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FLOOD HAZARD MAPPING BASED ON MULTI-CRITERIA SPATIAL ANALYSIS IN THE SAMIN WATERSHED, INDONESIA

Sofyan Sholeh[1]*, Chatarina Muryani[2], Suryanto[1]
[1]Department of Environmental Science, Universitas Sebelas Maret, Indonesia
[2]Department Geography Education, Universitas Sebelas Maret, Indonesia

*E-mail: sholehsofyan@gmail.com

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ABSTRACT

The Samin watershed which is located in the Mount Lawu area is vulnerable to flood disasters due to human activities. This research was carried out by inventorying parameter data to create a flood disaster vulnerability map using a GIS-based multi-criteria spatial approach. The seven parameters used in flood disaster analysis are Elevation, Slope, Distance from River, Drainage density, Topographic Wetness Index (TWI), Landuse, Rainfall, Type of Soil, Geology. The weight of each parameter is determined using the Analytical Hierarchy Process (AHP) which has the driving factors for flood disasters. The flood hazard map was obtained using a weighted overlay method and grouped into five classes, namely very low, low, medium, high and very high. The results of the analysis show that 11.36% of the study area has a very low hazard, 27.10% has a low hazard, 39.57% has a medium hazard, 20.43% has a high hazard and 1.54% has a very high hazard.

Keywords: *Flood; AHP; GIS; Samin watershed*

INTRODUCTION

Floods are one of the most destructive natural disasters and cause injuries and deaths, major infrastructure damage, major economic losses and social disruption throughout the world (Razavi Termeh et al., 2018; Rosser et al., 2017). The increase in flooding has increased over the past few years in several countries due to climate change, environmental degradation caused by rapid urbanization and inappropriate land use management (Caruso, 2017; Kundzewicz et al., 2014; Mostofi Zadeh et al., 2020; Sholeh & Yusup, 2023).

During the rainy season, rainfall with high intensity and shorter duration exceeds the capacity of the existing drainage system and often causes flooding, especially in urban or suburban areas. Even though flood disasters cannot be prevented, implementing appropriate management strategies can help reduce damage so that identifying flood-prone zones becomes the main aspect in flood disaster mitigation strategies (Bubeck et al., 2012). Remote sensing techniques are very useful in various aspects of environmental studies. Flood hazard mapping has been carried out using remote sensing and GIS data by many studies throughout the world and produces benefits with high accuracy (Mudashiru et al., 2021; Tehrany et al., 2014). Effective flood disaster management needs to emphasize geographic location and emphasize the socio-economic aspects of communities between upstream and downstream (Kazakis et al., 2015). Budiarti et al (2017)has carried out research related to flood disasters in the Samin watershed. The novelty of this research is related to the use of more detailed parameters and the use of AHP which plays the role of expert knowledge for mapping flood areas.

The Samin watershed in the upper reaches of the Solo River has an area of more than 32,457.76 hectares which passes through 2 districts, namely Karanganyar Regency and Sukoharjo Regency. The Samin watershed is a rain-fed river in its upstream area. This catchment area has 3 different physiographic categories (a) altitude areas >724 meters above sea level with steep – very steep topography (b) undulating topography 181 – 724 meters above sea level and (c) lowlands <181 meters above sea level with slopes <20. In terms of climatology, the research area experiences a humid tropical climate with the average annual rainfall distribution showing variations of 2572 - 3466 mm with maximum rainfall in the monsoon season.

The Samin watershed in the upstream area is experiencing massive changes in land use from open green land to built-up land. The factor of changes in land use due to the activities of the community, the majority of whom have their livelihoods in the service sector such as accommodation, restaurants, etc. This results in an increase in the amount of water flowing to downstream areas, resulting in increased flooding in the downstream areas of the Samin watershed. The aim of this research is to provide knowledge regarding areas that have high to very high levels of vulnerability, so that people are able to anticipate flood disasters. Apart from that, regional governance/planning in development prioritizes disaster factors in the policies implemented by the government.

MATERIALS AND METHODS

This research was conducted in the Samin River watershed (see **Figure 1**). The Samin watershed is a rain-fed river that is located upstream. This research uses the AHP method. The AHP method is a multi-objective and multi-criteria decision making approach (T. Saaty, 1980; T. Saaty & Vargas, 2012). This helps in decision making to find the thing that best suits the objectives and understanding of the problem and analysis of Flood hazard.

