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Application of GIS for Flood Modeling on Small Islands: A Case Study of Ternate Island, Indonesia

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Abstract. *Floods are hydrometeorological disasters that occur almost every year in Indonesia, including Ternate City. Floods that occurred in 2024 caused 15 people to be injured, 16 people to die, and as many as 25 units of houses to be affected by this disaster. One of the disaster mitigation efforts is to map flood-prone areas by utilizing GIS and remote sensing data. The variables used consist of elevation, slope, LULC, distance from the river, soil type, and rainfall. This research uses the multicriteria evaluation method, in addition to the multicriteria evaluation method, and also uses weighted linear combination. The results showed that the area in the high flood vulnerability class was 15.08%, or 1,532.92 ha; the medium class was 31.24%, or 3,175.21 ha; and the area in the low flood vulnerability level had an area of 5,454.24 ha, or 53.67%. The built-up land predicted to be affected by future flooding has the largest extent in the high-risk zone, covering 1,147.59 ha or 54.12%, compared to built-up land in the moderate and low-risk zones.. The results of this study are expected to help the Ternate government in overcoming the flood problem there.*

Keywords: *Flood; GIS; Spatial Analysis; Ternate*

1. Introduction

Floods are a disaster that occurs almost every year in various regions of Indonesia. Based on Law of the Republic of Indonesia No. 24 of 2007, a flood is defined as an event or condition in which an area or land is inundated due to an increase in water volume volume (Badan Nasional Penanggulangan Bencana, 2025). Floods can be triggered by natural or non-natural factors, such as human activities, resulting in material and non-material losses losses (Mshelia et al., 2024; Aizemu & Rakuasa, 2026). Almost every rainy season, areas in Indonesia experience flooding, including Ternate City, North Maluku Province (Handayani et al., 2022). The GIS-based flood vulnerability mapping in this study directly supports the achievement of global Sustainable Development Goals (SDGs), particularly SDG 11.5, which targets a significant reduction in deaths and economic losses from disasters, and SDG 13.1, which emphasizes strengthening resilience and adaptive capacity to climate-related hazards, thereby contextualizing local efforts within the sustainable disaster risk reduction agenda (Sugandhi, & Rakuasa, 2023; Rakuasa, 2023; Rifai et al., 2025).

August 25, 2024, floods hit the residential area of Ternate City, namely the village of Rua, resulting in 15 people injured, 16 people dead, and 25 houses affected by this disaster (CNN Indonesia, 2024). According to data from the Ternate City Regional Disaster Management Agency (BPBD), this area is frequently hit by floods and landslides every year.

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Since 2017, 52 houses have been affected, and in 2020, 62 houses were also affected (Badan Nasional Penanggulangan Bencana, 2025).

Based on data from the Sultan Baabullah-Ternate BMKG Station, high rainfall intensity is a factor contributing to flooding in the city of Ternate (BMKG, 2024). Geological data shows that flooding and landslides are also influenced by geological and geomorphological conditions and changes in the local landscape. The frequent flooding in Ternate City has certainly caused significant losses, both in terms of infrastructure and human lives (Handayani et al., 2022; Rakuasa & Rifai, 2025). Rapid changes in environmental conditions will lead to changes in the form of disasters, such as flooding, landslides, and others (Patel et al., 2025; Rakuasa et al., 2025). This is certainly a problem that threatens the people of Ternate City and requires serious attention.

Spatial analysis based on Geographic Information Systems (GIS) and utilizing remote sensing data certainly makes it very easy and quick to analyze, predict, and model flood-prone areas (Kaku, 2019; Mubialiwo et al., 2022; Mzuri et al., 2024). GIS plays a role in sustainable post-disaster development. During emergency response, it can provide informative and communicative data to aid decision-making, and in the medium and long term, it can become the main basis for development (Gupta & Dixit, 2022; Aytekin et al., 2025; Nair et al., 2025).

The city of Ternate was chosen as the location for this study because, based on data from the Indonesian Disaster Risk Index published by BNPB in 2024, Ternate is classified as having a moderate risk level with a score of 91.97, and in terms of flood vulnerability, Ternate is also classified as having a moderate risk level with a score of 9.58 (Badan Nasional Penanggulangan Bencana, 2025). Given the enormous impact of flooding on the number of victims it can cause and the implementation of development, a survey and mapping are needed to determine flood-prone zones in Ternate City to anticipate the losses that can be caused by flooding. The risks and impacts of frequent flooding in Ternate City can be reduced or minimized by preparing for and preventing floods. One of the measures taken is to identify and understand areas that are prone to flooding. Based on the above background, this study aims to predict flood-prone areas in Ternate City

