Flood Vulnerability Analysis on Paddy Fields Using the Spatial Multi-criteria Evaluation Method: A Case Study of Bantul Regency-Indonesia

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Abstract. Bantul Regency is one of the areas with highest agricultural productivity in Yogyakarta Province-Indonesia, particularly for paddy fields. This region is also vulnerable to floods, which has negative impacts on the local community, particularly farmers. This study aims to determine the level of flood vulnerability of paddy fields in the study area. Spatial Multi-Criteria Evaluation (SMCE) method was conducted to determine the priority value of flood vulnerability factors on paddy fields. The parameters used for determining flood vulnerability are rainfall, slope, elevation, land use, geology, soil type, landform, and distance to the river. Based on the results, flood vulnerability in paddy fields was classified into five classifications, namely very low, low, moderate, high, and very high. Almost half of the total paddy fields area is moderately vulnerable (49.78%). Most of the moderately vulnerable area is close to urban areas and had higher precipitation. It also located on a higher elevation than central Bantul. The southeast side (Imogiri Subdistrict) and southwest side (Srandakan, Pandak, and Sanden Subdistricts) of Bantul Regency are categorized as highly vulnerable. Compared to historical flood data, the SMCE modelling show a similarity. Therefore, it can be used as basis for disaster management in the study area.

Keywords: Bantul Regency · Flood · Paddy Fields · Spatial Multi-Criterial Evaluation · Vulnerability

1 Introduction

With an astronomical position on 6 °N to 11 °S and 95 °E to 141 °E, Indonesia is located close to the equator. This geographical setting contributes to the high amount of solar radiation throughout the year. The regional setting of Indonesia as an archipelago also affects the high humidity. Due to the above factors, Indonesia has a humid tropical climate with frequent rainfall. Indonesian Bureau of Statistics publication of Environmental Statistics Indonesia in 2015 (BPS, 2015) showed that in 2011–2015, Indonesia had an average rainfall of 2302.38 mm and an average number of rainy days of 184.39 days

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Table 1. Research Data Sources

Data	Data Sources	Description
Rainfall	Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)	0.05° Resolution Satellite Imagery, 2021
Slope	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021
Elevation	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021
Land Use	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021
Geology	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021
Soil Type	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021
Landform	Regional Development Planning Agency (Bappeda) of Bantul Regency	Scale 1:140.000; 2021

[2]. The high amount of rainfall is suitable for agricultural activities, particularly rice farming.

Flood is considered as a multi-factor disaster. Flood vulnerability can be determined by parameters of rainfall, land use, soil type, and slope [1]. Floods are significantly influenced by rainfall, particularly heavy rainfall. Floods can result from continuous precipitation over an area; the more intense the rain, the greater the likelihood of flooding [11].

Other factors that are related with flooding are land use, soil type, elevation, and slope. The conversion of the natural land cover into built-up land decreases the function of the watershed. Changes in land cover have the potential to cause flooding [5]. Soil influences the possibility of flooding depending on its ability to absorb rainwater. If the soil has a coarse texture, the water will infiltrate faster to the ground due to the higher soil infiltration capacity and permeability compared to fine-textured soils [6].

Additionally, area with low elevation with flat or gentle slopes, are more susceptible to flooding. In contrast, area with steep slopes produce greater velocity than area with gentle slopes.

The study area of this research is Bantul Regency, Special Region of Yogyakarta (DIY). Bantul is a major agriculture area and is the third largest region in the province. This area is one of the areas with highest agricultural productivity. In 2022, the heaviest rainfall occurred in Bantul Regency (BPS, 2022) with the highest number of rainy days in November up to 28 days. Land use in Bantul Regency is dominated by agricultural land covering an area of 27,876 hectares (55.53%), consisting of paddy field (30.25%) and non-paddy field (25.28%) [3].

Floods often occur in several subdistricts of Bantul which caused damage to paddy fields. Paddy fields on the three subdistricts in the southern part flooding, particularly in the event of heavy rains DPPKP, 2020. The paddy fields are in the districts of Sanden, Srandakan and Kretek, with a submerged area of around 10 hectares [13]. The potential impact of flooding on paddy fields, if not addressed immediately, can lead to losses.

