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Mapping of Flood Hazards to Affected Areas in South Batipuh District, Tanah Datar Regency

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ABSTRACT

Flash floods in South Batipuh District, Tanah Datar Regency, continue to recur and threaten settlements around Lake Singkarak. This study aims to map the level of flood danger and analyze the distribution of flood-affected areas to land use in the sub-district. The research uses a quantitative descriptive method with a Geographic Information System (GIS) approach. The flood danger level is calculated using the Paimin method by scoring and weighting five physical parameters of the area, namely watershed shape, slope slope, land use, land shape, and drainage density. The distribution of the affected area is analyzed through an intersect overlay technique between flood hazard maps and land use maps using ArcGIS 10.8. The results showed that the low-hazard class dominated the study area of 10,851.20 hectares or 68%, the medium class of 4,744.37 hectares or 30%, and the high class of 473.02 hectares or 2%. Forests dominated the low-hazard class, while rice fields and built-up areas dominated the high-hazard class, especially in Nagari Guguak Malalo and Nagari Padang Laweh Malalo. This study produced the latest data by combining the Paimin method, post-disaster field data, and Sentinel-2A imagery at the sub-district scale, which was not available in the previous study. These results can be a reference for the Tanah Datar Regency Government and BPBD in formulating spatial planning and disaster mitigation policies.

Keywords: *Flood Hazards, Paimin Method, Land Use, Geographic Information System, South Batipuh*

1. INTRODUCTION

Floods account for around 78% of hydrometeorological disasters in Indonesia and cause widespread damage [1]. South Batipuh District, Tanah Datar Regency, is prone to flash floods due to the topography of the hills near the river flow, with a flood hazard area of 315.63 hectares in the high class [2]. The November 2025 flash floods damaged settlements in six locations, isolated hundreds of families, and left the risk of aftershocks [3]. Flood hazard mapping with GIS, hydraulics, and satellite imagery has so far not reached the sub-district scale in detail and has not included the latest post-disaster data. This study fills the gap by mapping the level of flood danger and the distribution of areas affected by land use in South Batipuh using the latest field data and remote sensing images.

Flood hazard assessment through scoring of regional physical parameters was introduced by Paimin et al. (2012) and proved effective in classifying flood hazards into low, medium, and high [4]. Further research expands this approach through GIS in Padang [5], HEC-RAS 2D in Pati [6], NDWI in Sidoarjo [7], remote sensing in Nias [8], and Sentinel-1 SAR with machine learning [9].

These works still focus on large cities and rarely combine post-disaster field data with the latest images, so there has been no study of changes in the distribution of areas affected by repeated flash floods to land use at the sub-district level using a combination of the Paimin method, field data, and Sentinel-2A imagery.

This study combines the Paimin method, post-disaster field data, and Sentinel-2A imagery in the GIS framework in South Batipur. The main expected results are flood hazard maps with low classes dominant in hilly forest areas, and medium to high classes concentrated on the banks of Lake

Singkarak which is densely populated with settlements and agricultural land. These results are expected to be a reference for spatial planning policies, evacuation routes, and disaster mitigation for the Tanah Datar Regency Government and BPBD, as well as a methodological reference for similar areas.

2. LITERATURE REVIEW

2.1 Flood

Flooding is an event in which an area, especially lowland areas that should not be submerged, occurs due to high rainfall and is not supported by an adequate drainage system [10].

2.2 Factors Causing Flooding

Flooding is caused by the interaction of various physical factors of the land, including slope slope, land use, land shape, watershed shape, and drainage density. Sloping slopes slow down surface flow and trigger inundation, while steep slopes accelerate flow but can increase erosion and material movement [11]. Land use change from forests or green land to built-up areas reduces the soil's ability to absorb water, increase surface runoff, and sediment accumulation [12]. Lowland and valley land forms tend to be zones where water gathers, so they are more prone to flooding than high areas [13]. The shape of the watershed determines the direction and concentration of rainfall flows to the river; if the capacity of the river is exceeded, flooding occurs [14]. High drainage density accelerates the flow of water into the river, but when the discharge exceeds the capacity of the river, the risk of flooding increases, while low drainage causes water to last a long time on the surface, especially in hard-to-penetrate soils [15]. Thus, flooding is a combined result of topographic conditions, land cover, morphology, watershed characteristics, and drainage systems that affect each other.

2.3 Land Use

Land use has a great influence on the occurrence of floods because it is related to the ability of the soil to absorb and drain water. Changes in land function, such as from forests to settlements, industrial estates, or agricultural land, can reduce the ability of the soil to absorb rainwater. Natural forests and plants actually function to absorb water and slow down the flow of water on the surface, thus reducing the risk of flooding [16].

2.4 The Paimin Method

The Paimin method is one of the methods that can be used to determine the level of flood danger or vulnerability in an area. This method is carried out by looking at several factors that can affect the occurrence of floods, then each factor is given a value or weight according to the level of its influence on floods [17].

3. METHODS

This study uses a type of quantitative descriptive research with an approach using the paimin method, spatial analysis based on Geographic Information System (GIS). Descriptive research aims to describe systematically, factually, and accurately the condition of flood-affected areas in South Batipuh District based on the data obtained, while the quantitative approach is used to measure and analyze data numerically.

3.1 Research Location

This research was carried out in South Batipuh District, Tanah Datar Regency, West Sumatra Province. This area is astronomically located between. 0° 29' 38" and 0° 35' 30" South

Latitude and between 100° 22' 36" and 100° 31' 44" East Longitude. This research will be carried out when all the tools and materials to conduct the research have been fulfilled. For more details on the location of the research, it is presented in Figure 1.