In this process, implementation can be carried out through several steps as follows: developing a hierarchical structure for each criterion factor, comparing criteria against objectives, establishing a comparative assessment matrix, calculating priorities, assigning random index (AI) values, calculating λmax, calculating coherence index (CI) , calculating the coherence ratio (RC), creating a parameter table, determining sub-parameters in relation to the number of criteria studied, establishing a comparison table of sub-criteria, determining the relative value performance of each criterion, calculating aggregation, establishing alternative comparisons, determining the relative value performance of each alternatively by reporting the aggregation, calculating the final aggregation and stating the final decision.

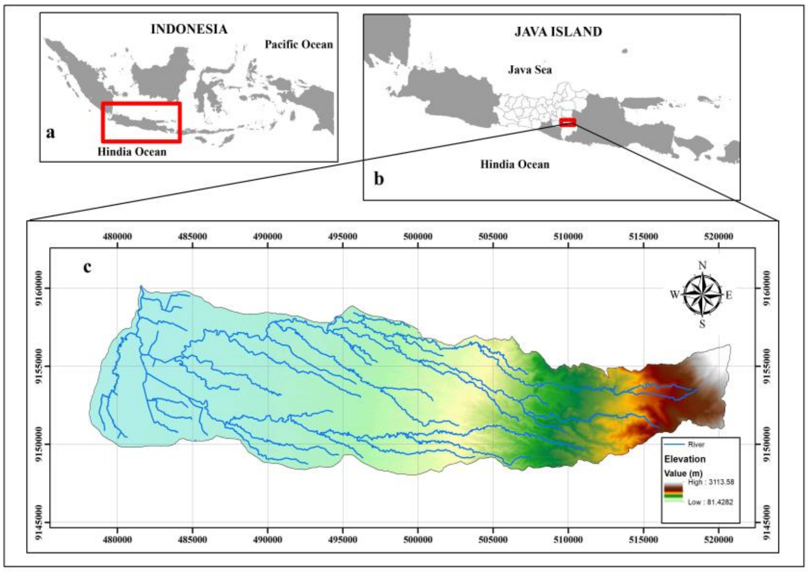

Figure 1. Research Location

The Samin watershed in the upstream area is experiencing massive changes in land use from open green land to built-up land. The factor of changes in land use due to the activities of the community, the majority of whom have their livelihoods in the service sector such as accommodation, restaurants, etc. This results in an increase in the amount of water flowing to downstream areas, resulting in increased flooding in the downstream areas of the Samin watershed

The main data collection in the research was collected from various sources (**Table 1**) and analyzed from a spatial database. For each flood parameter map, classification is then carried out (Kazakis et al., 2015; Razavi Termeh et al., 2018). All the resulting layers are then combined using factor and sub-factor weights determined by the AHP method to produce a flood hazard map. All parameter layers are then integrated into the GIS system using a combination of the AHP method. Distance factors to the distance from river were calculated using the Euclidean Distance Tools in Arcgiss 10.8. Meanwhile, land use was obtained through analysis of Landsat 8 OLI imagery on 11/10/2023 which had radiometric and atmospheric corrections carried out. Factors related to topography such as slope are obtained from National Digital Elevation Model (DEMNas) analysis.

Table 1. Sources of research data

Data	Information	Sources
Landsat 8 OLI	Downloaded	https://earthexplorer.usgs.gov/
DEMNas	Downloaded	https://tanahair.indonesia.go.id/
Elevation	DEMNas	DEMNas
Slope	DEMNas	DEMNas
Topographic Wetness Index (TWI)	DEMNas	DEMNas
Landuse	Landsat 8 OLI and Observation	https://earthexplorer.usgs.gov/ and observation
Tipe of Soil	Soil	Center for Agricultural Land Resources Research and Development
Distance from River	Extracted River Data	Geospatial Information Agency
Drainage density	Extracted River Data	Geospatial Information Agency
Rainfall	Extracted	Meteorology Climatology and Geophysics Council
Geology	Geological Map Digitization 1: 100,000	Geological Map of Ponorogo Sheet 1: 100,000
Flood Location	The location of the flooding points in the study area	Observation

