



Flood Vulnerability Analysis Using Ahp Method in Puwajaya Village, East Kalimantan, Indonesia

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Abstract. The analysis of flood-vulnerability areas in this study uses the help of a Geographic Information System (GIS) where GIS capabilities can be harmonized with remote sensing. This analysis uses five criteria, namely (1) Slope (2) Land Use (3) Distance to River (4) Rainfall (5) Rock Unit. By using three alternative approaches, where Scenario 1 was analyzed with five basic criteria, Scenario 2 was analyzed with 4 basic criteria except rock units, and Scenario 3 was with 4 basic criteria except rainfall. The results of the analysis of all parameters were then compared and weighted using the Analytic Hierarchy Process (AHP) Pair-wise Comparison matrix. The weight value for scenario 1 is 0.278, scenario 2 is 0.436 and scenario 3 is 0.284. The highest scenario is scenario 2 with the weight criteria being 0.53 rainfall, 0.20 land use, 0.14 slope, and 0.13 distance to the river. From the slope analysis, the research area is located in plains (at a slope level of 0–13% to 21–55%). The dominant land use in the research area are forest and ex-mining areas. The closest distance to the river is a distance of <100 m. Rainfall analysis using the Ishoyet method resulted in the distribution of rainfall <13.6 mm which was included in the low category. All analysis results are combined using the Overlay Intersection method in ArcGIS 10.4 to produce a map of flood-vulnerability areas based on the 4 criteria used. It was found that 5% of the research sites is very vulnerable to flood, 25% of the research sites is vulnerable to flood and 10% of the research sites is endangered to flood.

Keywords: Flood · Geographic Information System (GIS) · Analytical Hierarchy Process (AHP) · ArcGIS

1 Introduction

The research took place in Purwajaya Village, Kutai Kertanegara Regency, East Kalimantan Province, Indonesia, an area that often floods in the last two years with its peak on early 2021 when large and long floods occurred. Floods that occur in Indonesia are a combination of natural and anthropogenic factors. The main factor for flooding is rain with high intensity and lasts a long time [1]. As for other factor that contribute to the flood disaster, one of the main factors is weak supervision of land use in flood-vulnerability zones. This shows the low effectiveness of spatial planning instruments in dealing with flooding, as happened in Purwajaya Village, which is a coal-producing area in Kutai

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Kartanegara. Flooding in Purwajaya Village is aggravated along with the increasing mining activities that changes the land form of the area and the river sedimentation [2].

Map of flood-vulnerability areas was created using a combination of Multi-Criteria Decision Making (MCDM). The result of this methodology is a flood risk map that shows the spatial distribution of flood risk along with the level of intensity, from very high to very low risk [3]. This study used the basic concept of AHP (Analytic Hierarchy Process), specifically the pairwise comparison matrix (paired comparison matrix) to produce relative weight values between criteria and alternatives. One criterion was compared to another in terms of how important it is to the achievement of the goal. The main tool of AHP (Analytic Hierarchy Process) is a functional hierarchy with the main input being human perception. This study used a Geographic Information System approach with ArcGIS 10.4 software to find out which alternative greatly affects the occurrence of flooding in the research area, to know the calculation of the weight of the criteria that are the main causes of flooding in the area and finally to know which areas in Purwajaya Village are frequently flooded [4].

2 Methods

2.1 Research Location

The research location is in Purwajaya Village, Loa Janan District, Kutai Kertanegara Regency, East Kalimantan Province. Can be seen in Fig. 1.

2.2 Research Procedures

2.2.1 Analytic Hierarchy Process

The Analytical Hierarchy Process (AHP) method is based on pairwise comparison matrix in forming all priorities to determine the ranking of alternatives consisting of objectives,