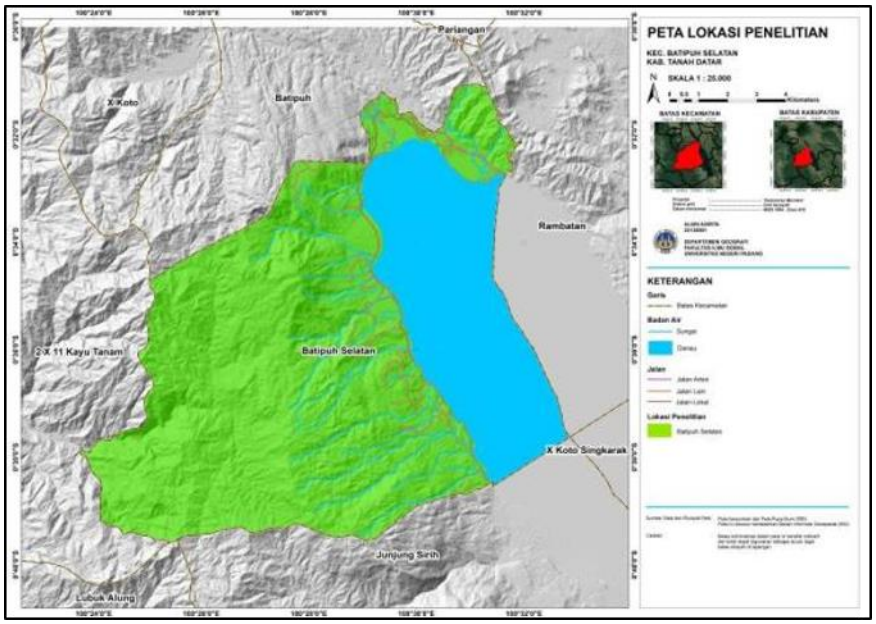

Figure 1. Map of the Research Location

3.2 Data and Data Sources

The research data consists of primary data and secondary data. Primary data is obtained through field observations conducted to verify and complete information from secondary data. Secondary data, with data sources including the Geospatial Information Agency (BIG), the Ministry of Energy and Mineral Resources (EMR), the Ministry of Environment and Forestry (MoEF), and the Sentinel-2A satellite image from the Copernicus Data Space Ecosystem. Data processing is carried out using ArcGIS 10.8 software through the stages of data collection, spatial data processing, parameter analysis, and presentation of results in the form of maps.

3.3 Data Analysis Methods

3.3.1 Analysis of the Level of Flood Danger in South Batipuh District

The level of flood danger in South Batipuh District was analyzed using the method of Paimin et al. (2012) through scoring and weighting of five physical parameters of the area, namely watershed shape, drainage density, slope slope, land shape, and land use. Spatial data in the form of digital elevation models (DEM), land use maps, river network maps, and watershed maps were processed to produce maps of each parameter, then overlaid using the Geographic Information System with the formula:

$$BB = 0{,}05x\ B.DAS + 0{,}05xKD + 0{,}05xKL + 0{,}3xBL + 0{,}4xPL$$

Information:
BB : Flood Hazards
B. DAS : Watershed Shape KD : Drainage Density
KL : Slope Gradient

BL : Land Form
PL : Land Use

The value of the flood hazard index (BB) generated from this overlay is then grouped into interval classes using the formula:

$$I = \frac{R}{K}$$

Information:
I : Class Interval Width
R : Range of High Value and Low Value
K : Numbers of Class Intervals

Table 1 Flood Hazard Score and Weight

No	Parameters / Weights	Classification	Category	Score
1	Watershed Shape (5%)	Oval	Low	1
		Slightly Elongated	Somewhat Low	2
		Medium	Medium	3
		Somewhat Rounded	Somewhat High	4
		Round	Height	5
2	Drainage Density (5%)	Seldom	Low	1
		Somewhat Rare	Somewhat Low	2
		Currently	Medium	3
		Meeting	Somewhat High	4
		Very tight	Height	5
3	Slope Gradient (5%)	< 8	Low	1
		8 - 15	Somewhat Low	2
		16 - 25	Medium	3
		26 - 45	Somewhat High	4
		> 45	Height	5
4	Land Form (30%)	Mountains, Hills	Low	1
		Fan and Lava	Somewhat Low	2
		Plains Terrace	Medium	3
		Plains, Terrace (slope < 2%)	Somewhat High	4

Source: [18]

3.3.2 Analysis of the Spatial Distribution of Flood-Affected Areas in Relation to Land Use in South Batipuh District

The distribution of flood-affected areas on land use was analyzed using the intersect overlay technique using the Geographic Information System (GIS). Two maps were stacked, namely the flood hazard level map from the analysis of the first problem formulation and the land use map of South Batipuh District, after both were equalized with the coordinate system and the boundaries of the area so that the overlay results were accurate. This overlay technique combines the two maps so

that each overlapping area can be identified, so that the type of land use, such as settlements, rice fields, plantations, and forests, that are at each flood hazard level is known.

The area of each type of land use in each hazard class is then calculated in hectares and its percentage, to determine the most extensive land use affected by the low, medium, and high hazard classes. The results of the analysis are presented in the form of a map of the distribution of land use affected by floods and a table of land use areas based on the level of flood danger in South Batipuh District.

4. RESULTS AND DISCUSSION

4.1 Analysis of Flood Hazard Levels in Batipuh Selatan District

The analysis of the level of flood danger in South Batipuh District used the Paimin method through scoring and weighting five physical parameters of the area, namely watershed shape, slope slope, land use, land shape, and drainage density. These five parameters were processed separately using the Geographic Information System (GIS) before being stacked to produce a map of the flood hazard level. The results of processing each parameter in the study area covering an area of 16,068.59 hectares are described as follows.

4.1.1 Slope Gradient

Slope gradient data was processed from DEMNAS (BIG) with a resolution of 8×8 meters. Flat slopes (0-8%) dominate the area around Lake Singkarak and the northern part of the study area. This area is where water gathers and is difficult to flow quickly, making it prone to inundation. The sloping (8-15%) and slightly steep (15-25%) classes dominate the central part, indicating hills with relatively smooth water flow.

The steep class (25-45%) is spread in the western part, while the very steep class (>45%) is only found in a small area.

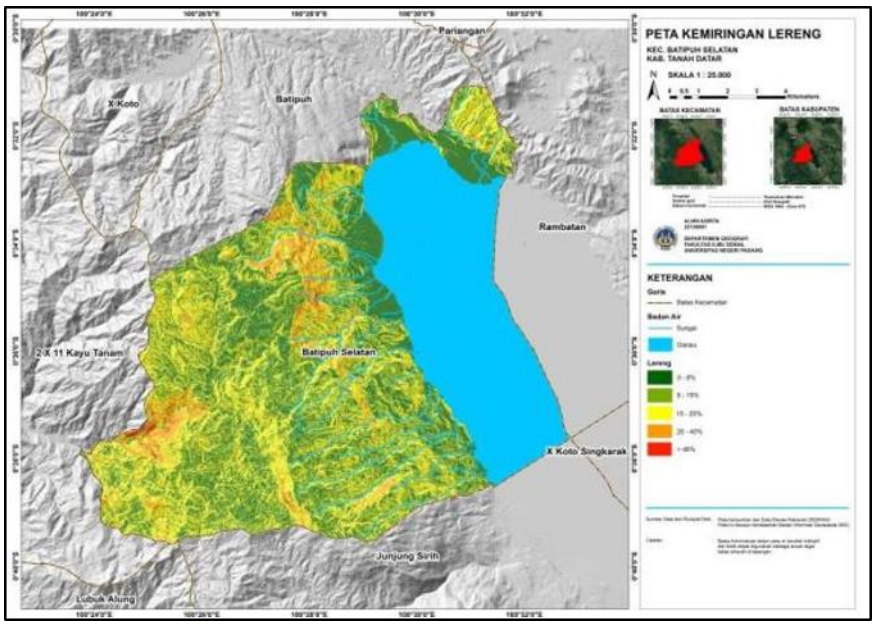

Figure 2. Slope Gradient Map

Table 2 Classification of Slope Gradient

No	Slope	Area (Ha)	Percentage (%)
1	0 - 8 %	7.040,40	43,81
2	8 - 15 %	4.497,72	27,99
3	15 - 25 %	3.581,75	22,29
4	25 - 45%	906,88	5,64

5	>45 %	41,84	0,26
Total Area		16.068,59 Ha	100 %

Source: Processed Researcher, 2026

The flat slope class (0–8%) which covers almost 44% of the study area is a factor that needs to be watched out for, because the flat topography slows down the flow of water, especially around Lake Singkarak.

