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AMBON CITY PORTRAIT OF FLOOD VULNERABILITIES: SPATIAL ANALYSIS AND IDENTIFICATION OF CAUSING FACTORS

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ABSTRACT: Ambon City is one of the cities with a relatively high flood disaster intensity. This study aims to analyze the factors that cause flooding and determine the vulnerability of flooding. The method is based on a geographic information system (GIS) by integrating secondary and primary data. Parameters analyzed include elevation, rainfall, slope, soil type, and land use. Study results show that the factors causing flooding in Ambon City include relatively high-intensity rains, land use patterns dominated by mixed gardens, slopes in lowland areas, low elevations, and soil types easily inundated with water. The flood hazard zone is divided into three classes, namely high, medium, and low hazard zones. Areas with high vulnerability are 2,251.3 ha (6.99%) of the total area of the study area. For this reason, the community and the Ambon City government need to pay attention to this area in dealing with flood disasters.

Keywords: Flood Vulnerability, Spatial Analysis, Identification of Causative Factors

1. INTRODUCTION

Floods are natural disasters [1, 2] that are very damaging and can occur all over the world [3] and have various socio-economic impacts [4], damage to infrastructure and property, and cause human lives to be lost every year [5, 6]. It is also the cause of various other disasters, such as erosion, landslides, and sinkholes [7]. Flood disasters often occur naturally, both in intensity and in the number of locations each year [8]. Floods have become a global problem experienced by humans, both caused by natural factors and human activities [9]. Flood disasters endanger people's lives and livelihoods [10]. These disasters can cause death, environmental damage, material losses, and adverse psychological impacts [11].

Floods occur when drainage systems, whether natural or modified, are unable to hold water. The risk of flooding is higher when it affects people, infrastructure, and settlements. The more frequent floods occur, the greater the damage that can be done to the economy, human life, transportation, ecosystems, infrastructure, and cultural heritage sites [12, 13]. This natural phenomenon occurs after prolonged rainfall, heavy snowmelt, or a combination of the two with unfavorable environmental conditions. Increasing environmental damage, such as population growth, deforestation, and urbanization, are the main factors in increasing the frequency of floods over the past decade [14].

In some areas, floods occur regularly every year. Floods can occur in urban and rural areas and developing and developed countries [8]. Urban flooding is a natural hazard that threatens life and property in cities worldwide. The rapid urbanization of the 21st century has increased the city population and property density, resulting in significantly increased flood susceptibility [15, 16]. Globally, floods account for more than 30% of total disaster losses each year [17], and the impact of flooding has an increasing trend due to climate change and ongoing urbanization [18, 19, 20]. The devastating flood disaster that hit Beijing on July 21, 2012, killed more than 70 people and affected 1.6 million [14, 18]. The recent flood disaster occurred in Zhengzhou, China, on July 20, 2021, causing hundreds of deaths and an economic loss of 40 billion RMB. Urban floods caused by intense rainfall are usually associated with highly variable processes over a short period. Rapid flood risk assessment provides an essential tool for disaster risk reduction [15]. In Jakarta in 2022, there were 14 cases of flooding which resulted in hundreds of people losing their homes [21]. Due to the frequent occurrence of floods, it is necessary to carry out good flood risk management to reduce the negative impact [8].

Flood disasters can cause many effects or losses [22]. One of the reasons is that people are less responsive in dealing with floods, so they need help knowing where to flee, finally deciding to stay in houses prone to flooding [23]. Climate change and socio-economic development also directly impact flood events, increasing the risk of future flooding and endangering the community [3]. can also lead to public ignorance and the absence of flood evacuation routes [24, 25]. In order to reduce possible losses, it is necessary to do prior planning [26]. Various efforts can be made to reduce this impact, such as socializing areas vulnerable to disasters aimed at the community [27].

Ambon City is one of the cities in Indonesia with a relatively high flood risk. Floods in Ambon City are caused by several factors such as high rainfall intensity, flat and low contour geographical conditions, and being in a coastal area, as well as a lack of good drainage management and having several rivers crossing its territory and land use patterns that are not by the provisions as well also exacerbated flood vulnerability in Ambon City. In addition, the impact of urban development in Ambon City is a reduction in the green area that functions as a water absorption area and an increase in buildings covering the land. As a result, flooding or inundation will occur when there is heavy rain for a relatively long time.