2. Methods

2.1. Study Area and Data Collection

This research was conducted in Ternate City, North Maluku Province, Indonesia. Administratively, Ternate City consists of the subdistricts of West Ternate, North Ternate, South Ternate, Central Ternate, North Ternate, and Ternate Island. The spatial location of the research can be seen in Figure 1. Based on literature studies and field observations in Ternate City, it was found that the variables that influence the frequency of flooding and used in this study are elevation or land height, slope, land use, distance from rivers, soil type, and rainfall. The flood vulnerability variables for Ternate City were then classified based on Table 1. The data used in this study included Ternate City administrative shp data obtained from the Geospatial Information Agency (BIG), Digital Elevation Model (DEM)-BIG, PlanetScope satellite imagery data with a spatial resolution of 3 meters recorded on May 10, 2025, obtained from Planet Labs, soil type maps obtained from the Regional Development Agency (BAPEDA) of Ternate City, and monthly rainfall data obtained from the Sultan Baabullah-Ternate BMKG Station. ArcGIS Pro 4.3 software was used to create a flood-prone map of Ternate City.

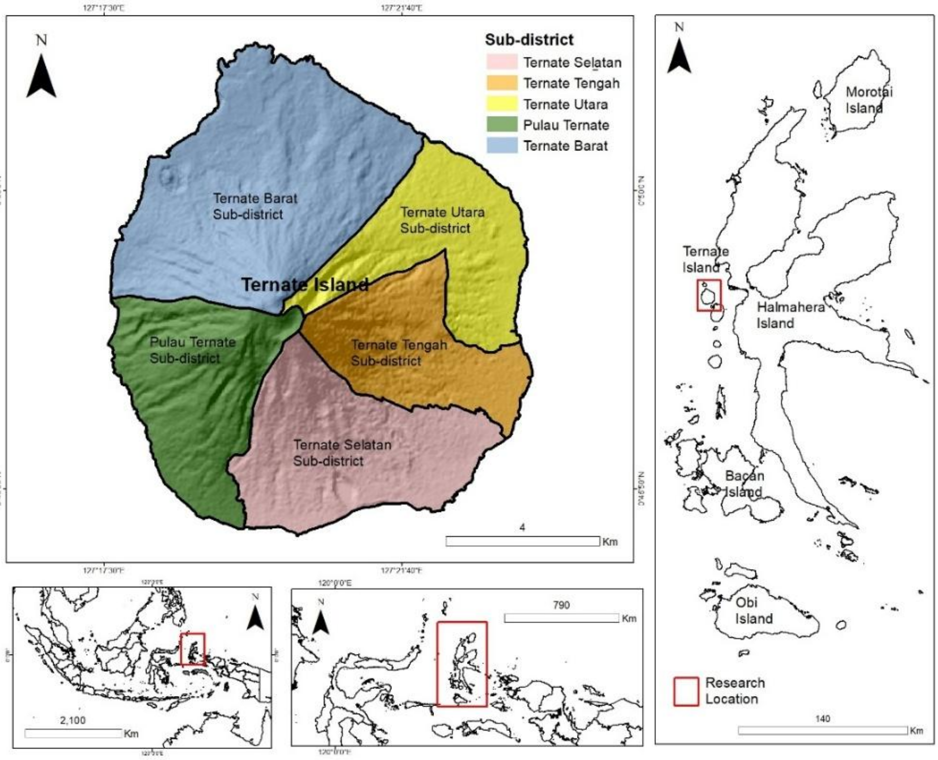

Figure 1 Research Location: Ternate City, Indonesia

Table 1. Flood-Prone Variables in Ternate City, Indonesia

No	Variables	Classification	Score	Weight
		0 – 20 m asl	5	
		21-50 m asl	4	
1	Elevation	51- 100 m asl	3	20
		101-300 m asl	2	
		>300 m asl	1	
		0-8 %	5	
		9-15 %	4	
2	Slope	16-25 %	3	10
		26-40 %	2	
		>40 %	1	
		Water Body	5	
		Open Land	4	
3	Land Use	Built-Up Land	3	20
		Agricultural Land	2	
		Protected Forest	1	
		0 – 25 m	5	
		26 – 50 m	4	
4	Distance from River	51 – 75 m	3	20
		76 – 100 m	2	
		>100 m	1	
5	Soil Type	Regosol	4	10
6	Rainfall	2,000 - 2,500 mm/month	4	25

Source: (Patel et al., 2025; Rakuasa et al., 2025).

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2.2. Data Analysis

Elevation and slope variables are the results of DEM data analysis conducted in ArcGIS Pro, classified based on Table 1. Land use data was obtained from the interpretation and digitization of PlanetScope satellite imagery, while distance variables from rivers were obtained from river buffer analysis in ArcGIS Pro. Rainfall variables were obtained from IDW (Inverse Distance Weighted) analysis based on monthly rainfall data obtained from the Sultan Baabullah-Ternate BMKG Station. Soil type data was then re-digitized into a shp file so that it could be used for overlay analysis with other data.