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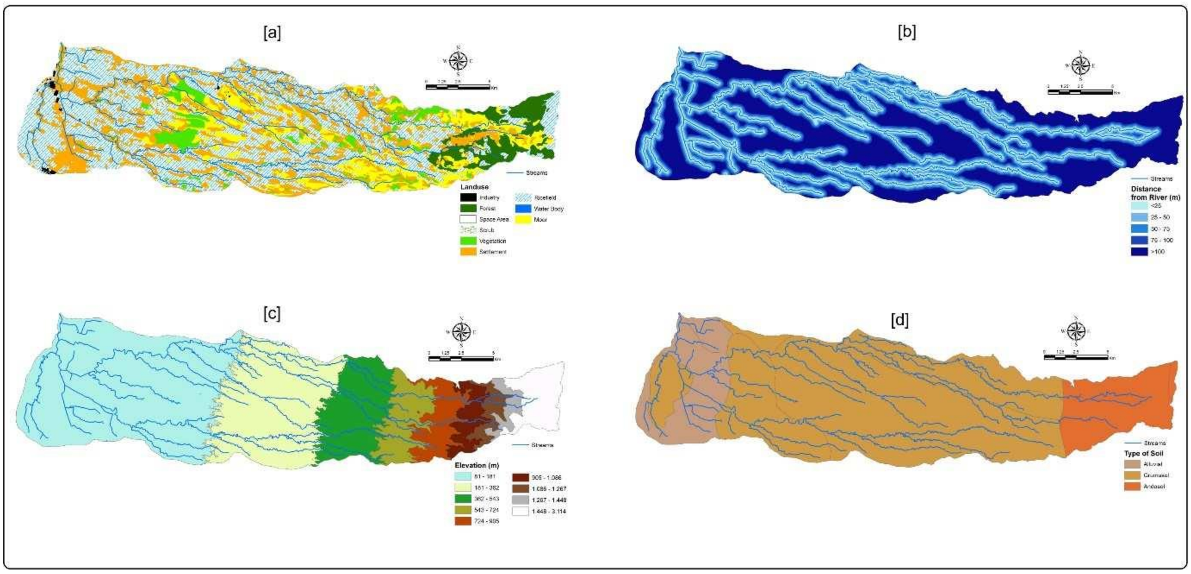

Figure 2. Flood Hazard Factor [a] Landuse, [b] Distance from River, [c] Elevation, [d] Tipe of Soil.

To determine inconsistencies in the comparison of each criterion of the analysis, a hierarchical classification approach is carried out, where this approach also makes it possible to check the coherence of the approach by calculating the consistency ratio (CR) which is expressed by the following equation (1).

$$CR = \frac{CI}{RI} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

This formula shows that RI is a random consistency index and CI is a consistency index which is expressed as equation (2).

$$CI = \frac{\lambda maks}{n-1} \dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$

λmax is the eigenvalue of the matrix and n is the order of the matrix. According to (T. Saaty & Vargas, 2012), the coherence ratio must be ≤10%. The principle compares decisions with random weighting of elements. The last is the acquisitive nature of the weights integrated into various classes of causes in the flood vulnerability index using equation (3).

$$FH = \sum_{i-1}^{n} R_1 * W_1 \dots\dots\dots\dots\dots\dots\dots(3)$$

Where FH is the vulnerability to flood disasters, Ri is the class rating of each factor and Wi is the weight of each factor that conditions flood disasters.

The resulting flood hazard map is classified into five classes, namely very low, low, medium, high, very high) using equation (4)

