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Flood Vulnerability Analysis of The Bengawan Solo Watershed with Overlay Method in Sukoharjo Regency, Central Java Province: The Utilization of Mass Media to Flood Reporting

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ABSTRACT

This study is aiming to (1) provide mapping spatial area of the flood vulnerability and (2) analysis regarding level the flood vulnerability in Sukoharjo Regency, Central Java with accuracy assessment, (3) mapping the frequency of flood from by mass media report. The method used is an overlay analysis with a scoring every variable. The main software utilized is ArcMap 10.82. The base map data used is the Indonesian Topographic Map at a 1:25.000 scale, supplemented by secondary data such as rainfall, soil types, slope gradient, elevation, land use, and river buffer zones. Data were obtained from various government institution and previous research. Slope gradient and elevation were derived from processed Digital Elevation Model (DEM) data, while soil types were obtained from GeoMap. River buffer zones were obtained from data provided by Ina-Geoportal and manual geospatial processing. Land use data were also sourced from Ina-Geoportal. The scoring process refers to previous research. The results of this study are as follows: flood vulnerability mapping classified 31% of Sukoharjo Regency as high, 37% as moderate, and 32% as low vulnerability, with Sukoharjo, Mojolaban, and Grogol sub-districts exhibiting the greatest at-risk areas. Accuracy assessment against 16 historical flood locations yielded a precision of 75%, recall of 65%, F_1-score of 72.9%, and overall accuracy of 75%.

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1. INTRODUCTION

The phenomenon of flooding has become a critical issue for regions traversed by rivers. The incidence of flooding in a particular area is influenced by the complex interactions between biophysical components within a watershed (Marfai, 2012). The watershed plays a significant role in the occurrence of floods. Flooding is a disaster that disrupts human life, manifesting as water inundation, ranging from minor to major scales, caused by both natural and human factors. Floods occur when water flow exceeds the river's capacity, leading to the overflow of water onto lower-lying land (Setiawan *et al.,* 2020). There are many causes of flood disaster in the regions that traversed by the watershed. The reduced capacity of rivers due to sedimentation can lead to the inability to contain excessive rainfall, resulting in flooding (Devianto *et al.*, 2017). Other hand, the characteristics of a watershed are crucial in determining the flood vulnerability level of an area (Raharjo, 2021).

Bengawan Solo has a river length of around 600 kilometers; around 75% of the Bengawan Solo watershed area is located in the lowlands; and the slope of the river bed only ranges from 0.01% to 0.0001% (Sari and Krestanto, 2015). The Bengawan Solo River frequently encounters issues in every regency it passes through, affecting the river's quality (Rustinsyah *et al.*, 2021). The characteristics of the watershed, such as area, slope gradient, and river density, significantly contribute to the flood vulnerability in the region (Azizah *et al.*, 2021).

According to a report by the United Nations Office for Disaster Risk Reduction (UNDRR) covering 1998-2017, floods are one of the types of disasters that often occur throughout the world, and tend to cause the highest number of fatalities compared to other disasters. Data from Badan Nasional Penanggulangan Bencana (BNPB) show that flood disasters have increased quite significantly in 5 years (2016-2021) throughout Indonesia. This means that flood incidents have increased in the last few decades.

Flood disaster, in Sukoharjo Regency, has been an ongoing problem for the past several years. At the end of 2020, several areas in Grogol and Mojolaban Sub Districts experienced flooding (Firdaus, 2020). By early 2021, Grogol, Mojolaban, and Polokarto Sub Districts were still affected by floods (Hamdani, 2021). At the end of 2022, four sub districts—Grogol, Mojolaban, Weru, and Baki—experienced flooding (Putra, 2022). In early 2023, five sub districts were affected by floods, impacting a total of 16,484 people (BPBD Sukoharjo, 2023). In the last three years, the intensity of flooding in Sukoharjo Regency has often occurred. Several areas that were submerged in floods were also passed by the Bengawan Solo River.

