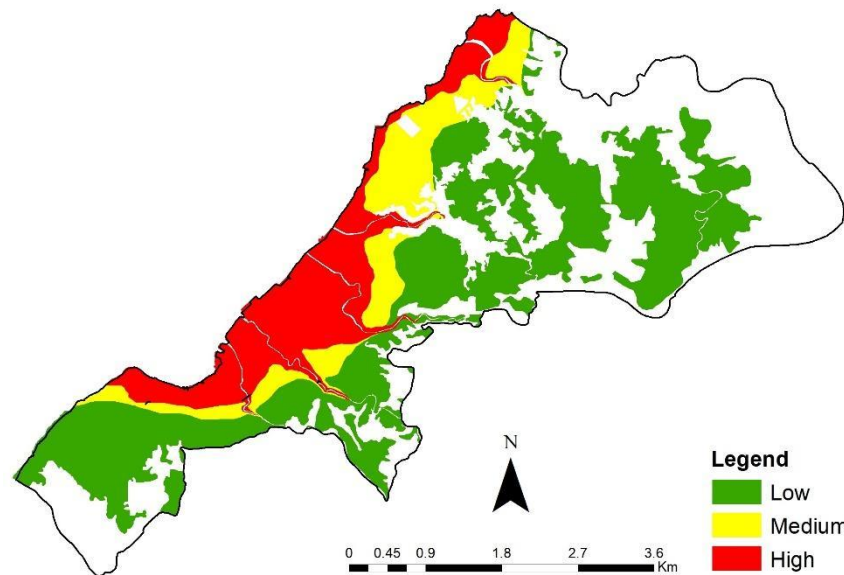


Figure 4. Map of Residential Areas Affected by Flood Vulnerability in the Central City Area of Ambon

A total of 15.74% of built-up land falls into the medium impact category, which is generally located in the transition zone between safe and flood-prone areas. These areas require special attention as they may experience increased risk along with changes in rainfall intensity (Wang et al., 2023). Soil permeability and building density are the main determinants in this classification. The high-impact category covers 23.58% of built-up land, indicating that almost a quarter of the urban area has the potential for severe flood damage. These areas are generally concentrated in low-lying areas with a history of recurrent flooding and limited drainage capacity. The predominance of impermeable surfaces in these zones exacerbates the condition by increasing surface runoff.

Table 3. Area of Built-up Land Affected by Floods

Level of Flood Affected Settlements	Area (ha)	%
Low	827,15	60,68
Medium	214,51	15,74
High	321,46	23,58
Total area	1.363,13	100,00

This spatial distribution of predicted flood impacts shows a strong correlation with previously identified flood vulnerability patterns. High-impact areas tend to coincide with high-vulnerability zones that have unfavorable hydrological characteristics (Msabi & Makonyo, 2021). This pattern is consistent with the findings of other studies in tropical regions with high rainfall (Hossain & Mumu, 2024). These findings emphasize the need for risk zoning-based mitigation strategies to protect urban assets. Areas with high predicted impacts require structural interventions such as improving drainage systems and implementing flood-resistant building concepts (Demissie et al., 2024). Meanwhile, zones with moderate impacts can be managed through strict spatial regulations and early warning systems.

3.4. Policy Recommendations

Based on the mapping results of flood vulnerability levels and the predicted impacts on residential areas in the central region of Ambon City, a strategic policy recommendation is the implementation of flood risk management based on zoning according to varying degrees of vulnerability. Areas with high vulnerability and impact require structural interventions, such as improving and normalizing drainage systems, constructing flood-resistant infrastructure, and adopting building designs that are adaptive to flooding (Lin & Billa, 2021). Meanwhile, zones with medium and low vulnerability can be managed through non-structural approaches, including strengthening strict spatial planning regulations, community education on flood mitigation, and developing early warning systems to reduce disaster risks and impacts. Furthermore, policies controlling land-use changes are essential to prevent increased flood risk due to rapid urbanization, which has been shown to exacerbate waterlogging conditions in low-lying areas. The implementation of these policies should be supported by continuously updated GIS-based spatial modeling to ensure adaptive and effective responses to environmental dynamics and climate change.

4. CONCLUSION

The results of this study show that spatial modeling of flood-prone areas in Ambon's downtown area is critical in understanding and addressing the increasing risk of flooding due to natural and anthropogenic factors. Using geographic information system (GIS) and remote sensing technology, the research successfully identified key variables that affect flood vulnerability, such as elevation, soil type, and land use. The analysis indicated that most of Ambon's downtown area is vulnerable to flooding, which is exacerbated by limited drainage capacity and rapid urbanization. Therefore, the results of this study provide strategic recommendations for the development of more effective mitigation policies and spatial planning in order to increase community resilience to future flood disasters.

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