The process of creating flood-prone maps assigns scores and weights to each flood variable based on its level of influence. Flood vulnerability calculations use Composite Mapping Analysis (CMA), with the following steps: Determination of flood event maps based on location and frequency of floods occurring in the field, assuming: (a) Flood potential is caused by several factors with equal weight. (b) The ranking and score of each criterion and each factor refer to previous studies. (c) The first point results in the distribution of flood areas and the extent of flood areas. (d) Next, the flood distribution map is overlaid with each flood variable, where flood variables include: elevation, slope, soil type, land use, distance from rivers, and rainfall. The overlay process performed with each flood variable produces 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 results obtained are relative weights called spatial means. (g) Next, a composite of all variables is performed to obtain the weight of each variable causing flooding.

$$FV = E \times 20 + S \times 10 + LU \times 20 + DR \times 20 + ST \times 10 + RF \times 25 \quad (1)$$

Description= FV: Flood Vulnerability, E: Elevation, S: Slope, LU: Land Use, DR: Distance from River, ST: Soil Type, RF: Rainfall.

Flood-prone areas in the study were classified into three categories: low, moderate, and high. The flood-prone map was then overlaid with built-up areas to identify built-up areas affected by flooding.

3. Results and Discussion

3.1. Flood-prone variables in Ternate City

The results of the elevation variable analysis show that 38.88% or 3,950.73 ha of the study area is located at an elevation of >300 m above sea level, 2,666.87 ha or 26.25% is located at an elevation of 101-300 m above sea level, elevations of 51-100 meters above sea level covering an area of 1,432.96 hectares or 14.10%, elevations of 21-50 meters above sea level covering an area of 1,185.91 hectares or 11.67%, and low elevations of 0-20 meters above sea level covering an area of 924.66 hectares or 9.10%. In general, areas with low elevation are certainly very vulnerable to flooding during the rainy season. Spatially, the elevation map of Ternate City can be seen in Figure 2.

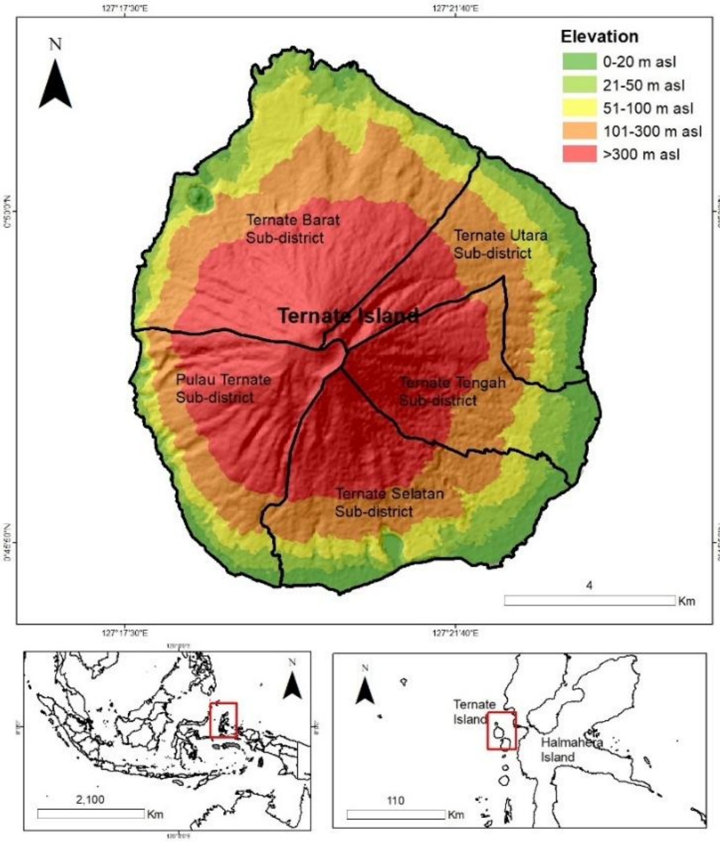

Figure 2. Elevation Map

The results of DEM data analysis show that 10.25% (1,041.78 ha) of the Ternate City area has a slope of 0-8%, while slopes >40% have the largest percentage in Ternate City, namely 29.66% with an area of 3,013.36 ha. Slopes of 8-15% cover an area of 1,771.89 ha or 17.44%, 15-25% has an area of 2,077.30 ha or 20.45%, and slopes of 25-40% have an area of 2,255.56 ha or 22.20% of the total area of Ternate City. Areas with a slope gradient >8% are certainly very vulnerable to flooding (Gupta & Dixit, 2022; Rakuasa & Pertuack, 2025) . Spatially, the slope gradient map of Ternate City can be seen in Figure 3.