Sukoharjo Regency is one of the areas traversed by the Bengawan Solo River. This research is located in Sukoharjo Regency, Central Java Province, Indonesia. The approach used is the overlay approach which is then used to rate and weight each existing variable such as rainfall, slope, elevation, soil type, and land use. Another important variable that will be used for the Bengawan Solo Watershed analysis is the river buffer. Rate and weighting use literature studies or previous research that has tested the standards of each parameter used.

Area of this research focused on Sukoharjo Regency, employing an overlay analysis approach with scoring and weighting applied to various variables. The research use the main parameter similar with previous study, such as rainfall, slope gradient, elevation, soil type, buffered river, and land use (Syafitri *et al.,* 2024). Additionally, an important data of this research is variable for analyzing the Bengawan Solo Watershed of the river buffer zone. The scoring and weighting processes are based on previous studies that have established standards for each parameter used (Pradipta. 2018). The media report utilization is used for data validation, which would be visualized by disaster intensity in any sub district in the 5 years before.

The aims of this research is to find out geographical information mapping spatial area distribution of flood vulnerability with three levels (high, moderate, and low) in each district, Sukoharjo Regency,

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Jawa Tengah Province. In addition, an objective is to find out the results of data parameters for the output model with divided by two segment which is measuring with the assessment accuracy. In other objective, mapping the vulnerability distribution with visualized from the current issue from media mass in the 5 last year. The results of this research can serve as a basis for policy decisions regarding regional development and expansion with current model. The analysis outcomes can be utilized in future research, particularly on flooding in Sukoharjo. Furthermore, the findings can inform disaster mitigation strategies, exactly for flood-prone areas along the Bengawan Solo River.

2. METHODS

2.1 The Source of Literature and Data

2.1.1 Tools and Materials

This study utilizes the Rupabumi Indonesia Map (RBI) or Indonesian Topographic Map downloaded from Ina-Geoportal at a scale of 1:25,000. Precipitation, soil type, slope gradient, elevation, land use, and river buffer zones were used as secondary data. Slope gradient and elevation were obtained from Digital Elevation Model (DEM) data, and soil type was obtained from GeoMap. Precipitation data were obtained from public sources provided by the Balai Badan Wilayah Sungai Bengawan Solo for annual precipitation from 2021 to 2023. Land use data was obtained from Ina Geoportal. The buffer zone of the Bengawan Solo River was obtained from the Indonesian Topographic Map (RBI) and subsequently processed by geoprocessing. **Tables 1** and **2.**

Table 1. Materials Research

No.	Data	Source
1.	Boundaries of Administration Sukoharjo	Ina-Geoportal
2.	The Bengawan Solo River	Ina-Geoportal
3.	Land use	Ina-Geoportal
4.	Elevation	DEMNAS
5.	Slope Gradient	DEMNAS
6.	Rainfall	BBWS-Bengawan Solo Year of 2021-2023
7.	Buffered River	Ina-Geoportal
8.	Soil Type	ESDM GEOMAP

Tabel 2. Tools Research

No.	Tools	Specification
1.	Laptop	Acer with 3 Different-Type
2.	ArcGIS Desktop	Version 10.82

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2.1.2 Flow Chart of Research