To deal with the problem of flooding, an information system that is reliable and can provide information about flood vulnerability in Ambon City is needed. One of the keys to preventing and reducing losses is providing reliable information to the public about flood risks through flood maps [28]. Geographic information systems (GIS) and remote sensing are two technologies that can be used to collect, process, and analyze spatial data related to flood vulnerability in Ambon City. A multidisciplinary approach has been proposed to utilizing Remote Sensing technology and Geographic Information Systems advances to map, monitor and manage floods more efficiently [29]. Using GIS technology and remote sensing, spatial analysis can be carried out on the factors that cause floodings, such as elevation, rainfall, land use, rivers and waterways, and drainage. The results of this analysis can be used as a basis for planning effective and efficient flood management in Ambon City.

Many current studies focus on creating flood vulnerability maps as an effective flood risk management tool [30]. Flood vulnerability shows the tendency of an area, based on its physical geographical characteristics, toward the potential for flooding [31]. Flood vulnerability mapping can also provide a spatial picture of flood events in a particular area [30, 31, 32]. Flood vulnerability analysis and mapping help identify areas most vulnerable to flooding and thus is an essential aspect of an early warning system for future flood prevention and mitigation [33].

Therefore, developing an information system based on GIS and remote sensing is essential to analyze flood vulnerability in Ambon City. Can assist authorities and stakeholders in carrying out appropriate disaster response and relief activities and achieving disaster risk reduction and mitigation at an early stage [34]. With this information system, it is hoped to help the government and people of Ambon City in mitigating flood risks and minimizing losses caused by flood disasters.

The purpose of analyzing flood vulnerability in Ambon City based on GIS and remote sensing is to obtain factual information as a reference in planning effective flood management. Accurate and timely information on flood vulnerability is expected to assist the government and the community in mitigating flood risks and minimize losses caused by flood disasters. GIS and remote sensing-based flood hazard analysis is expected to produce more accurate and detailed information regarding flood hazards in Ambon City. It can help the government and the community to plan more effective and efficient flood risk mitigation activities.

2. RESEARCH METHODS

The spatial approach in analyzing flood vulnerability in Ambon City based on geographic information systems and remote sensing refers to the GIS (Geographical Information System) technique to analyze and visualize spatial data in map form. This approach uses spatial data, such as land use maps, topographical maps, and hydrological maps, to map areas prone to flooding. The spatial approach is a way to study certain phenomena in more depth through an approach through space. In this approach, spatial variables have a vital role in every analysis so that information about the location and position of an object in space becomes very relevant. With this approach, you can better understand your symptoms or problems [35, 36].

In this study, the population studied was land units determined by overlaying *land* use maps, soil maps, and land slope maps. After the overlay, a map of the land units will be obtained and used as the sampling unit. A total of 45 land units resulting from the overlay were then used as the study population. In this study, 23 samples were selected by *purposive sampling* based on the similarity of features and characteristics of each existing land

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unit. In determining flood-prone areas, there are four variables: rain, slope, soil, and land use. This variable is used as a factor that influences the level of flood vulnerability. Considering these four variables, it is expected to provide an understanding of areas that can experience flooding.

In analyzing research data, spatial analysis based on GIS (Geographical Information System) is used to analyze and visualize spatial data in the form of maps by overlaying them by combining several maps and then giving a certain weight and combined into one map showing flood hazard *in* an area. This technique can be used to identify areas that are prone to flooding and produce flood hazard maps. In addition, multi-criteria analysis is also used: Multicriteria analysis is carried out using mathematical calculations to select the best alternative based on predetermined criteria.

RESULTS AND DISCUSSION

Factors Causing Floods

High rainfall intensity can be a threat because it can saturate the soil due to the distribution of rain daily, which tends to be high or, in other words, continuous. The soil continues to absorb water, and if it is saturated, every rainwater that falls will have the potential to cause puddles and floods. Therefore, Table 1 presents the values of the rainfall parameters, which are used as a reference in determining the level of flood vulnerability. The higher the rainfall conditions, the greater the potential for flooding, and vice versa; the lower the rainfall, the safer from flooding. Table 1 contains the classification and rainfall scores.