Determination the flood-prone areas are necessary in the decision planning of agricultural activities. This research aims to assess the flood sensitivity analysis of paddy fields in Bantul Regency, which has significant role in flood risk management. In detail, the purpose of this study is to determine the flood vulnerability of paddy fields in Bantul Regency.

2 Materials and Methods

2.1 Location of Research Study

Bantul Regency is one of the regencies in the Special Region of Yogyakarta with an area of 506.85 km^2, located in 7.886447 °S 110.327838 °E. Bantul Regency area consists of a flat area in the middle, hilly area in the east and west, and a coastal area in the south. Bantul Regency consists of 17 subdistricts as shown in the administrative map in Fig. 1.

2.2 Research Data Source

This research used government publication data from the Regional Development Planning Agency (Bappeda) of Bantul Regency and the Regional Disaster Management Agency (BPBD) of Bantul Regency. The data include rainfall, slope, elevation, land use, geology, soil type, landform, and distance to the river (Table 1). In addition, flood event data was also utilized to verify the model result with the actual flood events.

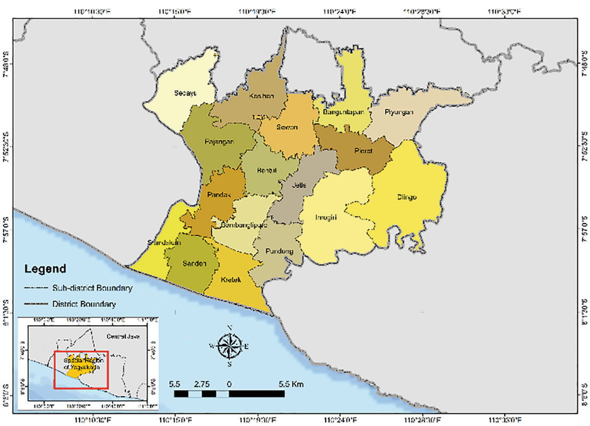

Fig. 1. Bantul Regency Administrative Map

2.3 Data Analysis

Spatial Multi-Criteria Evaluation (SMCE) method was used in this study to determine the factors affecting the flood vulnerability of paddy fields in Bantul Regency. SMCE is a statistical modeling method that combines spatial analysis using Geographic Information System (GIS) and multi-criteria evaluation. The model transforms spatial inputs and produce outputs in the form of decisions [8]. The SMCE use the standardized weights for each of the factor contributes to the flood vulnerability, which is determined using ILWIS (Integrated Land and Water Information System) software. The standardization of weights was determined by compiling the determinants through a pairwise comparison matrix. The value in the pairwise comparison matrix consisted of the lowest value to the highest value. The value represents the level of determinants from less important

Table 2. Distributions of The Main and Class of Sub-Parameters

Main Parameter	Class of Sub-Parameter	Score	Weight
Rainfall	188.25–193.18 mm/month	0.064	0.362
	193.18–196.23 mm/month	0.078	
	196.23–198.12 mm/month	0.110	
	198.12–199.28 mm/month	0.147	
	199.28–200.01 mm/month	0.211	
	200.01–201.18 mm/month	0.371	
	201.18–203.06 mm/month	0.372	
	203.06–206.11 mm/month	0.574	
	206.11–211.04 mm/month	0.779	
	211.04–219.00 mm/month	1.000	
Slope	0–8%	1.000	0.032
	8–15%	0.787	
	15–25%	0.318	
	25–45%	0.155	
	>45%	0.081	
Elevation	0–25 m	1.000	0.044
	25–50 m	0.595	
	50–75 m	0.345	
	75–100 m	0.193	
	100–250 m	0.108	
	250–500 m	0.063	
	>500 m	0.042	

(*continued*)

Table 2. (*continued*)