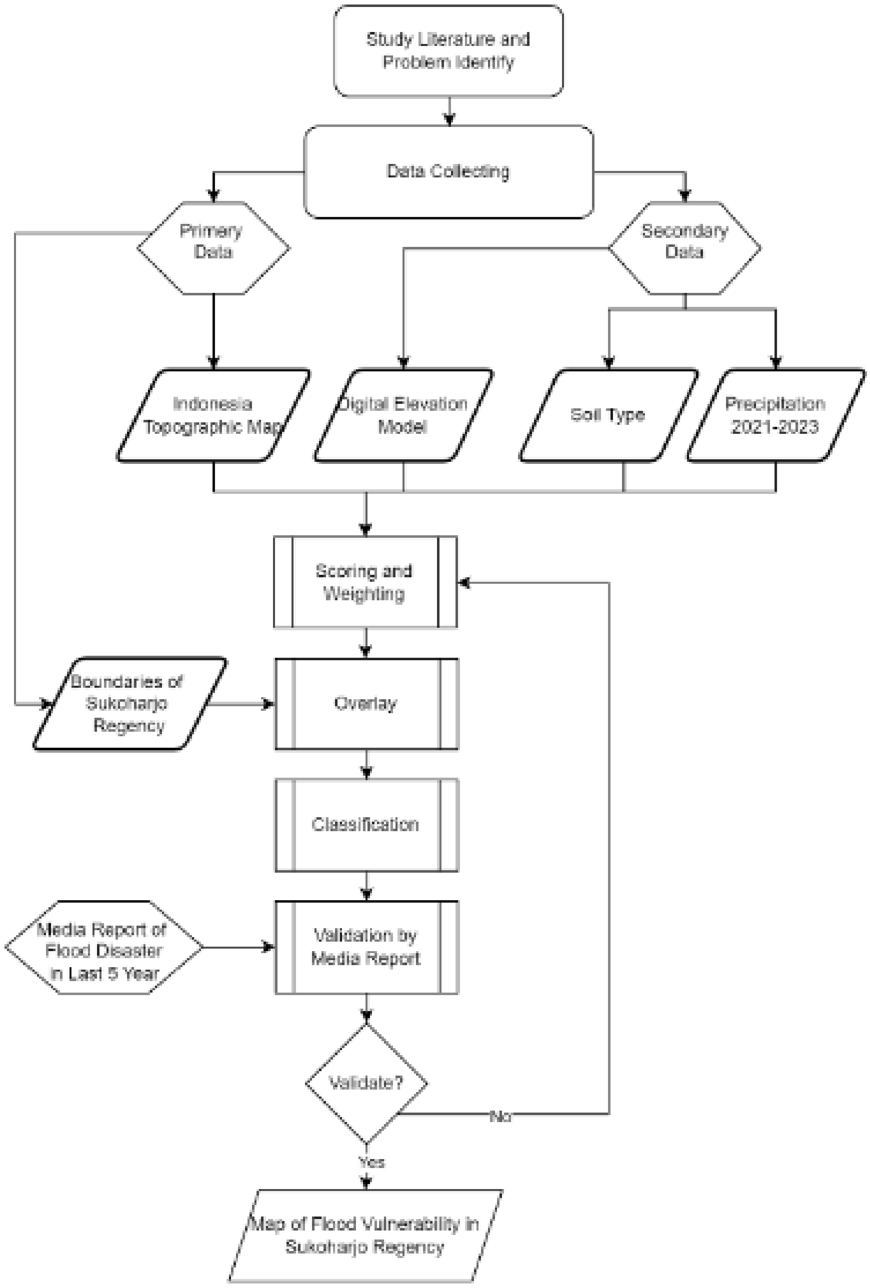

Figure 1. Flow Chart of Research

2.1.3 Study Area

Sukoharjo is one of the regencies in Central Java Province. The study was conducted in Sukoharjo Regency, Central Java Province. Geographically, Sukoharjo Regency is located at the coordinates 110° 57' 33.70" - 110° 42" 6.79" E - 7° 32' 17.00" - 7° 49" 32.00" S. Sukoharjo Regency, as part of Central Java, is administratively bordered by six regency, such in the north by Surakarta City and Karanganyar Regency, in the east by Karanganyar Regency, in the south by Gunung Kidul Regency (Yogyakarta Special Region) and Wonogiri Regency, and in the west by Boyolali and Klaten Regency.