Table 1. Rainfall Classification Score

Parameter	Average (mm/day)	Weight	Mark	Rain Score
Very high	> 100	0.15	5	0.75
height	51 - 100	0.15	4	0.60
Medium	21 - 50	0.15	3	0.45
Low	5 - 20	0.15	2	0.30
Very low	> 5	0.15	1	0.15

Table 1 shows that the rain conditions at the research location, based on data from the Pattimura Meteorological Station, have an annual average rainfall with relatively high parameters in the last ten years (2013-2022), which is around 26.162 m. Therefore, the criteria for the class of rain intensity and its area in Ambon City range from 27.7 – 34.8 m, which indicates that the rain intensity is moderate, with an average of 21-50 mm. Figure 1. visually shows this.

Changes from converted land use on open land to built-up land in Ambon City can impact decreasing water catchment areas and increase the amount of stagnant rainwater and further exacerbate flooding. The pattern of land use in Ambon City varies in each district. Table 2. describes the classification of land use based on score values,

Table 2. Land Use Classification Scores

Land Use	Weight	Mark	Land Scoring	Area (ha)	%
Built Area	0.15	5	0.75	5923.8	18.40
Plantation	0.15	4	0.60	6132.1	19.05
Mixed garden	0.15	3	0.45	10,832.2	33.65
Check	0.15	2	0.30	1.428,8	4.44
Forest	0.15	1	0.15	7.875,1	24.46

Table 2 shows that land use in Ambon City tends to vary and is not uniform in each district due to differences in regional characteristics and the needs of the local population. In the southern part of Ambon City, land use is dominated by mixed gardens, while in the central part, there are many plantation areas. In addition, settlements are reasonably extensive land use, especially in coastal areas such as Sirimau and Nusaniwe Districts, which are urban centers with high population density.

Patterns of land use that differ in each region can affect flood vulnerability in Ambon City. For example, areas dominated by built-up land tend to have fewer water catchment areas, which can increase the amount of rainwater runoff and the risk of flooding. Therefore, it is necessary to carry out a flood vulnerability analysis by considering the land use factor as an essential variable.

In general, the land use pattern in Ambon City is dominated by mixed gardens, which cover an area of approximately 10,832.2 hectares. In addition, there are other land uses such as forests and built-up areas with an area of approximately 7,875.105 and 5,923.8 hectares, respectively. Meanwhile, the minor land use is shrubs, with an area of around 1,428.8 hectares. Land use in Ambon City consists of several types, such as built-up areas, mixed gardens, plantations, shrubs, and jungle forests. More apparent Figure 1. b

The Ambon City land use map shows that most of the built-up land is in the Sirimau and Nusaniwe Districts, which are the city centers. In addition, plantations and mixed gardens also have a significant area in several sub-districts, such as South Leitimur, Ambon Bay, and Baguala Districts. As for jungle forests, they are found in several sub-districts, such as Salahutu, South Leitimur, and North Leitimur. That land use in Ambon City is not evenly distributed and depends on geographical conditions and the population needs in each sub-district.

The condition of the Watershed (DAS) in Ambon City is a significant potential water source, and its function can be utilized and maintained. Ambon City has several long rivers or wais, including Wai Batu Merah (4.25 Km), Wai Ruhu (9.10 Km), Wai Batu Gajah (3.10 Km), Wai Tomu (4.20 Km)), Wai Pia Besar (6 Km), Wai Lela (7.8 Km), Wai Tonahitu (6 Km), Wai Sikula and Wai Lawa (9.5 Km). The existence of this river can be used for washing and bathing activities, as well as other purposes. The closer to the river, the greater the risk of flooding. Therefore, the closer the distance, the higher the score, with a distance of <25m, given a score of 5. Conversely, the farther the distance of an area from the river, the score will be lower, given a score of 1.

Table 3. Region's Distance to the River

Class	Mark	Weight	Score	Area (Ha)	%
0 – 25	5	0.20	0.100	671.7	2.08
25 – 50	4	0.20	0.80	67,.2	2.09
50 – 75	3	0.20	0.60	678,2	2.10
75 – 100	2	0.20	0.40	682.4	2.11
>100	1	0.20	0.20	29,607.9	91.62

River buffer is a technique used to identify areas adjacent to rivers in Ambon City. The closer the distance from an area to the river, the higher the chance of flooding. Conversely, the farther the distance of an area from the river flow, the lower the possibility of flooding. This information is visually shown in Figure 1. c.

In the study area, embankments on the right and left of the riverbank channel can reduce the potential for flooding. The results showed that flooding was caused by water entering from the new river into the main river, so the buffer parameters were then calculated based on the river's flow.