4.1.2 Watershed Shape

The study area of 16,068.59 hectares is divided into two watersheds. The Anai watershed is somewhat oval in shape and is located in the western part, near the 2x11 Kayu Tanam and Lubuk Alung sub-districts. Its shape accelerates the collection of rainwater to the main river so that the risk of flooding during heavy rains is higher. The Indragiri watershed is oval in shape and dominates the central to northern part around Lake Singkarak. The flow is slower so the risk of sudden flooding is less than the Anai watershed

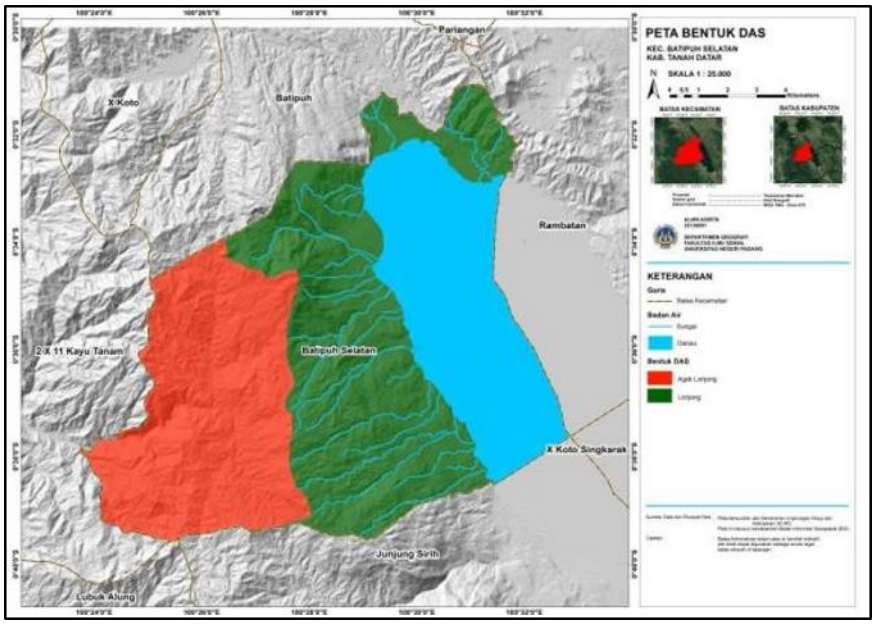

Figure 3. Watershed Shape Map

Table 3. Classification of Watershed Form

No	Watershed Shape	Classification	Area (Ha)	Percentage (%)
1.	DAS Anai	Slightly Elongated	5.183,23	32,26
2.	DAS Indragiri	Oval	10.885,36	67,74
	Total Area		16.068,59 Ha	100 %

Source: Processed Researcher, 2026

4.1.3 Land Use

Land use data is sourced from the 2025 Sentinel-2A image with a resolution of 10 meters. Forests dominate the study area and are widely spread in the western, central, and southern parts, indicating that natural vegetation cover is still preserved. The built-up area extends along the banks of Lake Singkarak, following a pattern of settlements that develop near water bodies. Rice fields are also found on the shores of the lake, while shrubs are scattered in small and separate areas.

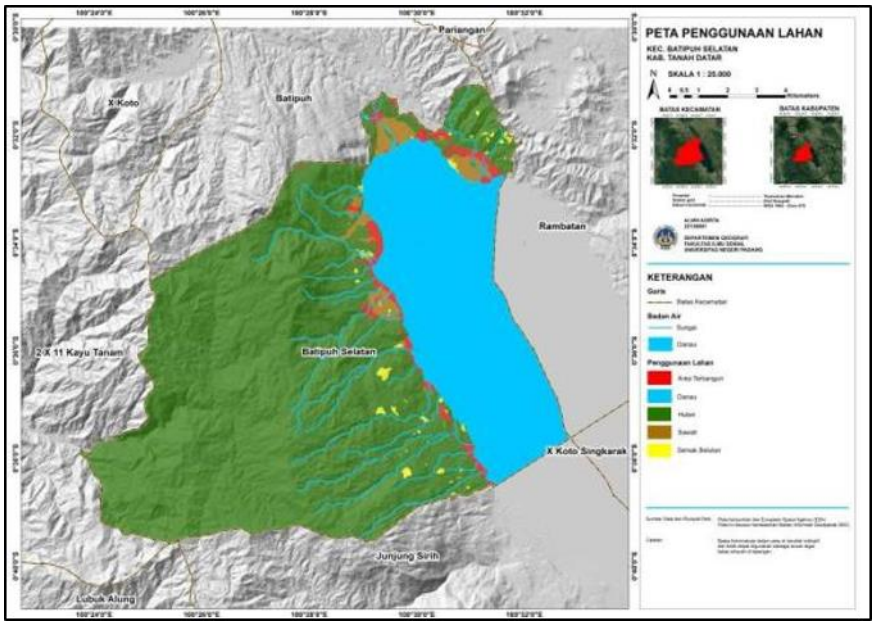

Figure 4. Land Use Map

Table 4. Classification of Land Use

No	Land Use	Area (Ha)	Percentage (%)
1	Built-up Area	288,78	1,8
2	Lake	4.195,82	26,1
3	Forest	11.168,97	69,5
4	Rice Field	317,53	2,0
5	Shrubland	97,49	0,6
Total Area		16.068,59 Ha	100 %

Source: Processed Researcher, 2026

Although the area is small, the built-up area that extends on the edge of the lake needs attention, because the covered surface of the building is difficult to absorb water and can accelerate the flow to the lake.