Sukoharjo comprises 12 Sub Districts, namely Kartasura, Baki, Gatak, Grogol, Mojolaban, Bulu, Bendosari, Nguter, Polokarto, Sukoharjo, Tawangsari, and Weru. The whole of location can bee seen by **Figure 2** and **3.**

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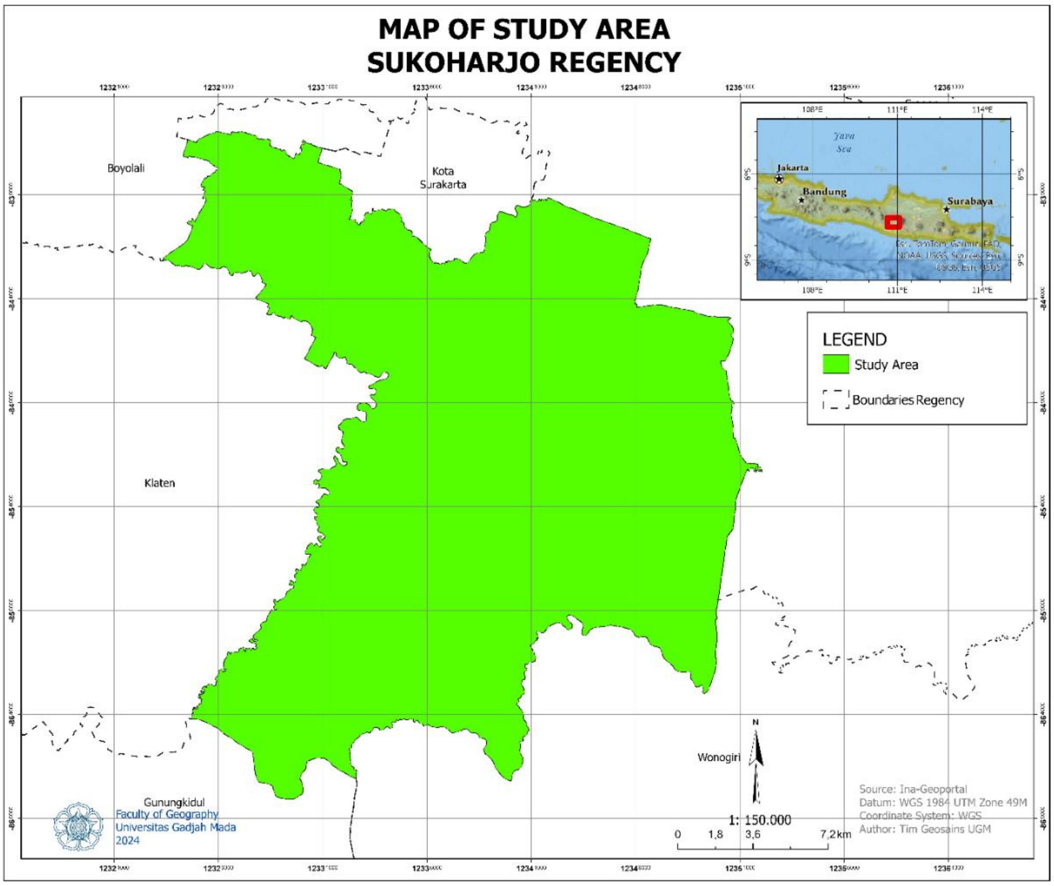