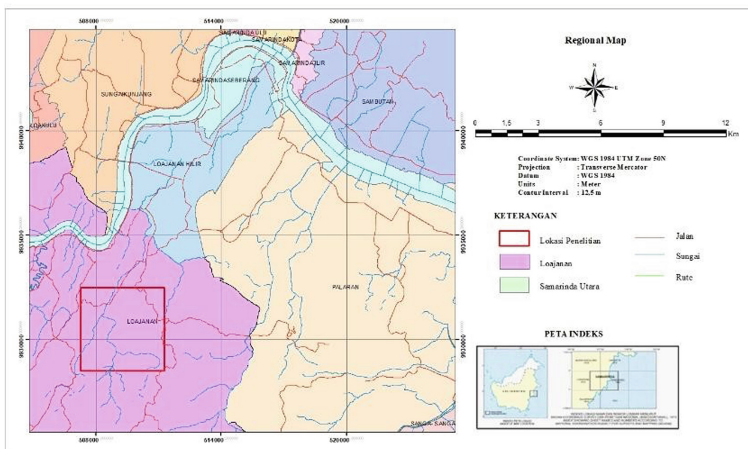


Fig. 1. Map of the area of the study location

criteria, and alternatives [5]. Each criterion and sub-criteria were assessed descriptively-qualitatively to obtain an influence value. The following are the stages in the Analytical Hierarchy Process (AHP) method [6]:

1. Decomposition, a simplified multi-criteria problem in the form of a hierarchy, consists of three main components, namely, objectives, criteria and alternatives.
 - a. Objectives: Flood Vulnerability Area
 - b. Criteria: Rainfall, Flow Distance to River, Land Use, Slope, and Type of Rock.
 - c. Alternatives: Scenario 1, Scenario 2, and Scenario 3.
 - d. These alternatives can be seen in Fig. 2.
2. Hierarchy structure is shown in Fig. 3.
3. Prepare a pairwise comparison table (paired comparison matrix scale) to determine the value of the comparison matrix between criteria.
4. The results of the comparison matrix are then normalized (synthesized) to find the eigenvalues by dividing each individual element by the total number of columns in the comparison matrix.
5. Finding the priority weight value by adding up the rows of eigenvalues then dividing by the number of parameters (n).
6. Testing the comparison ratio between matrices by testing the consistency ratio (CR) with the formula:

$$CR = CI/RI \tag{1}$$

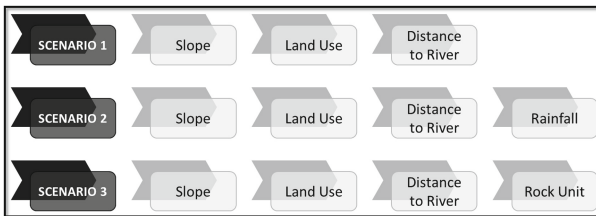


Fig. 2. Three scenarios with different criteria

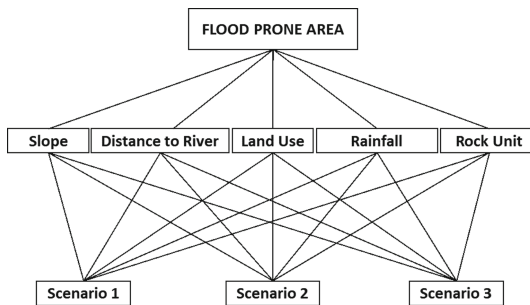


Fig. 3. Research Hierarchy Structure

Table 1. Random Consistency Index (RI)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

$$CI = (\lambda \text{ maks} - n)(n - 1) \quad (2)$$

$$\lambda \text{ maks} = \sum \text{kriteria}/n$$

Where:

CR : Consistency Ratio

RI : Random Index

n : Number of Criteria

The largest eigenvalue is obtained by adding up the results of multiplying the number of columns with the eigenvector. The inconsistency limit is measured using the Consistency Ratio (CR), which is the comparison between the consistency index (CI) and the random generator value (RI). This value depends on the order of the matrix n. Finding the RI value can be seen in Table 1. The Consistency Ratio value can be said to be consistent if the value is less or equal to 0.1 or 10%.

2.2.2 Flood Vulnerability Analysis

According to Kingma (1991), level vulnerability determination can be carried out by dividing the vulnerability values equally by the number of class intervals, which are determined by the following equation:

$$I = \frac{R}{n} \quad (4)$$

Where:

I : Interval width

R : The difference between the maximum value and the minimum value

N : Number of flood susceptibility classes

Areas that are very vulnerability to flooding will have a high total value, and conversely areas that are not vulnerability to flooding will have a low total value.