4.1.4 Land Form

Land form data is sourced from the Ministry of Energy and Mineral Resources' geomorphological data in 2025. Alluvial plains dominate the northeastern part of the region, precisely around Rambatan and the shores of Lake Singkarak. This land form is formed from deposits of river and lake materials so that the topography is flat and prone to inundation. The volcanic land form occupies the second largest position and follows a hilly pattern from South Batipuh to Lubuk Alung. The carbonate/karst land form forms an elongated path from north to south, while the land forms of metamorphic rocks and intrusive igneous rocks have the smallest area

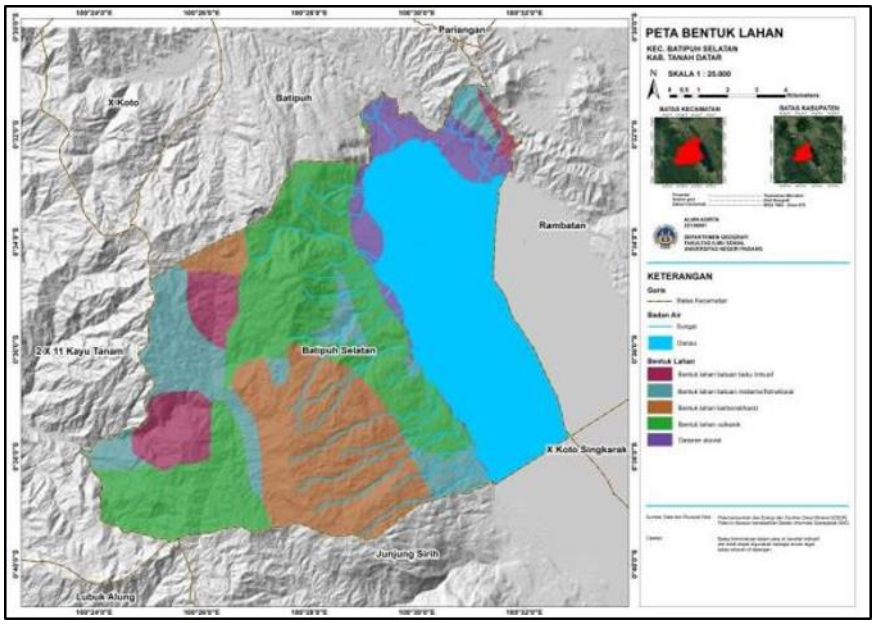

Figure 5. Map of Land Forms

Table 5. Classification of Land Form

No	Land Form	Area (Ha)	Percentage (%)
1	Intrusive Igneous Rock Landforms	1.059,21	6,59
2	Metamorphic Rock Landforms	2.003,10	12,47
3	Carbonate/Karst Landforms	3.114,11	19,38
4	Volcanic Landforms	4.777,17	29,73
5	Alluvial Plain.	5.115,00	31,83
	Total Area	16.068,59 Ha	100 %

Source: Processed Researcher, 2026

The dominance of alluvial plains that reach almost a third of the area, plus the shape of the surrounding hilly land, makes the plain area near Lake Singkarak the area with the most potential to accommodate water flow from the surrounding hills.

4.1.5 Drainage Density

Drainage density data is sourced from the 2025 Indonesian Terrain Map (BIG). The sparsely populated category dominates the eastern part of the area around Lake Singkarak, which is natural because the area is a body of water. The medium category is spread in the central part around South Batipur. The tight and very dense category is most commonly found in the western and southern parts, near the border of Lubuk Alung and Junjung Sirih, indicating many interconnected branches of small rivers.

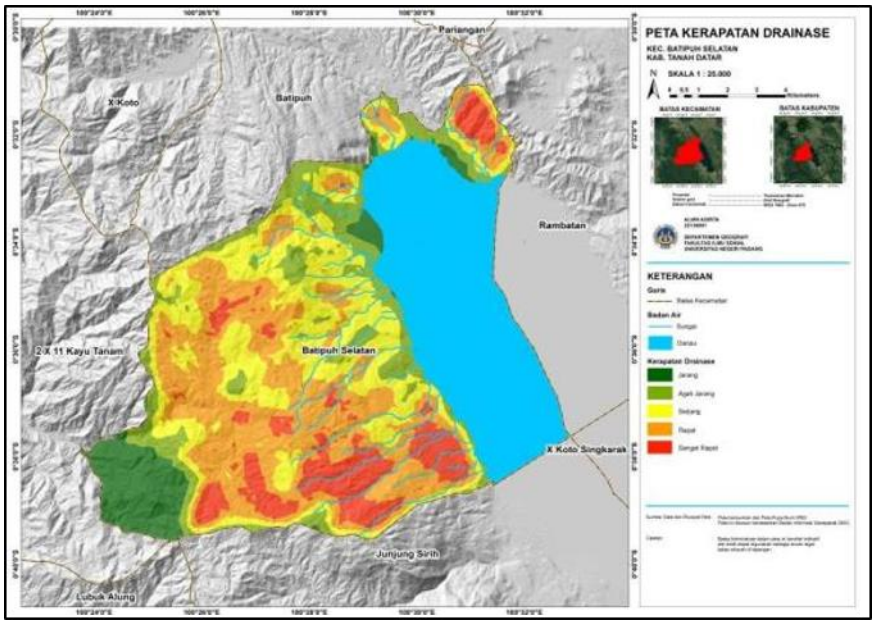

Figure 6. Drainage Density Map

Table 6. Classification of Drainage Density

No	Drainage Density	Area (Ha)	Percentage (%)
1	Seldom	5.027,14	31,28
2	Somewhat Rare	1.957,55	12,18
3	Currently	3.436,75	21,39
4	Meeting	4.015,16	24,99
5	Very tight	1.631,99	10,16
Total Area		16.068,59 Ha	100 %

Source: Processed Researcher, 2026

Although the very tight category has the narrowest area, this category is given the highest score because the dense river network accelerates the collection of water to the main river, so the western and southern parts of the study area need to be a special concern in flood mitigation efforts.

4.1.6 Calculation of Score and Weight of Flood Hazard Parameters with the Paimin Method

The flood hazard level was calculated from five parameters, namely watershed shape, slope slope, land use, land shape, and drainage density, which were processed with ArcGIS. Each category of parameters was scored from 1 to 5 according to the level of influence on flooding, then multiplied by the fixed weight of the Paimin method, which was 5% for watershed shape, slope slope, and drainage density, 30% for land shape, and 40% for land use.