Figure 2. Study Area of Sukoharjo Regency

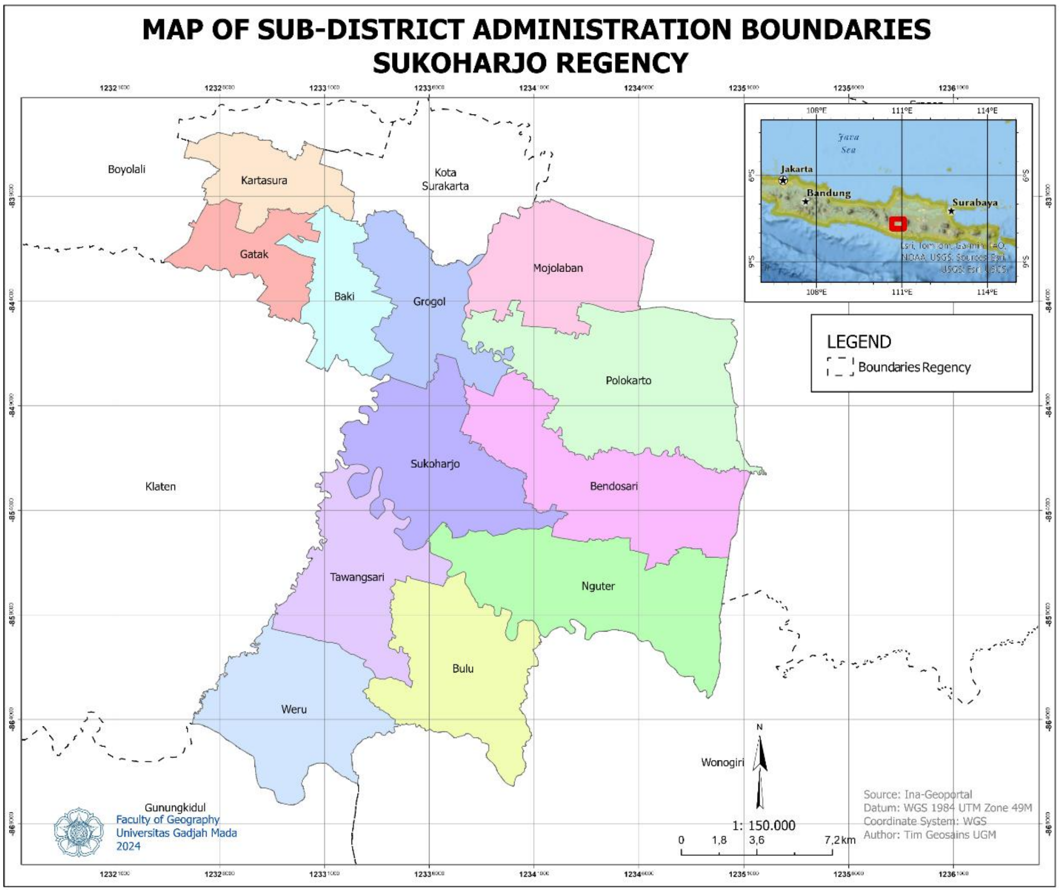

Figure 3. The Boundaries of Administration Sukoharjo Sub District

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2.1.4 Parameter of Flood Vulnerability (Scoring and Weighting)

The scoring and weighting process involves assigning numerical values. The higher the score and weight, the greater the influence of the variable on flood vulnerability. Conversely, if the scores and weights are low, the impact of the variable on flood vulnerability is minimal. The scoring process is based on previous literature. The details of the scoring and weighting can be seen in the following **Table 3 - 8** :

a) Precipitation

Tabel 3. Classification of Precipitation

No.	Precipitation (mm)	Description	Score	Weighting
1.	<1500	Very Light	1	
2.	1500 - 2000	Light	3	
3.	2001 - 2500	Moderate	5	15
4.	2501- 3000	Heavy	7	
5.	>3000	Very Heavy	9	

Source: (Sitorus *et. al.* 2021) with modification

b) Soil Type

Tabel 4. Classification of Soil Type

No.	Soil Type	Score	Infiltration	Weighting
1.	Regosol, Lithosol, Organosol	1	Highly Sensitive	
2.	Andosol	3	Sensitive	
3.	Brown Forest Soil, Mediterranian Soil	5	Moderately Sensitive	10
4.	Latosol	7	Insensitive	
5.	Alluvial	9	Highly Insensitive	

Source : (Darmawan *et. al.* 2017) with modification. (Indonesian Classify Soil)

c) Slope Gradient

Table 5. Classification of Slope Gradient

No	Slope Gradient (%)	Score	Description	Weighting
1.	>45%	1	Very Steep	
2.	26-45%	3	Steep	
3.	16-25%	5	Moderately Steep	10
4.	8-15%	7	Gentle	
5.	<8%	9	Flat	