Main Parameter	Class of Sub-Parameter	Score	Weight
Land Use	Emplacement	0.807	0.125
	Forest Land	0.079	
	Village	0.385	
	Mixed Forest	0.319	
	Bare Land	0.443	
	Coastal	0.050	
	Water Body	0.044	
	Irrigated Rice Field	0.503	
	Rainfed Rice Field	0.395	
	Settlement	1.000	
	Grassland	0.126	
	Shrubs	0.096	
	Pond	0.059	
	Sentolo Formation	0.211	
	Sambipitu Formation	0.055	
	Wonosari Formation	0.088	
Soil Type	Alluvial	1.000	0.136
	Grumusol	0.914	
	Litosol	0.113	
	Mediteran	0.087	
	Regosol	0.312	
Landform	Beach Ridge	0.424	0.072
	Alluvial Plain	1.000	
	Alluvial Plain Coasts	0.620	
	Volcanic Plain	0.861	
	Isolated Structural Hills	0.050	
	Monoklinal Hills	0.200	
	Structural Hills	0.115	
	Karst Hills	0.071	
Distance to River	<100 m	1.000	0.210
	100–200 m	0.464	
	200–300 m	0.208	
	>300 m	0.098	

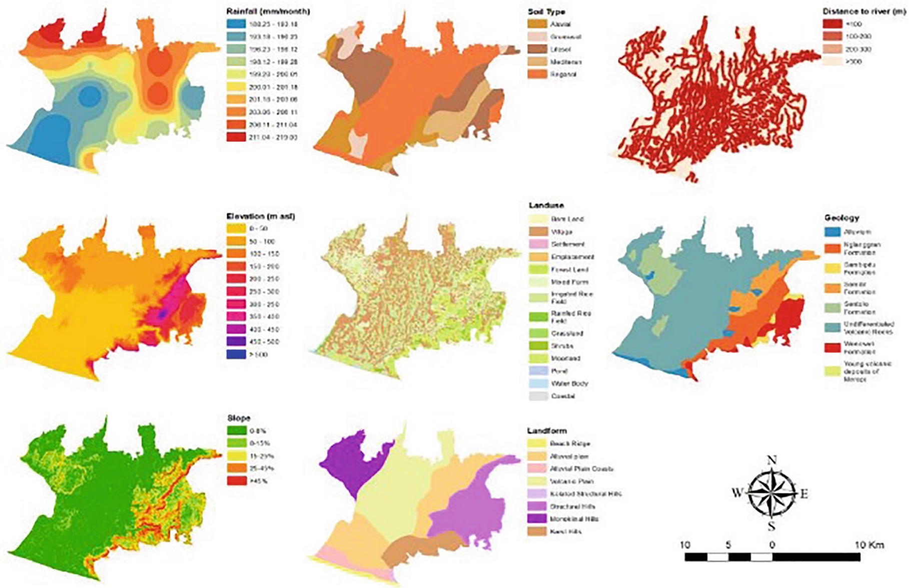

Fig. 2. Distribution of the Main and Sub-Criteria in the Bantul Regency

to much more important. The pairwise comparison matrix generated relative weights between factors was presented in Table 2 (Fig. 2).

3 Result and Discussion

3.1 Flood Vulnerability Analysis in Bantul District

The results showed that the weighting criterion that most affects flood vulnerability in the paddy fields is rainfall. Flooding is caused by precipitation as flood events coincided with high rainfall [12]. The next most important factor is the distance to the river. Flooding in Bantul Regency is caused by the overflow of river discharge. Floods are more likely to occur when a region is close to a river since the closer a region is to river, the greater the chance of flooding [7]. The next factors from the more important to less important are soil type, land use, formation, elevation, slope, and geology, respectively. The weight of each parameter is multiplied by scoring to describe the spatial distribution of floods.

The spatial distribution of flood vulnerability in Bantul Regency shows that there is a varying level of vulnerability in each subdistrict. Based on the results in Table 3, the districts that are least prone to flooding in Bantul Regency is Dlingo Subdistrict. On the other hand, Sedayu Subdistrict has the largest flood-prone area, (281.71 ha), followed by Banguntapan and Piyungan.