Table 7. Results of Weighting of Flood Hazard Parameters

Parameter	Classification	Score	Weight	Score x Weight
Watershed Shape	Slightly Elongated	2	0,05	0,1
	Oval	1		0,05
Slope Gradient	0 - 8 %	1	0,05	0,05
	8 - 15 %	2		0,1
	15 - 25 %	3		0,15
	25 - 45 %	4		0,2
	>45 %	5		0,25

Land Use	Built-up Area	5	0,4	2
	Lake	1		0,4
	Forest	1		0,4
	Rice Field	4		1,6
	Shrubland	3		1,2
Land Form	Intrusive Igneous Rock Landforms	1	0,3	0,3
	Metamorphic Rock Landforms	1		0,3
	Carbonate/Karst Landforms	1		0,3
	Volcanic Landforms	1		0,3
	Alluvial Plain.	5		1,5
Drainage Density	Seldom	1	0,05	0,05
	Somewhat Rare	2		0,1
	Currently	3		0,15
	Meeting	4		0,2
	Very tight	5		0,25

Source: Processed Researcher, 2026

The five parameter maps are combined through the intersect feature, so that each land unit contains a score value multiplied by the weight of the five parameters at once. These values are summed up to produce the total score of each land unit, which is then classified into three flood hazard classes, namely low, medium, and high, based on the minimum and maximum value intervals. The classification results are displayed with color, green, yellow, and red symbologies, resulting in a flood hazard map of South Batipuh District.

Table 8. Classification of Flood Hazards

Flood Danger Zone	Scoring Value	Area (Ha)	Percentage (%)	Color Symbols
Rendah	0,85 - 0,9	10.851,20 Ha	68 %	
Ssedang	1,95 - 2,85	4.744,37 Ha	30 %	
Tinggi	2,9 - 3,9	473,02 Ha	2 %	

Source: Processed Researcher, 2026

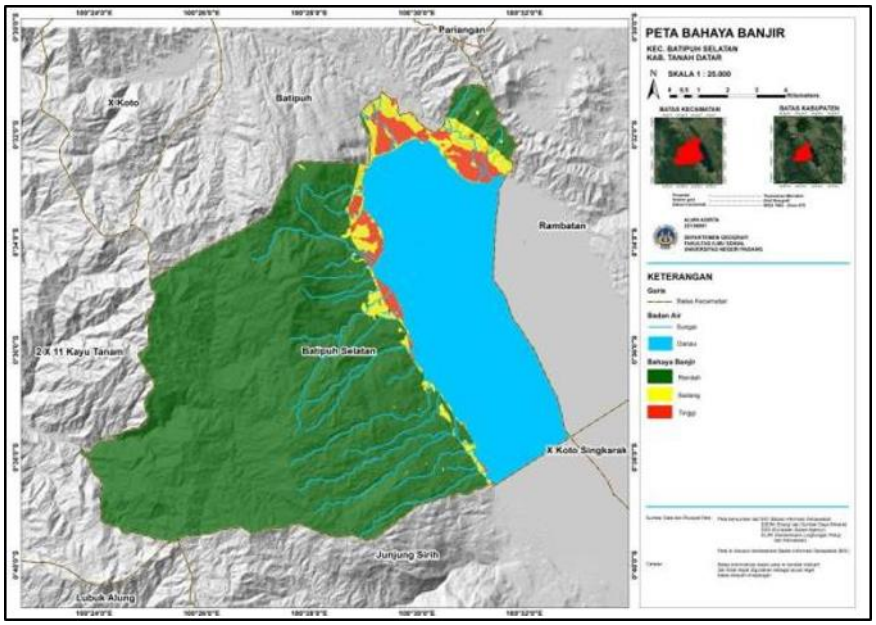

Figure 7. Flood Hazard Map

4.2 Analysis of the Distribution of Flood-Affected Areas on Land Use in South Batipuh District

The flood hazard map alone is not enough to describe the actual impact on the field. This analysis was carried out to find out what types of land use are in each flood hazard class, so that it is clear whether the risk area is in the form of settlements, agricultural land, forests, or water bodies. The flood hazard map from the previous analysis was superimposed on the land use map of South Batipuh District using the intersect technique in ArcGIS. The two maps were first equated with the coordinate system and the boundaries of the area so that the overlapping results were accurate.

In the first stage, the regions in each hazard class are separated into affected and unaffected areas using the Select by Attribute feature. The area of each category is then calculated using Calculate Geometry. The results are presented in Table 9.