Source : (Darmawan *et. al.* 2017) with modification

d) Elevation

Table 6. Classification of Elevation

No.	Elevation (MASL)	Score	Weighting
1.	>200	1	
2.	101-200	3	
3.	51-100	5	20
4.	10-50	7	
5.	<10	9	

Source : (Darmawan *et. al.* 2017) with modification

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e) Land Use

Table 7. Classification of Land use

No.	Land Use	Score	Weighting
1.	Forest	1	
2.	Shrubland, Plantation, Grassland	3	
3.	Cultivated Land/Field	5	25
4.	Settlement, Rice Field	7	
5.	Waterbody	9	

Source: (Kusumo and Nursari, 2016) with modification

f) River Buffer

Tabel 8. Classification of River Buffer

No.	Distance (m)	Score	Weighting
1.	> 100	1	
2.	76-100	3	
3.	51-75	5	20
4.	26-50	7	
5.	0-25	9	

Source : (Kusumo and Nursari, 2016) with modification

2.1.5 Weighting and Classification of Flood Vulnerability

This study references previous literature. The flood vulnerability weighting has been relied on in several studies that focus on watersheds. Since this research uses watershed variables, it will employ tested weightings.

According to (Kusumo, 2016), flood vulnerability weighting can be based on expert judgment, which considers which variables have the most significant impact on flood vulnerability. A similar approach has been used with the Analytical Hierarchy Process (AHP), which achieves a comparable weighting to the pairwise comparison approach in determining the level of importance or priority scale of each parameter (Aziza *et al.*, 2021). The flood vulnerability (KB) is calculated using the following equation (1):

$$KB = 25\,(PL) + 20\,(E) + 20\,(B) + 15\,(CH) + 10\,(JT) + 10\,(KL) \qquad (1)$$

Explanation:
PL: Land Use
E: Elevation
B: Bengawan Solo River Buffer
CH: Rainfall
JT: Soil Type
KL: Slope Gradient
KB: Flood Vulnerability

The result of the above calculation, Flood Vulnerability (KB), is expressed as a numerical value that can be classified based on interval width. The width of the intervals is used to determine the number of classes required. In this study, flood vulnerability was divided into three classes: low vulnerability, moderate vulnerability, and high vulnerability. The interval width is determined using the geometry classification; in this case, the data wasn't normally distributed.

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Table 9. Accuracy Assessment

	Predicted High Vulnerable	Predicted Moderate	Predicted Not Vulnerable	Total B
High Vulnerable	TP	FN	FN	TP+FN+FN
Moderate	FP	TN	FN	FP+TN+FN
Low Vulnerable	FP	FN	TN	FP+FN+TN
Total A	TP+FP+FP	FN+TN+FN	FN+FN+TN	**N=Total A + Total B**

To calculate the validation, this research would be using matrix validation (Yu *et al.,* 2021). From **Table 4**, the metric calculation has two main classes, predicted and actual classes, which are divided by TP (True Positive), FP (False Positive), TN (True Negative), and FN (False Negative) values. The validation of this model will be used by the recent location of flood from the PUSDATARU-Jateng from the years 2020-2024. Similar approaches have also been applied in previous studies using GIS and multi-criteria decision analysis for flood hazard zoning (Rahmati et al., 2016). In these cases, the validity of the model using this parameter Precision, Recall, F1, and Overall Accuracy in the equation of:

$$\textbf{Precision} = \frac{TP}{TOTAL\ A} \quad (4)$$

$$\textbf{Recall} = \frac{TP}{Total\ B} \quad (5)$$

$$\textbf{F1} = 2x\frac{Precison\ x\ Recall}{Precision+Recall} \quad (6)$$

$$\textbf{Overall Accuracy} = \frac{TP}{N} \quad (7)$$

Explanation:

TP :Total of Value True-Positif
TF: Total of Value True-False
TN: Total of Value True-Negative
FN: Total of Value False-Negative

2.2 Processing Data

The stages of data processing are shown in **Figure 4** and are arranged sequentially and in detail. ArcGIS 10.82 software was used to process and integrate all the data in this study. The scoring is done by modifying the attribute table of each shapefile. The first step after acquiring all the data is to customize the map projection method. In this study, the WGS 1984 map projection was used to adjust the 49S zone in the study area. Adjustment of the projection is necessary to obtain accurate results during the overlay process.