2.3 Data Analysis

The data collection stage is divided into two: primary data collection and secondary data collection. The primary data obtained are land use, rock types, and information on flood events at the research location. While the secondary data used in this study includes, rainfall measurement data at 3 stations throughout the province of East Kalimantan for

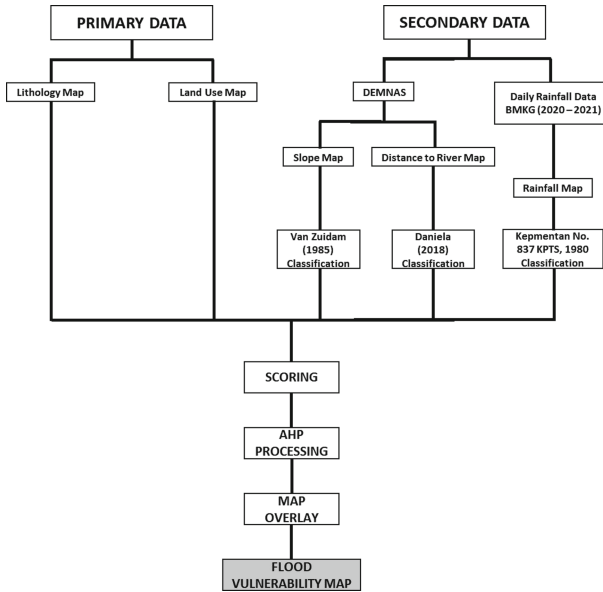


Fig. 4. Data processing stages

2 years from the Meteorology and Geophysics Agency of East Kalimantan Province, Digital Elevation Model (DEM) Map, Indonesian Earth and Administration Map, and Landsat 8 OLI Image Data [7]. A flood hazard map was constructed using a Geographic Information System (GIS). Data processing stages can be seen in Fig. 4.

3 Result and Discussion

3.1 Pairwise Comparison Analysis

In the alternative paired comparison, which was repeated 5 times according to the number of criteria. An example is the comparison between alternative 1 and alternative 2 against the slope criteria and so on [8]. The following are 5 basic criteria and pairwise comparisons of alternatives, so that the closest alternative is obtained for making a map of flood-vulnerability areas. From the pairwise comparison process between the criteria and also the alternative pairwise comparison of the five criteria, it can be concluded that the weights can be seen in Table 2 and Table 3.

Based on Alternative weights in tables above, it can be seen that the priority sequence for the flood-vulnerability area scenario is scenario 2 which consists of basic criteria with additional criteria of rainfall with the weight of the scenario being 0.38755383, scenario 3 which consists of basic criteria with additional criteria for rock units, the weight of the scenario is 0.31807955, and the last is scenario 1 which consists of basic criteria such as slope, distance to the river, and land use with the weight of the scenario being 0.29436662. While the priority order matrix in the table can be concluded that as an evaluation for flood-vulnerability areas, it is scenario 2 that meets the highest priority on the criteria of slope, rainfall, and rock units [9].

Table 2. Priority Sequence Matrix, on the criteria of slope, distance to the river, land use, rainfall, and rock units with scenario 2 as the highest weight

Criteria					
Priority	Slope	Distance to River	Land Use	Rainfall	Rock Unit
1	Scenario 2	Scenario 3	Scenario 3	Scenario 2	Scenario 2
2	Scenario 1	Scenario 2	Scenario 2	Scenario 1	Scenario 3
3	Scenario 3	Scenario 1	Scenario 1	Scenario 3	Scenario 1

Table 3. Alternative Weight Matrix against the criteria of slope, distance to the river, land use, rainfall, and rock units.

	Slope	Distance to River	Land Use	Rainfall	Rock Unit	Alternative Weight
Scenario 1	0,336489614	0,250032702	0,334044462	0,272317174	0,278949151	0,29436662
Scenario 2	0,365197259	0,339498018	0,301111511	0,495090825	0,436871516	0,38755383
Scenario 3	0,298313128	0,41046928	0,364844028	0,232592001	0,284179332	0,31807955

After determining the scenario 2 with the highest weight, the next step would be comparing one criterion with another in a comparison matrix. The criteria in scenario 2 are the slope, land use, distance to the river, and rainfall. The comparison matrix for the AHP process in the research area along with the influence of one criterion to other criteria in scenario 2 is shown in Table 4 and Table 5.