Based on Fig. 3 and Table 2, there are 5 classifications of the level of vulnerability. The analysis of flood vulnerability overlayed with paddy fields data showed that the very low vulnerability area occupies only a small part, which is 2.04% of the overall paddy fields. The low-level vulnerability covers 26.34% of the area. The area associated with

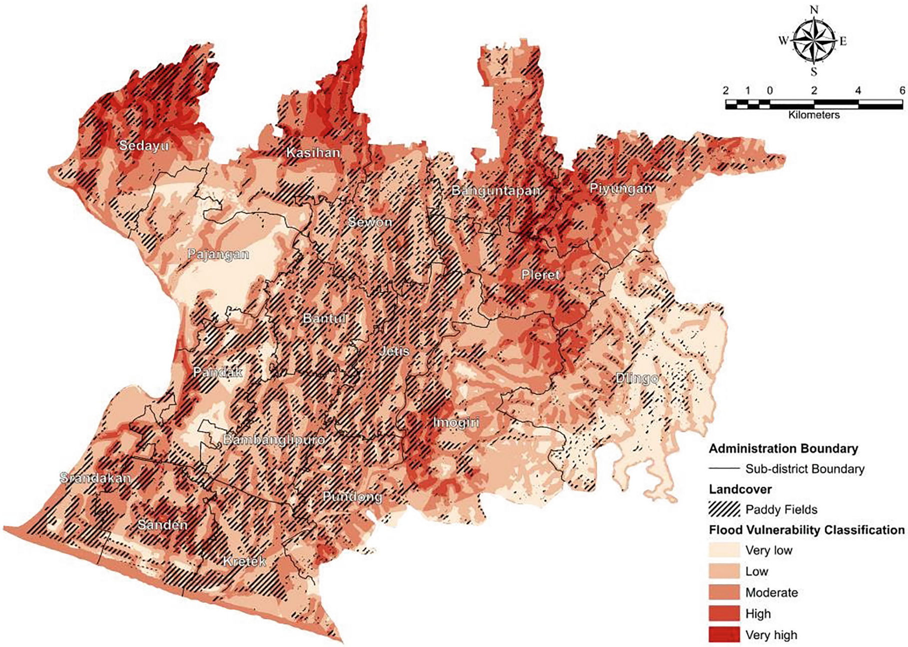

Fig. 3. Flood Vulnerability on Paddy Fields Utilization in Bantul Regency

moderate vulnerability reaches 49.78% of the total area. The area of high vulnerability, when combined with very high vulnerability, reached 21.83% of the total area. Areas with high and very high vulnerability must be prioritized in disaster management [14].

Figure 3 shows that paddy fields dominate the central part of Bantul Regency, where the level of flood vulnerability is mostly low to moderate. The central Bantul Regency area is a fluviovolcanic plain. This area consists of alluvium material and regosol-type soil. The soil is fertile and contains a high nutrient potential compared to the other type of soil, and highly suitable for agricultural activities [9]. The East and West sides of Bantul Regency have less paddy fields because it is an area with a steeper hilly topography and a higher elevation compared to the central part. This condition affects the flood vulnerability, which are more resistant to flooding. The east and west side of Bantul Regency consist of structural hills, namely the Baturagung Hills on the East side and the Sentolo Hills on the West side. This condition marks the difference in the soil material as well.

The highest level of vulnerability found in the northern part of Bantul Regency. The area intersects with Sedayu, Kasihan, Banguntapan, Piyungan, and Pleret Subdistrict. It is known that the northern part of Bantul Regency is directly adjacent to Yogyakarta City, so the paddy fields are not as much as the rural area in the central and southern parts. This is associated with the land use which is dominated by built-up land as it is close to urban areas. Built-up land can reduce rainwater infiltration due to impermeable land, thereby increasing the potential for flooding [15]. In addition, this area has higher precipitation which means that the flooding potential is also bigger.