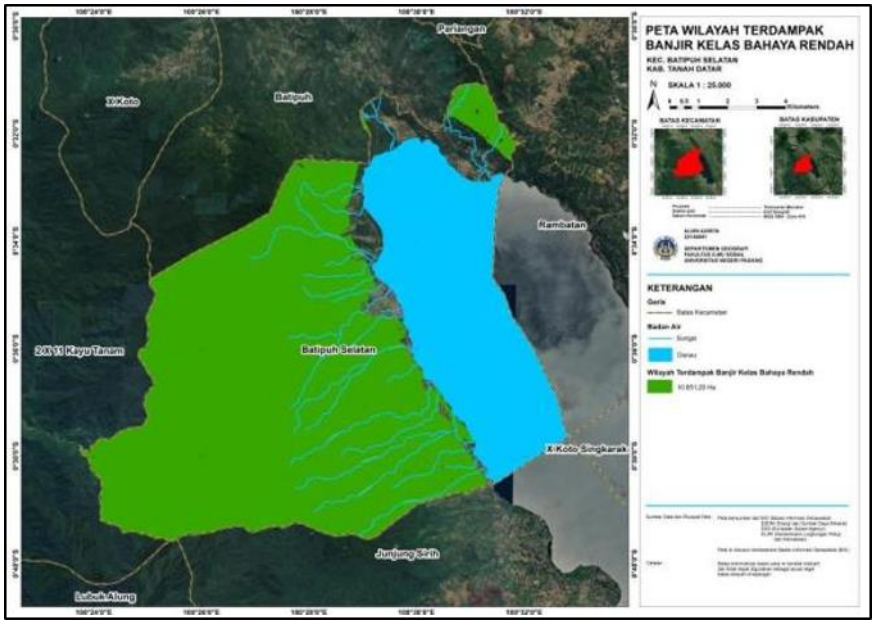

Figure 8. Map of Flood Affected Areas of Low Hazard Class

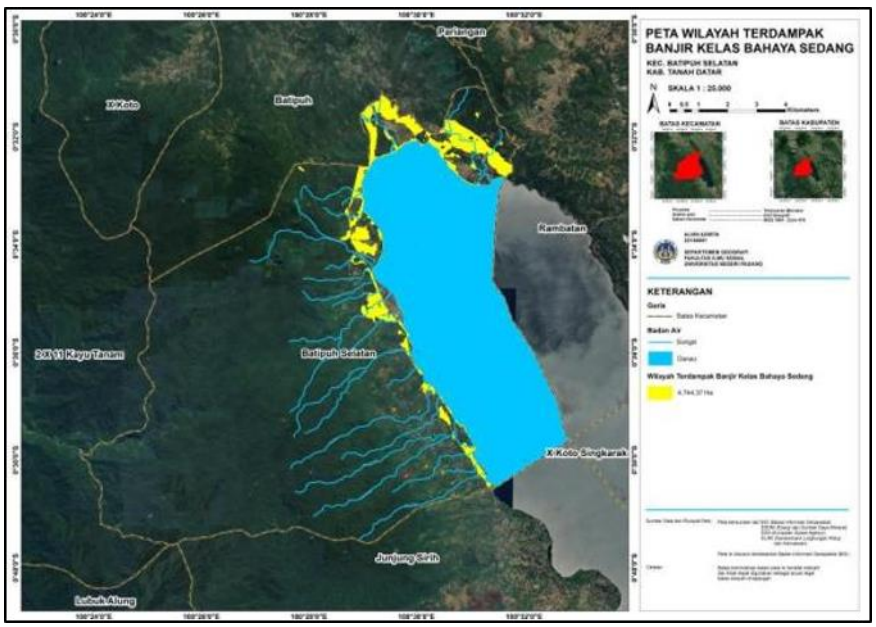

Figure 9. Map of Flood Affected Areas of Medium Hazard Class

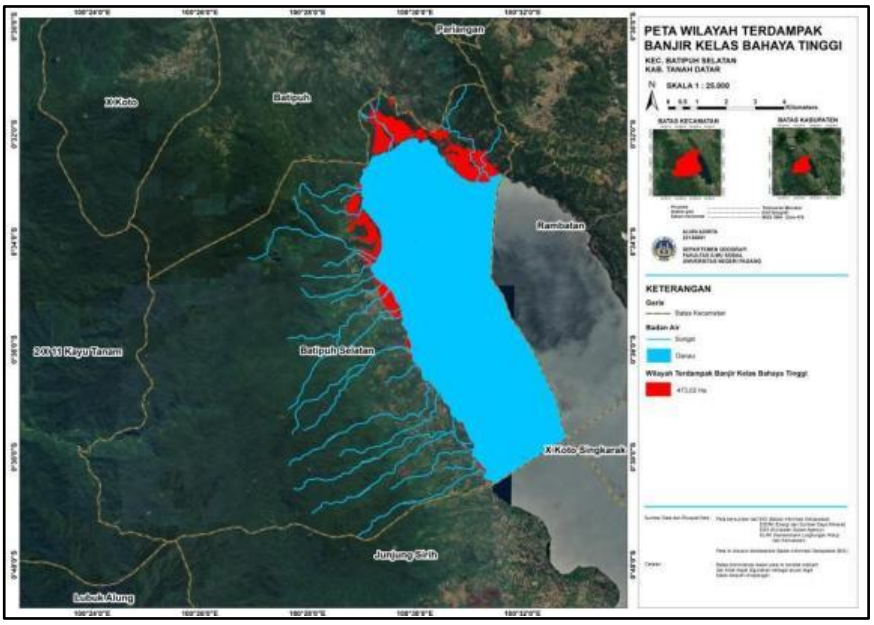

Figure 10. Map of Flood-Affected Areas of High Hazard Class

Table 5 Area of Flood-Affected Areas

Flood Hazard Class	Affected Areas (Ha)	Percentage (%)
Low	10.851,20 Ha	68 %
Medium	4.744,37 Ha	30 %
Height	473,02 Ha	2 %
Total area	**16.068,59 Ha**	**100 %**

Source: Processed Researcher, 2026

The low hazard class has the largest affected area, which is 10,851.20 Ha. The medium class covers 4,744.37 Ha, while the high class is only 473.02 Ha. The area of the high class is indeed the smallest, but this area still needs serious attention because the level of potential danger is the largest.

In the second stage, the flood hazard map and the land use map were recombined through an intersect to find out the type of land use in each hazard class. The combined results were broken down into three maps according to their class, then the area of each type of land use was calculated and converted to percentage. The results are presented in Table 10.