With the maximum principal eigen value (λ_{max}) is 4.110507236, the next step is to determine the consistency index by obtaining a consistency index, it will also obtain a consistency ratio which is the division of the consistency index with the Random Index [10]. The parameter used in this research are 4 parameters and according to the provisions, the Random Index should be 0.90 [11].

$$\begin{aligned} \text{Consistency Index} &= \lambda_{maks} - n/n - 1 \\ &= 4,110507236 - 4/4 - 1 \end{aligned}$$

Table 4. Comparison Matrix of Criteria affecting Flood Vulnerability Areas in Scenario 2, with criteria for slope, distance to the river, land use, and rainfall

	Slope	Distance to River	Land Use	Rainfall
Slope	1	0,866025	0,866025	0,27818
Distance to River	1,154701077	1	0,428013851	0,294348874
Land Use	1,154701077	2,33637299	1	0,288675135
Rainfall	3,594794737	3,397329117	3,464101615	1
TOTAL	6,904196891	7,599727107	5,758140466	1,861204009

Table 5. Normalization of the comparison matrix and determining the priority weight of scenario 2, with the criteria of slope, distance to the river, land use, and rainfall and the highest weight is rainfall

	Slope	Distance to River	Land Use	Rainfall	Weight
Slope	0,144839438	0,11395475	0,150400117	0,14946239	0,139664174
Distance to River	0,167246255	0,131583672	0,074331957	0,15814971	0,132827899
Land Use	0,167246255	0,307428538	0,173667177	0,155101286	0,200860814
Rainfall	0,520668051	0,447033041	0,601600749	0,537286614	0,526647114
TOTAL	1	1	1	1	1

Table 6. Criteria order for flood-vulnerability areas is seen from the priority weights in scenario 2, with the first order being rainfall, then land use, slope and finally the distance to the river.

Result	Criteria	Weight
1	Rainfall	0,526647114
2	Land Use	0,200860814
3	Slope	0,139664174
4	Distance to River	0,132827899

$$= 0,036835745$$

$$\begin{aligned} \text{Consistency Ratio} &= \text{Indeks Konsistensi/Random Indeks} \\ &= 0,036835745/0,90 \\ &= 0,0409286 \\ &= 4\% \end{aligned}$$

From the result above, the consistency ratio test gets a value of 0.03683575 which represents a consistent value from a comparison matrix. The consistency ratio value can be said to be consistent if it has a value of less than 0.1 or 10%. Where the order of criteria in scenario 2 is obtained can be seen in Table 6.

3.2 Data Processing

1. Slope Map

The slope of the study area only includes five classes out of a total of seven classes, namely areas with a slope of 0% to 70%. The assessment of each class is sorted from the class with a gentle slope having the lowest value to the class with a very steep slope having the highest value, as in the research area with grades 5 to 3 which are marked in dark green to easily a flat area that occupies settlements and as well as ex-mining areas. Meanwhile, grades 2 to one, which are marked in yellow and orange, are very sloping to steep areas that occupy forest and hilly areas [12].

Where it can be concluded that the highest class is very influential on flooding. Can be seen in Fig. 5.

2. Distance to River Map

Distance to the river is a factor that also needs to be considered in analyzing flood-vulnerability areas because areas that are very close to the river flow have the potential for higher flooding than areas that are far away from river flows. In the research area, the distance between residential areas and the river is quite close [13]. Besides that, the community also uses the river as a source of water for rice fields and plantations. Where the first high class is the area closest to the river and has the potential for flooding. The fifth class occupies a distance of <100 m from the river marked in blue, the fourth class is 100–300 m from the river, the third class is 300–500 m, the second class is 500–1000 m, and the last is the first class which has the lowest value with a distance of >1000 m. from the river (Fig. 6).

3. Land Use Map

Land use is one of the most important factors in flood-vulnerability areas, where changes in land use could cause changes in flood discharge conditions in watersheds. As a result of land use change, rainwater that falls has more potential to become surface runoff than is absorbed by the ground surface. In this study, land use has the second highest weight after rainfall. In the study area which has 50% forest area, in addition there are areas where the change of land use into mining areas causes a very large flood risk. The land use map of research area can be seen in Fig. 7.