The slope of slope refers to the ratio of the percentage between the vertical distance (height) and the horizontal distance. The steeper the slope of the land, causing water to flow faster when compared to sloping land, will increase the possibility of flooding with a steep slope. Slopes in Ambon City have various values, from 0 to 45 degrees, as presented in Table 4 regarding the parameters of the land slope.

Table 4. Slope Classification Score

Slope	Weight	Mark	Slope Score	Area (Ha)	%
Flat to Sloping	0.20	4.00	1.00	5087.6	15.80
Slightly tilted	0.20	3.00	0.80	6974.2	21.66
Crooked	0.20	2.00	0.60	9380.6	29,14
Very slanted	0.20	1.00	0.40	10,750.0	33,39

The slope area of the slopes in Ambon City has different variations. The area with the widest slope is the one with a slope of > 30%, with an area of 10,750.0 ha. Areas with a slope of 15-30% have an area of 9,380.6 ha, a slope of <15% has an area of 6,974.2 ha, and a slope of 0-8% has an area of 5,087.6 ha. From these results, it can be seen that the slopes in Ambon City consist of highlands and lowlands. Complete information can be seen in Figure 1.d.

The height of land can be measured based on its height above sea level and affects the possibility of flooding. Low areas have a high risk of flooding, while high areas tend to be safer from flooding. In Ambon City, the elevation ranges from 0 to 1551 m, with a flat relief in the west and very steep mountains in the north. From the table presented, the higher the possibility of flooding, and the appropriate value is given in Table 5.

Table 5. Land Altitude Classification Score

Elevation (masl)	Weight	Mark	Score	Area (Ha)	%
< 10	0.10	5	0.50	8757,1	27.20
10 – 50	0.10	4	0.40	2,660.6	8.26
50 – 100	0.10	3	0.30	11754.6	36.51
– 200	0.10	2	0.20	7,995.0	24.83
>200	0.10	1	0.10	1025,1	3.18

Table 5 shows that the north and south coastal areas of Ambon City have an elevation of less than 50-100 meters above sea level with an area of 11,754.6 ha. In addition, there are also areas with an elevation of < 10 masl covering an area of 8,757.1 ha, an elevation of 100-200 masl covering an area of 7,995.0 ha, and an area with an elevation of > 200 masl covering an area of 1,025.1 ha. Areas with an elevation of <10 masl are seacoast areas and have great potential for flooding because the lower the elevation in an area, the higher the vulnerability to flooding. This information can also be seen visually in Figure 1. e.

Physically, various factors affect the ability of the soil to infiltrate, such as density, humidity, and plants growing on it. Over time, the rate of infiltration will decrease due to increased

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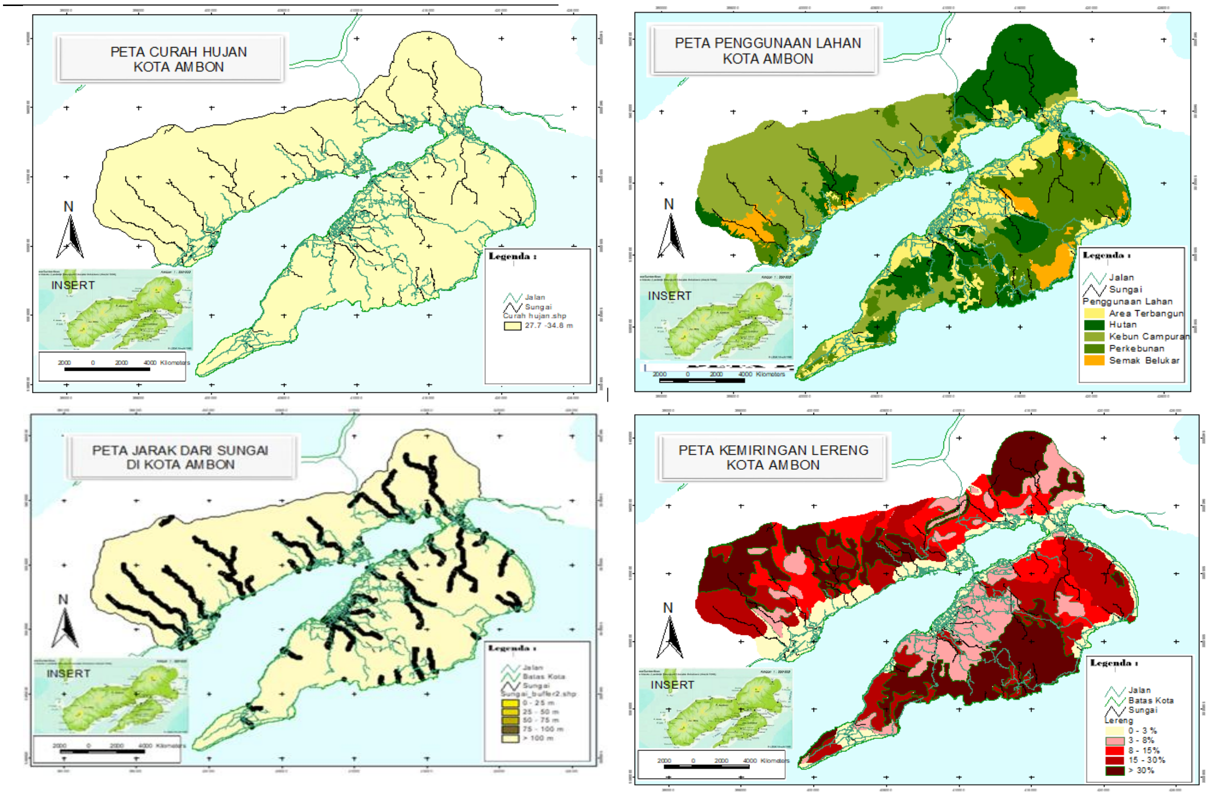
humidity. The higher the absorption and infiltration capacity of the soil to water conditions, the lower the vulnerability to flooding, and vice versa; the lower the absorption capacity, the greater the potential for flooding. In the Ambon City area, the soil consists of alluvial, latosol, podzolic, litosol, and Mediterranean deposits. Alluvial soil types have a low infiltration rate, which can cause flooding, as shown in Table 6.