Based on the soil type map of Ternate City, the overall soil type in Ternate City is regosol soil. The characteristics of regosol soil in Ternate City, which is coarse-grained, poor in organic matter, and has low water absorption, limit the soil's ability to retain and absorb rainwater, thereby contributing significantly to the high risk of flooding in the area, especially during high rainfall and changes in land cover (Motta et al., 2021; Ibrahim et al., 2024; Mushwani et al., 2025; Ray, 2025). Spatially, the soil type map of Ternate City can be seen in Figure 4.

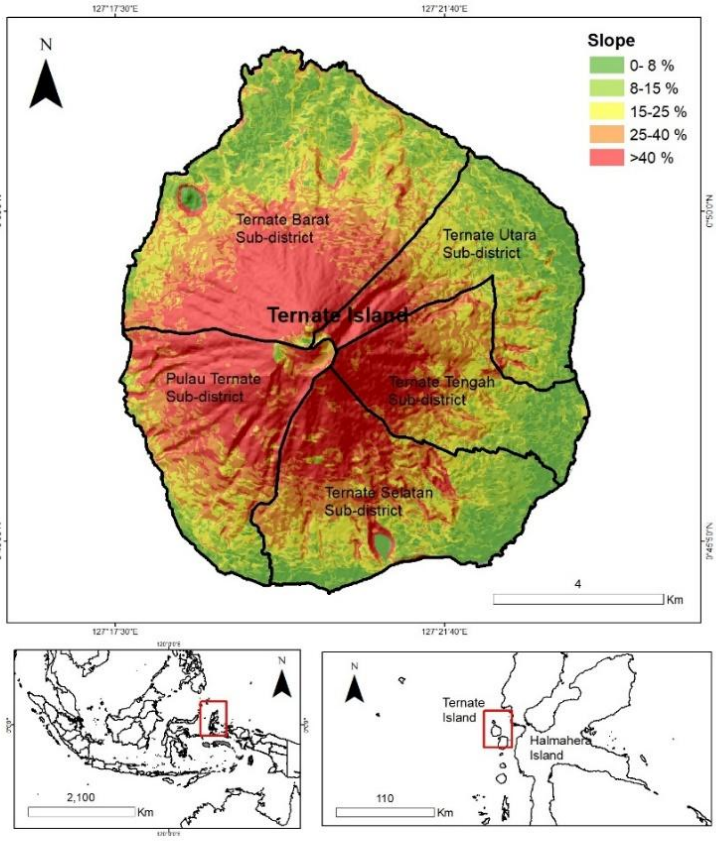

Figure 3. Slope Map

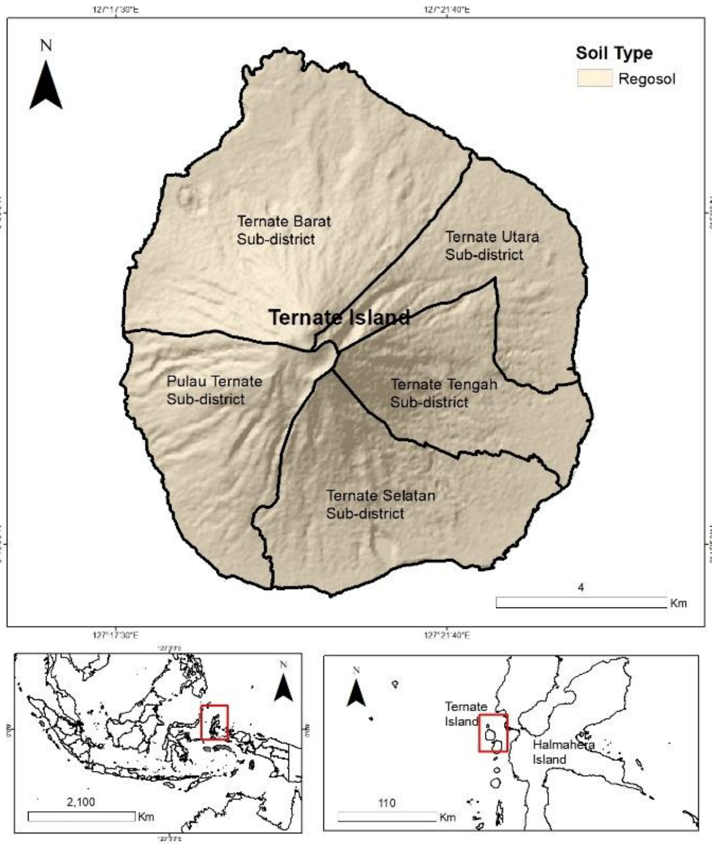

Figure 4. Soil Map

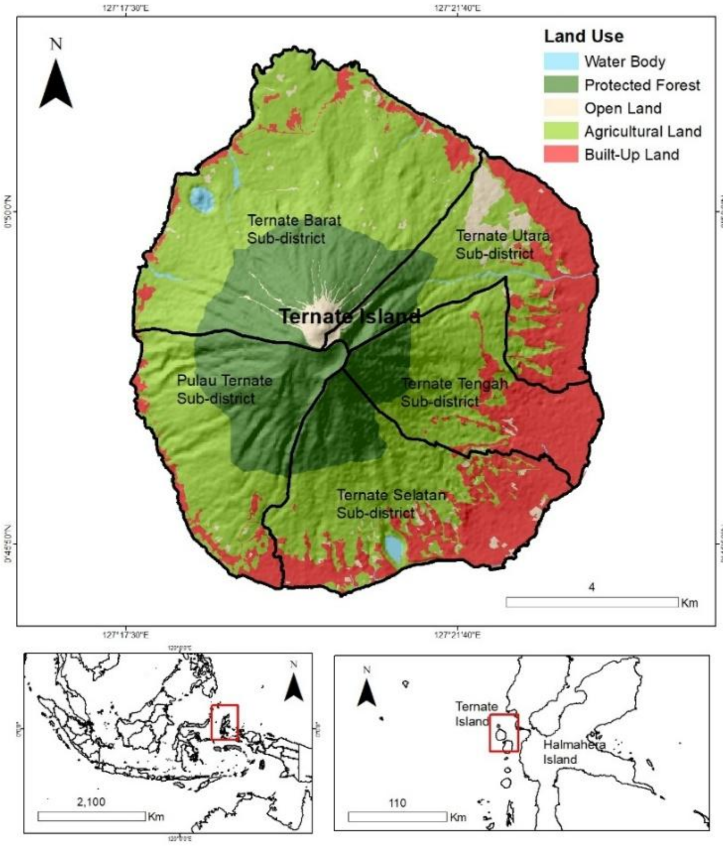

Figure 5. Land Cover Map

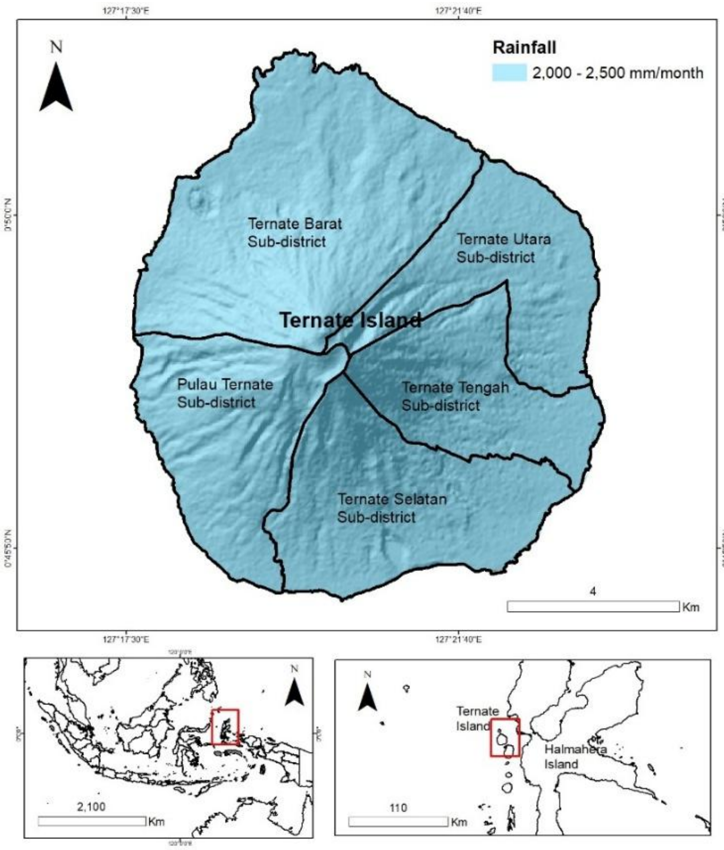

Figure 6. Rainfall Map

The results of the 2025 PlanetScope image interpretation show that built-up land covers an area of 2,120.46 ha or 20.87% of the total area, open land covers an area of 377.67 ha or 3.72%, agricultural land covering an area of 5,317.38 ha or 52.32%, protected forest covering an area of 2,279.55 ha or 22.43%, and water bodies covering an area of 67.58%. Water bodies, open land, and residential areas in Ternate City have a significant influence on flooding, where water bodies such as rivers that experience narrowing and sedimentation due to volcanic material and erosion from the slopes of Mount Gamalama increase the risk of water overflowing into residential areas. while the conversion of open land into built-up areas worsens water absorption and accelerates surface runoff, thereby increasing the potential for flooding during high rainfall (Ibrahim et al., 2024; Guan et al., 2024; Rakuasa & Khromykh, 2025; Rifai et al., 2025). Spatially, the land use map of Ternate City can be seen in Figure 5.