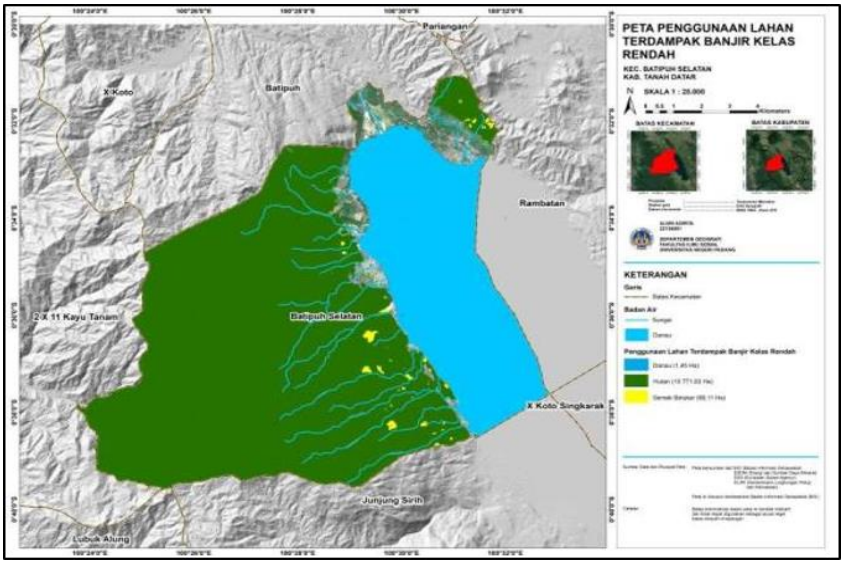

Figure 11. Map of Land Use Affected by Floods Low Hazard Class

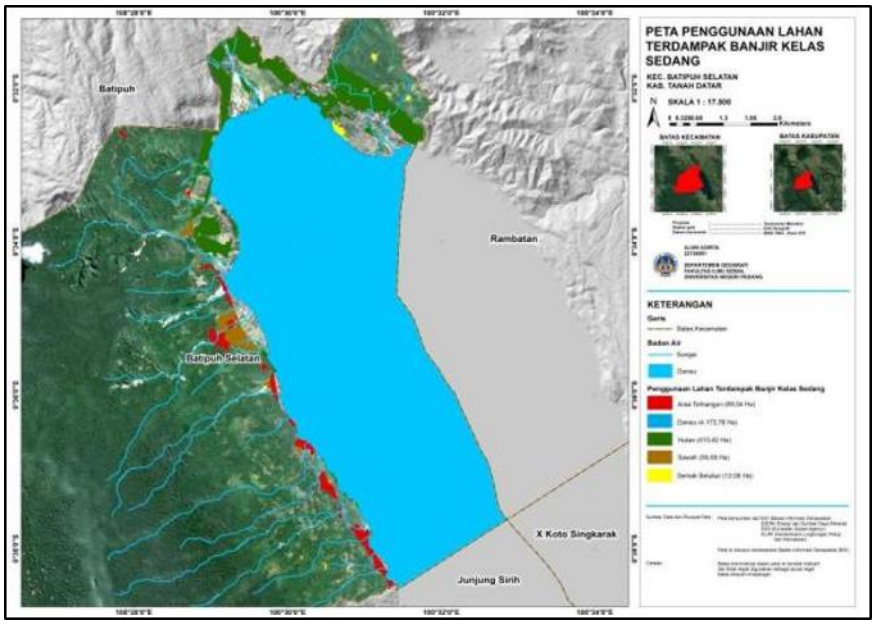

Figure 12. Map of Land Use Affected by Floods Medium Hazard Class

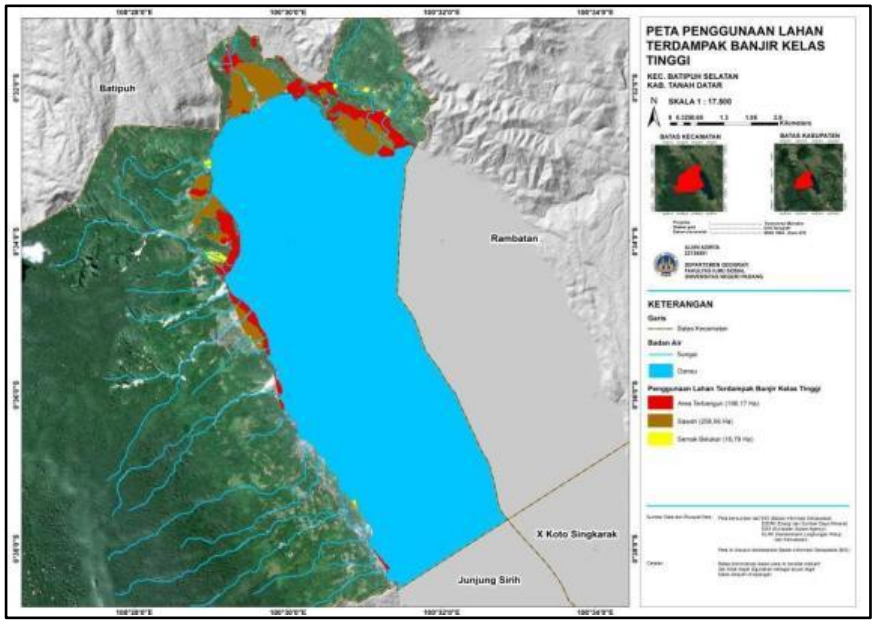

Figure 13. Map of Land Use Affected by High Hazard Class Floods

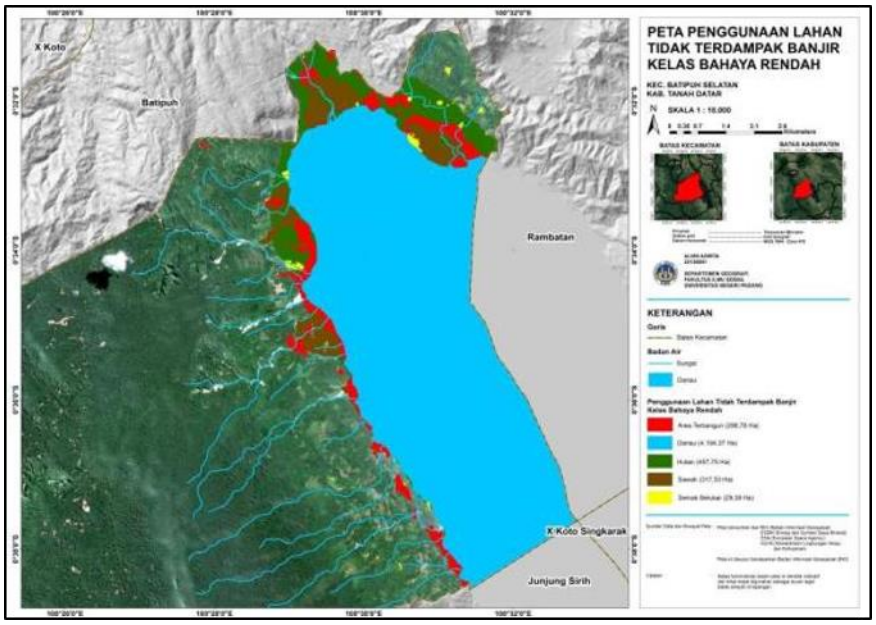

Figure 14. Map of Land Use Not Affected by Flood Low-Hazard Class

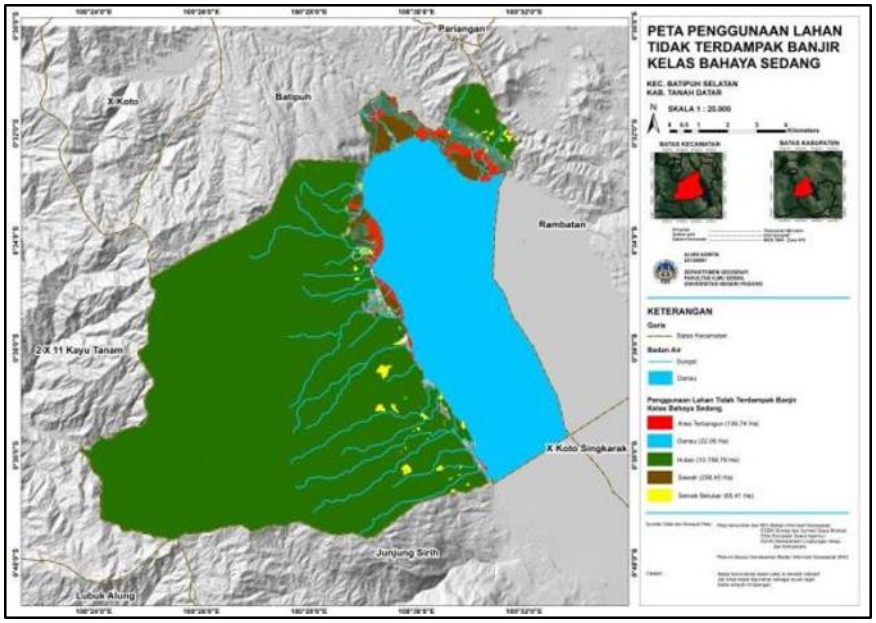

Figure 15. Map of Land Use Not Affected by Flood Medium Hazard Class

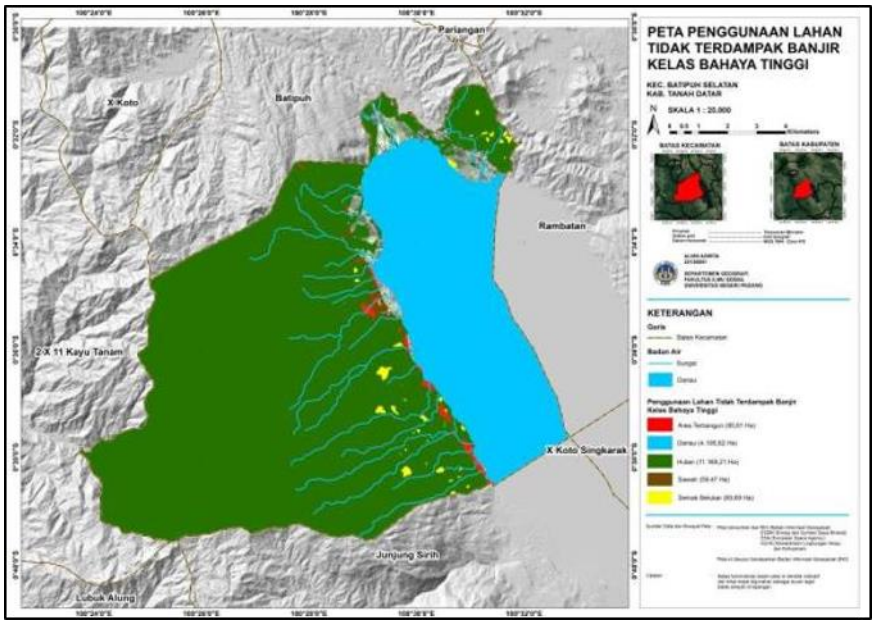

Figure 16. Map of Land Use Not Affected by High Hazard Class Floods

Table 6 Distribution of Affected Land Use Based on Each Flood Hazard Class

Hazard Class	Land Use	Affected by Floods (Ha)	Percentage (%)	Not Affected by Flooding (Ha)	Percentage (%)	Area (Ha)	Percentage of Used Area (%)
Low	Built-up Area	-	0	288,78	1,80	288,78	1,80
	Lake	1,45	0,01	4.194,37	26,10	4.195,82	26,11
	Forest	10.711,47	66,66	457,75	2,85	11.169,22	69,51
	Rice Field	-	0	317,53	1,98	317,53	1,98
	Shrubland	68,11	0,42	29,38	0,18	97,49	0,61
SubTotal		**10.781,03 Ha**	**67,09 %**	**5.287,81 Ha**	**32,91 %**	**16.068,84 Ha**	**100 %**
Medium	Built-up Area	89,04	0,55	199,74	1,24	288,78	1,80
	Lake	4.173,76	25,98	22,06	0,14	4.195,82	26,11
	Forest	410,42	2,55	10.758,79	66,95	11.169,21	69,51
	Rice Field	59,08	0,37	258,45	1,61	317,53	1,98
	Shrubland	12,08	0,08	85,41	0,53	97,49	0,61
SubTotal		**4.744,38 Ha**	**29,53 %**	**11.324,45 Ha**	**70,47 %**	**16.068,83 Ha**	**100 %**
Height	Built-up Area	198,17	1,23	90,61	0,56	288,78	1,80
	Lake	-	0	4.195,82	26,11	4.195,82	26,11
	Forest	-	0	11.169,21	69,51	11.169,21	69,51
	Rice Field	258,06	1,61	59,47	0,37	317,53	1,98
	Shrubland	16,79	0,10	80,69	0,50	97,48	0,61
SubTotal		**473,02 Ha**	**2,94 %**	**15.595,80 Ha**	**97,06 %**	**16.068,82 Ha**	**100 %**

Source: Processed Researcher, 2026

Note: "The small difference in the total area (± 0.25 Ha) is due to the geometric tolerance during the inter-layer overlay process as well as the decimal rounding of the area calculation using GIS software."

In the low danger class, forests dominate the affected areas with an area of 10,711.47 hectares or 66.66 percent of the total study area. This figure far exceeds the area of unaffected forests, which is 457.75 hectares or (2.85%). This condition shows that almost all forest areas are in the safe zone.

Conditions began to shift to the medium danger class. The built-up area began to be affected by 89.04 hectares (0.55%), followed by rice fields covering an area of 59.08 hectares (0.37%). Lake Singkarak dominates this class with an area of 4,173.76 hectares (25.98%), because its shoreline is right on the boundary between low and medium classes.