Table 6. Soil Type Classification Score

Land Unit	Weight	Mark	Score	Area (Ha)	(%)
Alluvial, Cambisol, Regosol, Gleisol	0.20	4	0.80	3,300.1	10.25
Cambisol, Latosol, Regosol	0.20	3	0.60	23,599.7	73.31
Latosol, Cambisol	0.20	2	0.40	1969.0	6.12
Rensina, Cambisol, Litosol	0.20	1	0.20	3,323.7	10.32

Almost all areas in Ambon City have soil types of Kambisol, Latosol, and Regosol which cover an area of 23,599.7 hectares. However, in some coastal areas of Ambon City, there are alluvial, cambisol, regosol, and gleisol soil types covering an area of 3,300.1 hectares. This soil type is very prone to flooding because it absorbs little water. This type of soil is distributed in almost the entire area of Sirimau, Nusaniwe, and Ambon Bay sub-districts, as well as a small part of Ambon Baguala Bay and South Leitimur. This information can be seen as a whole, presented in Figure 1. f.



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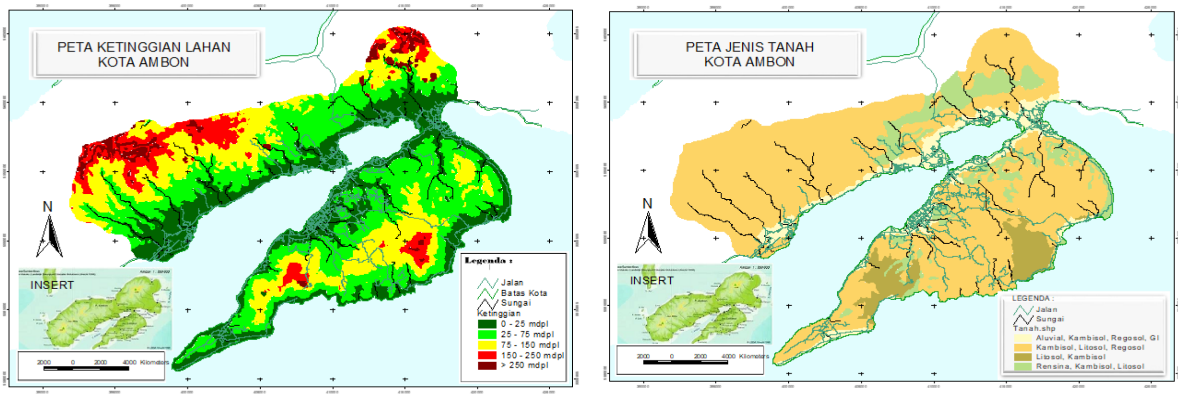

Fig 1. (a) Rainfall Map, (b) Land Use Map, (c) Distance Map from River, (d) Slope Slope Map, (e) Land Altitude Map, and (f) Soil Type Map

Flood Vulnerability

Considering the flood risk level, an area zoning can be made for Ambon City, as shown in Table 7. The non-prone zone is considered an area that is safe from flooding. This area is identified as outside the river segment buffer for more than 100 meters, with land use consisting of plantations and settlements. The analysis results show that the area with low flood risk in the study area covers an area of 23,059.9 ha or around 71.65% of the total area.