$$IK = \frac{t-r}{n} \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

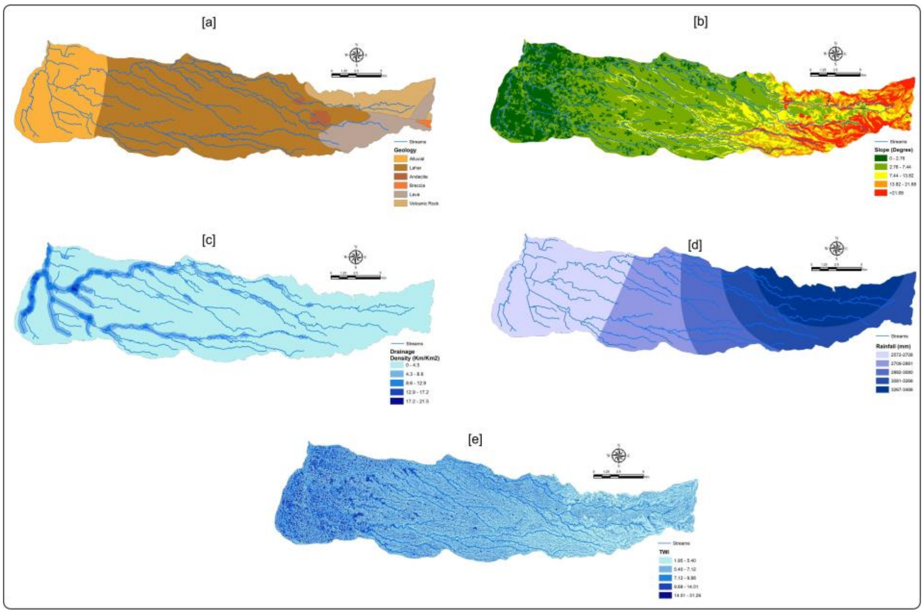

Figure 3. Flood Hazard Factor [a] Geology, [b] Slope, [c] Drinage Density, [d] Rainfall, and [e] TWI

Table 2. Scale

Value	Definition	Information
1	Equally Important	Both elements are very important
3	A Little More Matters	One element is somewhat more important than the second element
5	Obviously more important	One element is more important than the second element
7	It's clearly more important	One element is more important than the second element
9	Definitely/Absolutely is more important	One element is absolutely more important than the second
2,4,6,8	If in doubt between two adjacent values	Values between two adjacent values

Source: (T. Saaty & Vargas, 2012)

RESULTS AND DISCUSSION

In this research, GIS-based AHP is used as a multi-criteria approach to identify potential flood disaster events in the Samin watershed. The seven parameters in determining hazards are Elevation, Slope, Distance from River, Drainage density, Topographic Wetness Index (TWI), Landuse, Rainfall, Type of Soil, Geology.

Table 3. Comparison matrix and main eigenvectors

Parameter	E	S	Dr	Dd	TWI	L	R	TS	G
Elevation (E)	1								
Slope (S)	2	1							
Distance from River (Dr)	1	1/2	1						
Drainage density (Dd)	1/3	1/3	1/2	1					
TWI	1/6	1/6	1/5	1/6	1				
Landuse (L)	1/9	1/9	1/7	1/7	1/5	1			
Rainfall (R)	1/7	1/8	1/7	1/6	2	4	1		
Type of Soil (TS)	1/3	1/4	1/3	1/2	3	7	5	1	
Geology (G)	1/4	1/5	1/4	1/2	2	5	4	1/2	1

As shown in tables 3 and 4, the pairwise comparison matrices for relative parameters and sub-parameters were processed based on the Saaty method (T. Saaty & Vargas, 2012). CR is calculated for all parameters and the calculation results must be less than 0.10, which means the weights are distributed appropriately and reliably. As a result, flood hazard maps can be produced in GIS. Based on the analysis results shown in table 5, very low, low and medium hazards have a percentage of 24.19%, 13.11% and 37.98% respectively. while the high and very high dangers are 13.02% and 11.70% respectively.

Validation of the results of the flood disaster vulnerability map was carried out by cross-checking data on flood disaster events by observing in the field using Global Positioning System (GPS) (Entin Hidayah, et al., 2021) and using social media such as news media. The news media is able to provide real information through pictures and videos of coverage, so this research is very accurate in mapping flood disaster vulnerability (Kankanamge et al., 2020).

Hazard zone that have a high - very high level of vulnerability are in the middle and downstream parts of the watershed. Areas with high to very high food hazard zones are distinguished by low slope, lower elevation, low rainfall density, and proximity to rivers, all of which are significant conditioning variables on the ping of the flood hazard map. There are very low to low food hazard zones, which are mainly located along the upper reaches of watersheds and vary by their steep slopes, higher elevations and low rainfall density.