The results of the Inverse Distance Weighted (IDW) analysis show that rainfall is evenly distributed in Ternate City, ranging from 2,000 to 2,500 mm/month, indicating very high precipitation intensity, which has the potential to increase the risk of flooding, especially in areas with suboptimal drainage systems and low soil absorption capacity (AlFanatseh, 2021; Rakuasa et al.., 2024). The spatial rainfall map of Ternate City can be seen in Figure 6.

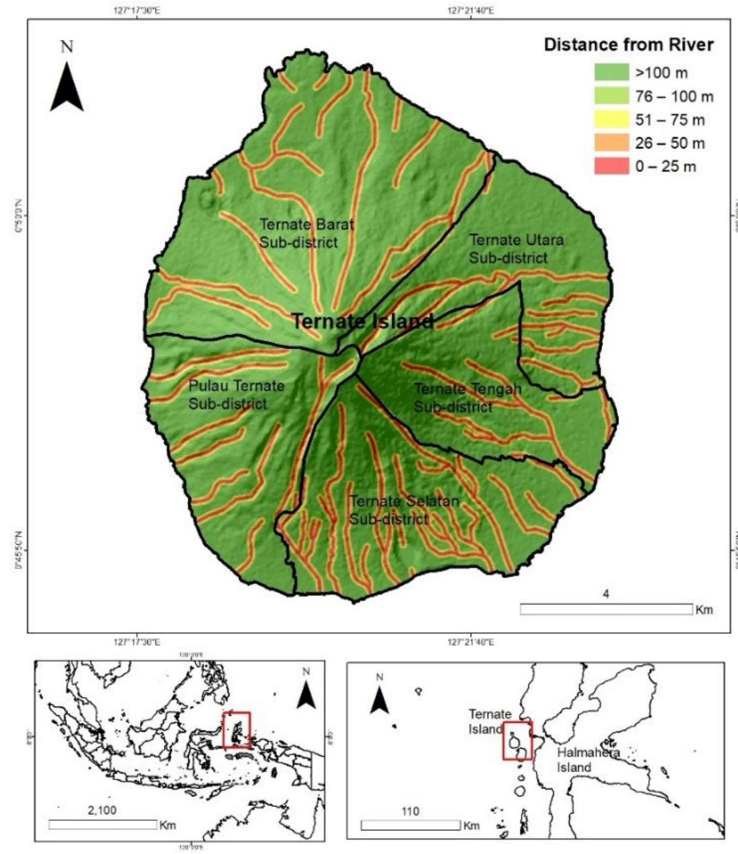

Figure 7. Distance from River Map

The results of the buffer analysis for the distance from the river show that 6.76% or 686.46 ha is >25 meters from the river, an area of 694.26 ha or 6.83% is at a distance of 26-50 meters, an area of 697.59 ha or 6.86% is located at a distance of 76-100 meters, and an area of 7,388.57 ha or 72.71% is located >100 meters from the river. Residential areas located near rivers are at high risk of flooding when rivers overflow during the rainy season (Rakuasa &

Khromykh, 2025). The spatial distance from river map of Ternate City can be seen in Figure 7.

3.2. Flood-prone areas in Ternate City

Flood vulnerability classes in Ternate City are defined as classifications of the level of vulnerability to flood risk based on physical factors or variables such as elevation, slope, soil type, weather variables such as rainfall, and variables influenced by human activities such as land use and distance from rivers. The flood vulnerability classification in Ternate City is simply divided into 3 classes, namely low, medium, and high. Spatial analysis shows that 15.08% of the area, or 1,532.92 ha, is classified as highly vulnerable to flooding. In general, areas classified as highly vulnerable are located near rivers, have low elevations, and have gentle slopes. Rainfall intensity is also a factor that greatly influences flooding in Ternate City (Alafostergios и др., 2025). South Ternate District is the largest area compared to other districts, covering an area of 488.79 ha. The flood hazard map of Ternate City can be seen in Figure 8.