Table 7. Flood Vulnerability Level

Intervals	Vulnerability Level	Area (Ha)	%
15 – 21	Prone	6874.3	9:36
22–27	Very Prone	2251.3	6.99
8 – 14	Not Prone	23,059.9	71.65

Areas included in the hazard-prone zone in Ambon City have the potential to experience flooding with a critical level of vulnerability. The temperate zone is 25 - 50 meters from the river and is used as a settlement or mixed garden. Based on an analysis of the vulnerability to flooding, the area included in the vulnerable category is 6,874.3 ha (21.36%) of the total area of the study area.

Areas included in the very vulnerable zone are the most critical areas for flooding. This zone is spread over 0 - 25 meters from the buffer to river segments whose distribution is based on land use, namely settlements. The analysis results of the vulnerability to flooding, the area included in the high includes 2,251.3 ha (6.99%) of the entire study area. Therefore, this area is the focus of attention for Ambon City residents and the government. More detailed information is presented in Figure 2.

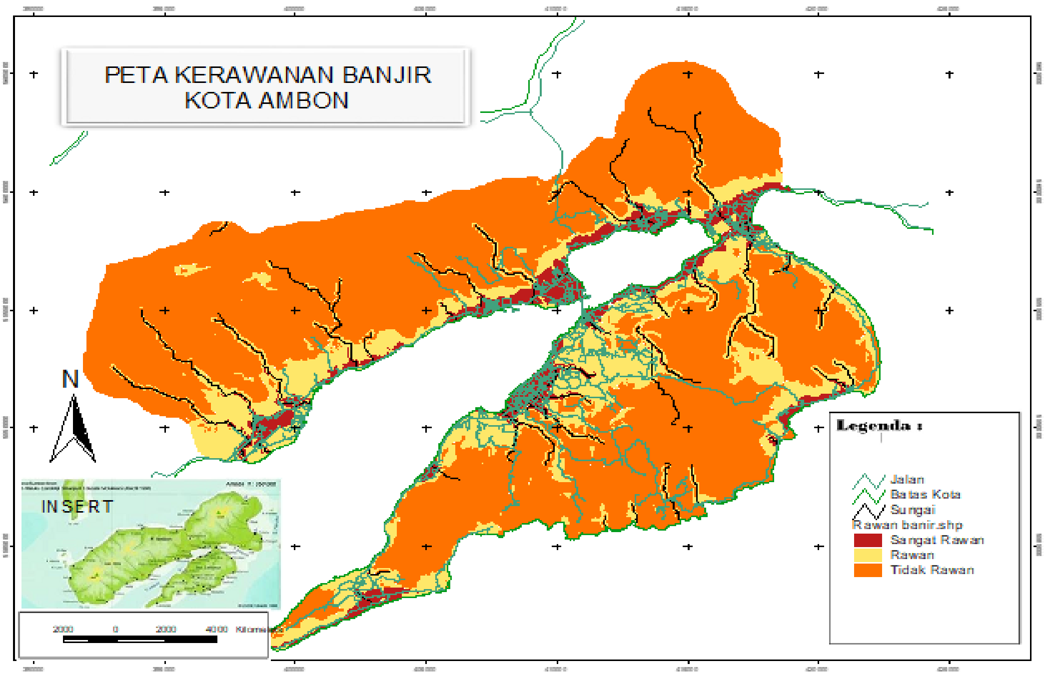

Fig 2. Zoning Map of Flood Hazard in Ambon City

3. CONCLUSION

Based on the presentation of the discussion study, it was concluded that factors such as rain intensity, land use pattern, slope, elevation, and soil type significantly influence the risk of flooding in Ambon City. The analysis results also show two flood hazard zones, namely the hazard zone and the same hazard zone. Therefore, effective preventive and mitigation measures are needed to reduce the impact of flooding in Ambon City, such as improving drainage infrastructure and realigning land use that is safer from the risk of flooding

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