4. Rainfall Map

The rainfall data used is data from the Meteorological & Geophysics Agency using the Ishoyet method from three rainfall stations in East Kalimantan, namely the Temindung Meteorological Station, the Sultan Aji Muhammad Sulaiman Sepinggang Meteorological Station, and the Kalimantan Meteorological Station. Where the annual rainfall data is used at the three rainfall stations. The results obtained in the study area are < 13.5 mm with a very low classification, the following table shows the classification of rainfall. Can be seen in Fig. 8.

3.3 Flood Vulnerability Area Analysis

Based on the results of calculations that have been carried out on five maps that affect flood-vulnerability areas, the total score obtained was in the ranges between 1 as the lowest value and 2.88 as the highest value. Next step is to determine the size of the class interval using the formula [14]:

$$I = \frac{R}{n} \\ = \frac{2,88 - 1}{5} = 0,376$$

Where:

I : Interval Width

R : The difference between the maximum value and the minimum value

n : Number of Flood Vulnerability Class

Classification of Flood Vulnerability for Scenario 2 is presented on Table 7.

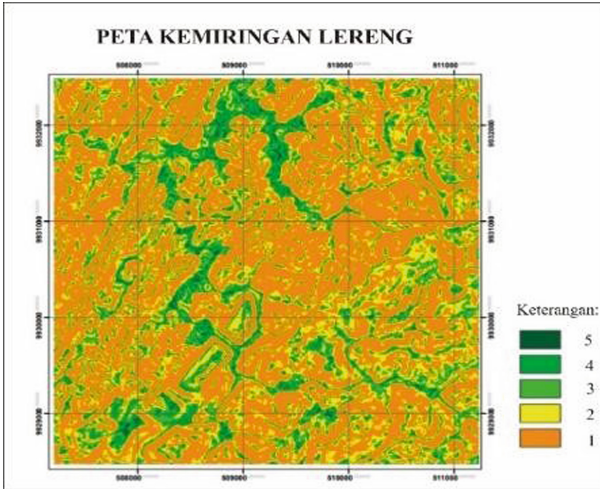


Fig. 5. Slope Map, with five classes. The higher the class, the more the area vulnerability to flooding

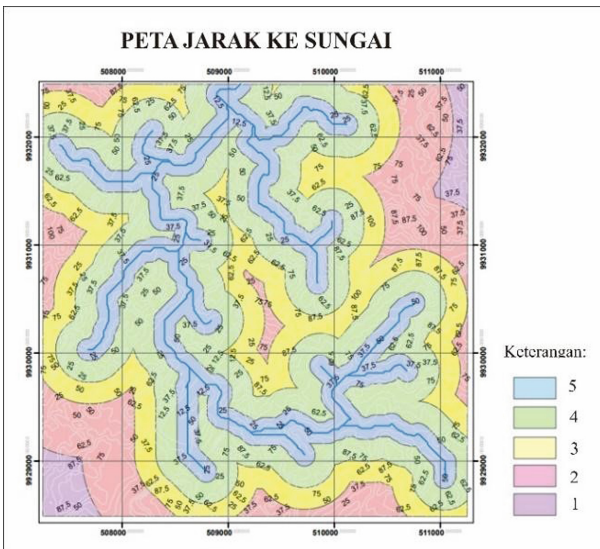


Fig. 6. Distance to River Map with five classes. The higher the class, the more the area vulnerability to flooding

3.4 Flood Vulnerability Area

Based on Scenario 2 with 4 factors that can trigger flooding, of which are slope, land use, distance to river, and rainfall, Flood Vulnerability Area Map was then made with 5 stages of Vulnerability based on Table 7.

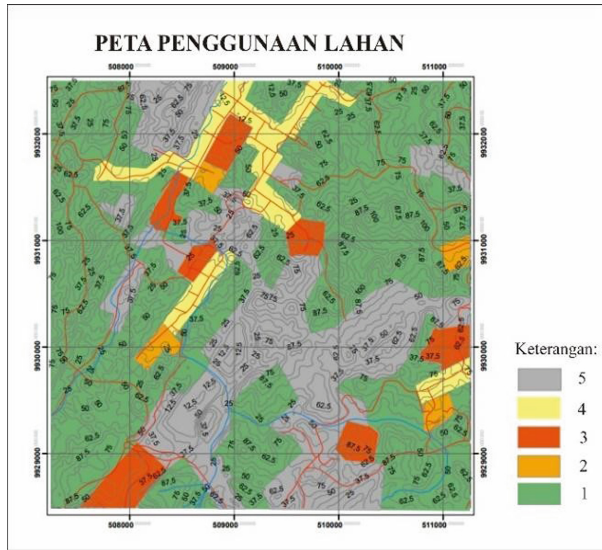


Fig. 7. Land Use Map, with class 5 being mining areas, class 4 settlements, class 3 plantations, class 2 being rice fields, and class 1 being forest areas