Table 4. Parameter weights using the AHP pairwise matrix

Factor	Sub-factor	Score	Weight	Factor	Sub-factor	Score	Weight
	81 - 181	0,31		Landuse	Industry	0,13	0,02
	181 - 362	0,22			Forest	0,02	
	362 - 543	0,15			Space Area	0,05	
	543 - 724	0,11			Scrub	0,07	
Elevation	724 - 905	0,08	0,20		Vegetation	0,04	
	905 - 1086	0,05			Settlement	0,06	
	1086 - 1267	0,04			Ricefield	0,17	
	1267 - 1448	0,03			Water Body	0,43	
	1448 - 3114	0,02			Moor	0,04	
	0 - 2.76	0,50		Rainfall	2572 - 2708	0,50	0,03
	2.76 - 7.44	0,26			2709 - 2881	0,26	
Slope	7.44 - 13.84	0,13	0,27		2882 - 3080	0,13	
	13.84 - 21.68	0,07			3081 - 3266	0,07	
	>21.68	0,03			3267 - 3466	0,03	
	<100	0,50		Geology	Alluvial	0,50	0,06
	100 - 200	0,26			Lahar	0,21	
Distance from River	200 - 300	0,13	0,18		Andecite	0,13	
	300 - 400	0,07			Breccia	0,08	
	>400	0,03			Lava	0,05	
	17.2 - 21.5	0,50			Volcanic Rock	0,03	
Drainage density	12.9 - 17.2	0,26	0,12	Type of Soil	Alluvial	0,72	0,09
	8.6 - 12.9	0,13			Grumusol	0,22	
	4.3 - 8.6	0,07			Andosol	0,06	
	0 - 4.3	0,03					
	1.95 - 5.40	0,50					
	5.40 - 7.12	0,26					
Topographic Wetness Index	7.12 - 9.88	0,13	0,04				
	9.88 - 14.01	0,07					
	14.01 - 31.26	0,03					

Source: Research Analysis, 2023

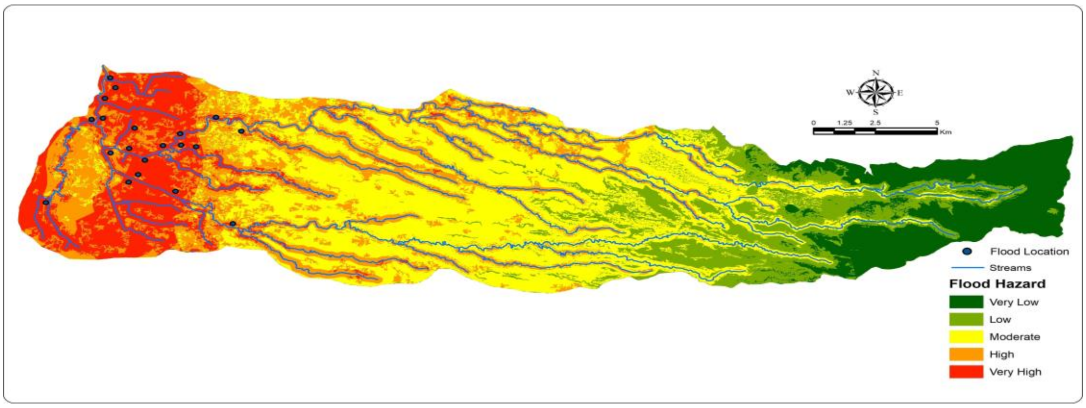

Figure 4. Flood Hazard Map based on AHP

Based on the results of the analysis, land use in the upstream area greatly influences surface flow discharge. The upstream area which should have been a rainwater catchment area has instead become a built-up area (Atharinafi & Wijaya, 2021; Sajikumar & Remya, 2015; Sonu et al., 2022). Falling water cannot experience infiltration but experiences run off. This is also exacerbated by very high rainfall in the upstream area (Sholeh & Yusup, 2023). Apart from that, areas that have high vulnerability are in areas on the outskirts of the main river, this occurs due to the results of river overflows which provide high weight (Mardikaningsih et al., 2017; Perdana et. al, 2019).

Table 5. Flood Hazard Class

Hazard Classes	Area (Ha)	Area (%)
High	7851,98	24,19
Low	4255,24	13,11
Moderate	12325,97	37,98
Very High	4225,69	13,02
Very Low	3798,87	11,70
Total	**32457,76**	**100**

Source: Research Analysis, 2023

CONCLUSIONS

Recognizing areas and mapping flood hazards that are at risk of flood disasters is an obligation for institutions and researchers. Flood vulnerability analysis can be carried out if data related to causal parameters can be analyzed using the AHP method. Flood disasters in the Samin watershed can occur due to the geology and geomorphology of the study area.

Apart from that, community activities such as the conversion of green open land in upstream areas are triggers for increased flooding. Regional planning against flooding is a policy that must be implemented in the study area, both downstream and upstream.

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