Table 3. Distribution of Flood Vulnerability in the Rice Fields by Subdistrict in Bantul Regency

Subdistrict	Rice Fields Area Classified by Flood Vulnerability				
	Very Low (Ha)	Low (Ha)	Moderate (Ha)	High (Ha)	Very High (Ha)
Bambanglipuro	0.06	344.2	662.11	0	0
Bantul	2.09	227.22	803.97	0	0
Pajangan	0	88.5	109.36	9.45	0
Jetis	0.02	294.69	901.77	10.59	0
Kretek	0.52	378.79	568.02	32.69	0
Kasihan	1.28	84.88	227.46	180.39	62.35
Sewon	0	593.89	575.77	29.06	0
Pundong	18.14	248.39	694.33	18.7	0
Pandak	28.08	379.55	369.8	545.57	0
Srandakan	3.68	213.56	307.03	80.42	0
Sedayu	0	93.81	189.09	373.65	281.71
Sanden	2.76	180.28	427.06	386.88	0
Dlingo	237.71	348.57	167.35	27.77	0
Banguntapan	0	99.89	426.91	318.42	134.57
Piyungan	0.25	49.81	523.91	189.05	106.05
Pleret	0	171.44	260.87	271.96	31.62
Imogiri	16.01	204.98	348.94	225.96	0.02
Total Area (ha)	310.60	4002.45	7563.75	2700.56	616.32
Percentage	2.04%	26.34%	49.78%	17.77%	4.06%

Area with high vulnerability is also found on the Southeast and Southwest sides of Bantul District. Imogiri Subdistrict, which is on the Southeast side, and Srandakan, Pandak, and Sanden Districts on the Southwest side of Bantul Regency are prone to flooding because it is a downstream area. Floods are particularly resulting from the water accumulation from the upstream. This area is more vulnerable to flooding because it forms a basin surrounded by hills. The hilly slope can accelerate the runoff which causes flooding in the lower areas [4]. Large amounts of runoff coming from higher area into the lower area resulted in water overflowing into paddy fields, and even into residential areas.

3.2 Comparison of Flood Vulnerability Modeling with Flood Events

To determine the accuracy of the model, a comparison with the actual flood events was made. The comparison was made based on a flood event map for each subdistrict in Bantul Regency. The flood events were classified using the standard deviation of

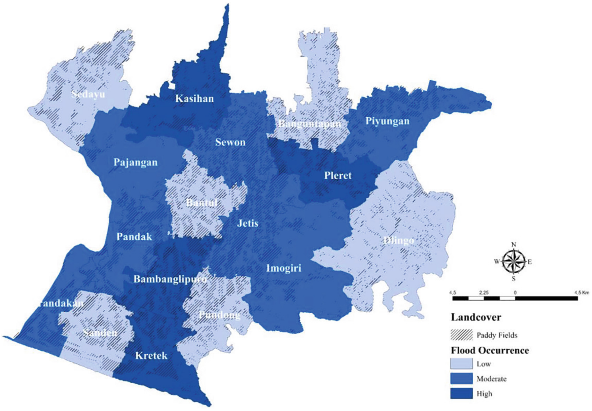

Fig. 4. Flood Occurrence in the Bantul Regency

the number of flood events in each subdistrict. The three classifications were obtained according to the Fig. 4.

Based on the actual flood event (2011–2019) map in Fig. 4 and the flood vulnerability map in Fig. 3, several differences have been identified. For example, in Bambanglipuro and Kretek Subdistricts, both subdistricts were characterized by frequent flood events. However, the flood hazard modeling showed that the two subdistricts are classified as areas with low to moderate vulnerability.

The modeling was less accurate because there was a slight difference with the existing flood events. The simplification in the modelling process is supposed to be the source of the difference, so that the model cannot be precisely similar to the actual condition [10]. Another factor that affects the accuracy is the data used in the modeling. A more accurate model can be constructed by improving the validity and the resolution of the data.

4 Conclusion

Based on the results, the level of flood vulnerability in Bantul Regency varies from very low to very high. Almost half of the total paddy field area in the regency has a moderate vulnerability (49.78%). The highest level of vulnerability was identified in the northern part of the study area, particularly in Sedayu, Kasihan, Banguntapan, Piyungan, and Pleret Subdistrict. This area was dominated by built-up land close to urban areas and has higher precipitation. This means that the precipitation water converted to runoff that causes flooding is also higher. To measure the accuracy of the model, validation was carried out using a chronological archive of flood events. The modeling results indicate that both data were similar and can be used in disaster risk management in the future.

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