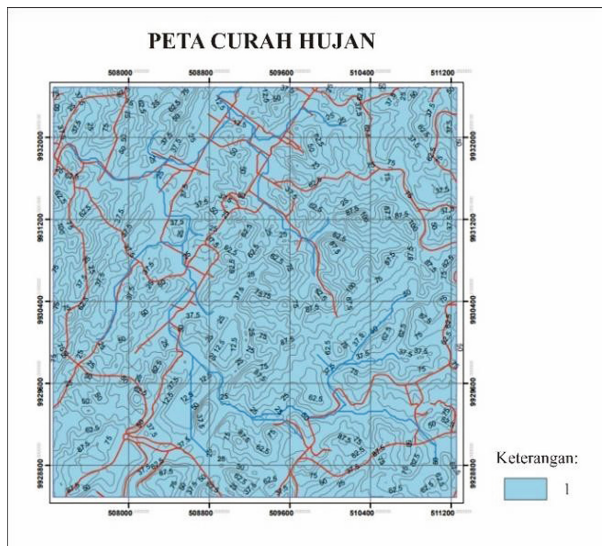


Fig. 8. Rainfall Map, with very low classification with <math>< 13.5</math> mm rainfall

The Most Vulnerable Area as shown on Fig. 9 with 5% coverage area is located within the buffer area from the river/stream and mostly is used as settlement. Area with vulnerability class Safe with 25% coverage area is used as settlement and former mining area. While area with Threatened Class with 10% coverage area is primarily used as

Table 7. Classification of Flood Vulnerability based on Scenario 2 [15]

No	Intersection Class	Vulnerability
1	1–1,38	The Safest
2	1,38–1,75	Safe
3	1,75–2,13	Threatened
4	2,13–2,50	Vulnerable
5	2,50–2,88	The Most Vulnerable

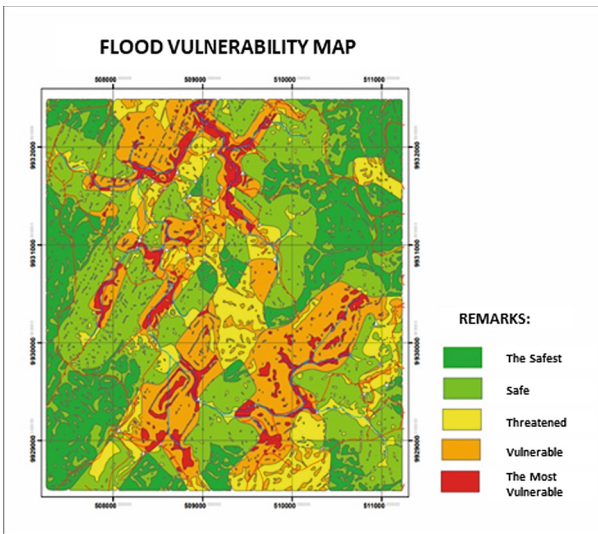


Fig. 9. Flood Vulnerability Map of Purwajaya Village with 5% area of The Most Vulnerable, 25% of Vulnerable, 10% area of Threatened, 35% area of Safe, and 25% area of The Safest

plantation and rice field. This is reasonable because those area has quite decent water infiltration properties due to all the vegetation. Those area are also located outside the buffer from the river/stream. Safe Class with 35% coverage is in dense vegetation area and is located between 500 m–1.000 m distance from the river. The Safest Class has 25% coverage and is also in forest and dense vegetation area with distance from the river between 500 m–1.000 m. The determinant factor of The Safest Class from Safe Class is the slope. The Safest Class has very sloping to steep slope.