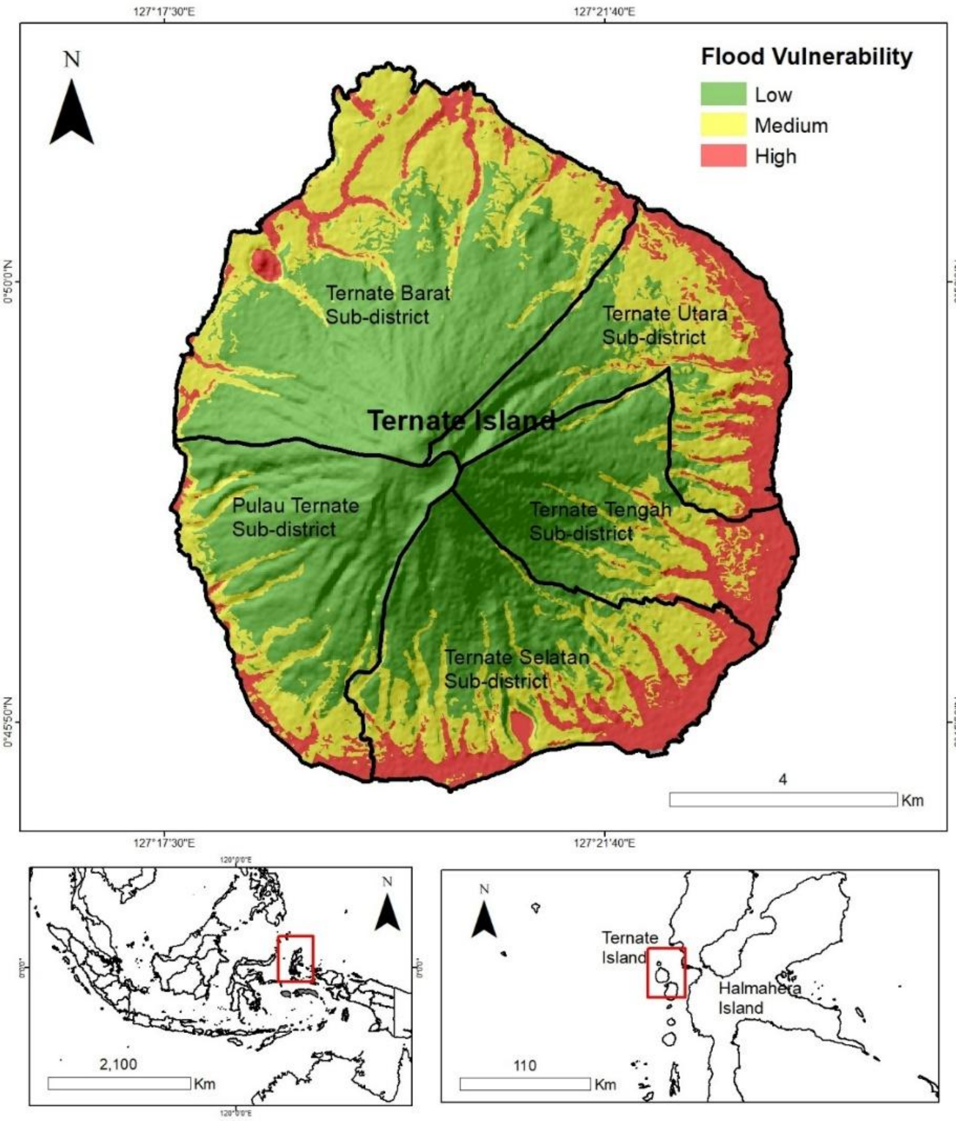

Figure 8. Flood Hazard Map of Ternate City

The moderate flood risk level in Ternate City has a percentage of 31.24% or an area of 3,175.21 ha. In general, areas located more than 75 meters from rivers are dominated by residential and agricultural land use, with a slope of 15-25%, an elevation of 51-100 meters above sea level, and high rainfall intensity. The Ternate Barat subdistrict has the largest area compared to other subdistricts in Ternate City, covering 1,166.98 hectares, while the Tengah subdistrict has the smallest area, covering 317.78 hectares.

Areas with a low flood risk level cover an area of 5,454.24 ha or 53.67%. In general, areas in this zone are those far from rivers, at an elevation of >50 m above sea level, and with agricultural and forest land use. The Ternate Barat subdistrict has a larger area than other subdistricts, covering 1,950.84 ha, while the smallest is Ternate Utara, covering 552.44 ha.

3.3. Distribution of Built-up Areas Based on Flood Vulnerability Classes in Ternate City

The distribution of built-up areas affected by flooding was obtained from the overlay of built-up areas in Ternate City in 2025 with a flood vulnerability map. The distribution of built-up land in the high hazard class has the largest area compared to other classes, covering 1,147.59 ha or 54.12%. Built-up land in this class is spread across areas with low and gentle elevations and is located near rivers (Shrestha et al., 2025). The distribution of built-up land affected by flooding can be seen in Figure 9.