The most striking change was seen in the high hazard class. Rice fields were the largest land use affected, reaching 258.06 hectares (1.61%), followed by a built-up area of 198.17 hectares (1.23%). In contrast, forests were not recorded to be affected by this class at all (0%). These findings confirm that the higher the flood hazard class, the greater the proportion of built land and rice fields affected, while forests are consistently in safe zones.

CONCLUSION

This study succeeded in mapping the level of flood hazard as well as identifying the most affected types of land use in South Batipuh District, Tanah Datar Regency, using five physical parameters of the area in the Paimin method. The study area is divided into three hazard classes. The low class covers the largest area, which is 10,851.20 hectares or (68%) of the total study area. The medium class covers 4,744.37 hectares or (30%), while the high class is only 473.02 hectares or (2%).

Even though the area is the smallest, the high class still needs to be watched out for because the level of potential danger is the largest.

When the flood hazard map is stacked with the land use map, the results show a clear trend. Forests dominate the low-hazard class with an area of 10,711.47 hectares or (66.66%), so almost all forest areas are in a relatively safe zone. On the other hand, none of the forest areas were recorded to be affected by the high hazard class. In fact, rice fields and built-up areas were most in the most at-risk areas, with an area of 258.06 hectares and 198.17 hectares, respectively. This condition is most noticeable along the shores of Lake Singkarak, especially in Nagari Guguak Malalo and Nagari Padang Laweh Malalo, two areas that were hit by flash floods in November 2025.

This finding confirms one important point. The location of settlements and agricultural land on the shores of the lake is the main factor in flood risk, not just due to high rainfall. Land use even has a large weight in the calculation of the level of flood hazard, so changes in land function around the lake need to be monitored more closely. The Tanah Datar Regency Government and BPBD can use the results of this mapping as a reference in preparing spatial planning, determining evacuation routes, and designing disaster mitigation programs, especially in Nagari Guguak Malalo and Nagari Padang Laweh Malalo. For further research, the addition of rainfall data and hydrological simulations will make the results of flood hazard mapping at the sub-district level more accurate.

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