3.5 Flood Vulnerability Area Verification

Purwajaya Village has an area approximately 1.500 Ha. This village has 5 Sub-Village (Dusun), of which are Mekar Jaya Hamlet, Sarimulya A Hamlet, Sarimulya B Hamlet, Magamulya Hamlet, and Bangun Sari Hamlet. There are also 5 coal mining concessions in Purwajaya Village and some illegal mining activities within those concessions.

These open-pit mining activities combined with high rainfall and river silting due to sedimentation that make Purwajaya Village vulnerable to flooding.

Based on flood data from Purwajaya Village and interview result from the community, it is to be discovered that flooding occurred in Sarimulya Hamlet, Bangun Sari Hamlet dan Mekar Jaya Hamlet whenever there is high intensity rain, but if the holes from mine-out pits in several mining concessions were not able to hold the rainwater and overflow, then all the Hamlets in Purwajaya Village are flooded [16].

Based on analysis of flood-prone areas carried out using the AHP method and the Geographic Information System approach, there are four points of the Most Vulnerable areas, namely Sarimulya Hamlet, Bangun Sari Hamlet, Margamulya Hamlet, and Mekar Jaya Hamlet. The Eastern side of Margamulya Hamlet is a former mining area and also a mine that is still operating. In the West of Sarimulya Hamlet there are ex-mining activities and small mines that are still operating so that there is a lack of water absorption area and causes sedimentation in the river. Meanwhile, Mekar Jaya Hamlet can be called as the heart of Purwajaya Village which is a place for public services such as village offices, schools, and the main road access to Purwajaya Village. The cause of frequent flooding in this hamlet is the drainage system which is quite small and cannot accommodate rainwater runoff with sufficient intensity [17]. Furthermore, the losses that are often experienced by the community are their houses and their rice fields being submerged. The location of each Hamlets on map is shown on Fig. 10.

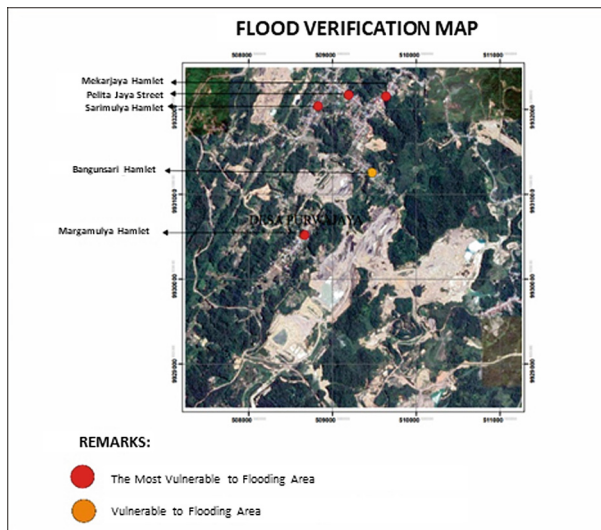


Fig. 10. Flooding verification Map. Red Dot Shows the Most Vulnerable To Flood Area, Orange Dot shows Vulnerable Area to flooding

4 Conclusion

1. The order of priority for the flood-prone area scenario is scenario 2 with a weight of 0.38755383. Based on the priority order matrix, it can be concluded that as an evaluation for flood-prone areas, scenario 2 meets the highest priority on the criteria of slope, rainfall, and rock units.
2. Obtained from a pairwise comparison, the criteria for Scenario 2 is that the Rainfall criterion ranks first in the analysis of flood-vulnerability areas with the highest priority weight of 0.526647114, then in second place is the Land Use criterion with a priority weight of 0.200860814, then, then in the order of the third is the slope with a priority weight of 0.139664174 and the last criterion in determining flood-vulnerability areas is the distance to the river with a priority weight of 0.132827899.
3. The Vulnerable to Flood and The Most Vulnerable to Flood areas are influenced by four criteria, namely the slope of the slopes from sloping to flat which can cause water runoff. Most of the locations are residential and ex-mining areas that are prone to flooding due to lack of vegetation to absorb water, furthermore the distance to the river which also affects where the affected location has a very close distance to the river thus it is affected by surface water runoff. The most important thing is rainfall where all the above criteria can affect flooding if the rainfall is high and long intensity.

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