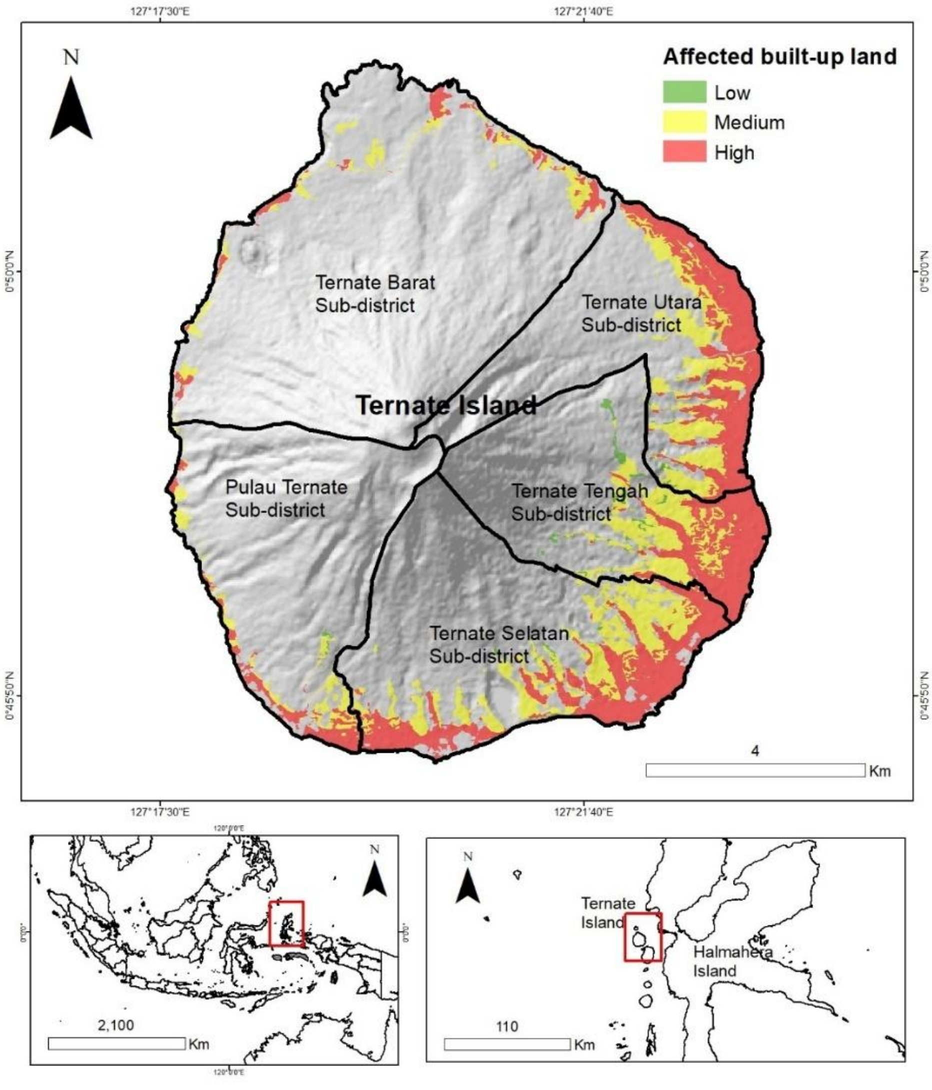

Figure 9. Map of Built-Up Land Distribution Based on Flood Risk Classes in Ternate City

Built-up land in the moderate hazard class in Ternate City covers 44.25% or 938.26 ha, while built-up land affected by low hazard covers 34.67 ha or 1.64%. This built-up land is generally located at high elevations far from rivers and has steep slopes. Data from the Ternate City Disaster Management Agency (BPBD) said that on August 25, 2024, flooding hit residential areas in Ternate City, particularly in the village of Rua, causing 15 individuals to suffer injuries, 16 individuals to lose their lives, and around 25 residential units to be affected by this disaster. This area has indeed been prone to flooding and landslides every year. Since 2017, 52 houses have been affected, while in 2020, 62 houses were also affected.

3.4. Future Policy Recommendations

Future policy recommendations for the Ternate City Government should be formulated as a transformation agenda for flood risk governance and climate adaptation, through the revision of the Regional Spatial Plan that integrates flood vulnerability zoning derived from GIS modeling, the implementation of green-blue infrastructure (mangrove belts, riparian corridors, and integrated detention ponds) as spatial utilization control instruments in high-risk zones, and the establishment of an inter-agency collaboration framework (local government, BMKG, BPBD, PUPR, Bappeda, research institutions, and local communities) for developing a GIS-based early warning system supported by dynamically calibrated HEC-RAS hydrological modeling using BNPB data; this entire policy package must be strengthened through mainstreaming disaster education, periodic evacuation simulations, and the development of spatially differentiated climate-resilient agriculture on volcanic islands with limited adaptation space, thereby sustainably mitigating risks of fatalities, infrastructure disruptions, and pressures on food security.

Conclusions

Based on this results of research on flood-prone areas in Ternate City using the six parameters modified from previous researchers, it shows that areas with high vulnerability are those located at flat and low elevations and slopes, very close to watersheds, dominated by residential and open land cover types, have Regosol soil types, and are affected by high rainfall intensity. This level of vulnerability is widespread in the coastal areas of Ternate City. Conversely, areas with moderate and low vulnerability levels are located further away from rivers and on hilly topography, making it highly unlikely for them to be flooded. One form of anticipation and mitigation against flood disasters is to predict the extent of built-up land in flood-prone areas. It is known that the extent of built-up land in areas with high vulnerability is in North Ternate District.

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Conflicts of Interest

The authors declare no conflict of interest.

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