Land use data processing is obtained from the RBI shapefile. The RBI data is consolidated to review the entire Land Use. Each Land Use shapefile is assigned scores based on the parameters mentioned previously by adding a new field to the attribute table.

The Bengawan Solo River data is obtained from the RBI. The river buffer data is derived from the RBI and then geoprocessed with a clip operation to match administrative boundaries. The next step uses the Analyst Tools in the Multiple Ring Buffer function. The resulting buffer data is then clipped to the administrative boundaries.

To obtain slope data, the Spatial Analyst tool is used, and the slope is processed in the surface section. The output measurement for slope data is percent rise. The subsequent step is performing a focal statistic with a rectangle mean of 15 x 15 to smooth the results. The final step is converting

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raster data to vector data and then scoring according to the classification from the literature. At the same time, Elevation data from DEMNAS is already in height format. The elevation data is directly processed by converting it to vector data, with scoring based on classification.

Rainfall data for the period 2021–2023 obtained from the Bengawan Solo River Basin Organization (BBWS Bengawan Solo). The dataset comprises records from four rainfall stations, including three located in Sukoharjo and one in Surakarta. Annual average rainfall was calculated for each station. Subsequently, the spatial distribution of rainfall was interpolated using the Inverse Distance Weighting (IDW) algorithm. The resulting rainfall surface was then classified into categories based on literature-derived thresholds, with corresponding scores and weights assigned to each class.

Soil type data is sourced from GeoMAP. Soil data were obtained from the GeoMAP website, which provides both vector and raster data. This study uses vector data from the GeoMAP ESDM detailed classification. Soil type classification refers to the official website of Pusat Informasi Spasial Daerah (PISDA) Sukoharjo, with scoring based on previous literature in the attribute table (Subardja et al., 2014).

The next stage is weighting. Weighting is calculated based on the weight of each parameter assigned scores. Land use has a weight of 25, while river buffer and elevation have weights of 20. Rainfall has a weight of 15, and soil type and slope have weights of 10. Weighting follows previous literature and is adjusted based on subsequent research, modifying the attribute table as needed.

The following stage is the overlay process. Overlay uses the intersect tool in *ArcToolBox* to combine all parameters such as rainfall, land use, soil type, elevation, slope, and river distance, along with the administrative boundaries of sub-districts.

Flood vulnerability classifications are generate based on the results of flood vulnerability. The results are performed in the attribute table by adding a new field for the flood vulnerability classification. The results of the flood vulnerability are categorized based on data intervals. For the purpose of this study, three classes are used from the high vulnerability, moderate vulnerability and low vulnerability.

Data validation uses information by PUSDATARU-Jateng and *Badan Nasional Penanggulangan Bencana* (BNPB) of flood location report. Flood history data, point-based form, from the PUSDATARU-Jateng and BNPB used to calculating Overall Accuracy (OA). Overall Accuracy genereted by the table 9, then calculating the parameters. The previous data of flood have 16 locations in the year of 2016-2024.

This study next examines flood frequency using media reports at the sub-district level on an annual basis. We compiled flood news for Sukoharjo Regency from 2019 to 2024, sourcing and filtering articles from reputable outlets in accordance with Indonesia Press Council guidelines. Four digital press media served as validation sources: Solopos, Detik, Inilah Jateng, and Harian Jogja. Local news items were then used to calculate flood event intensity in each sub-district. Finally, the observed flood frequencies were classified into three categories and compared descriptively with the model's spatial vulnerability pattern before.

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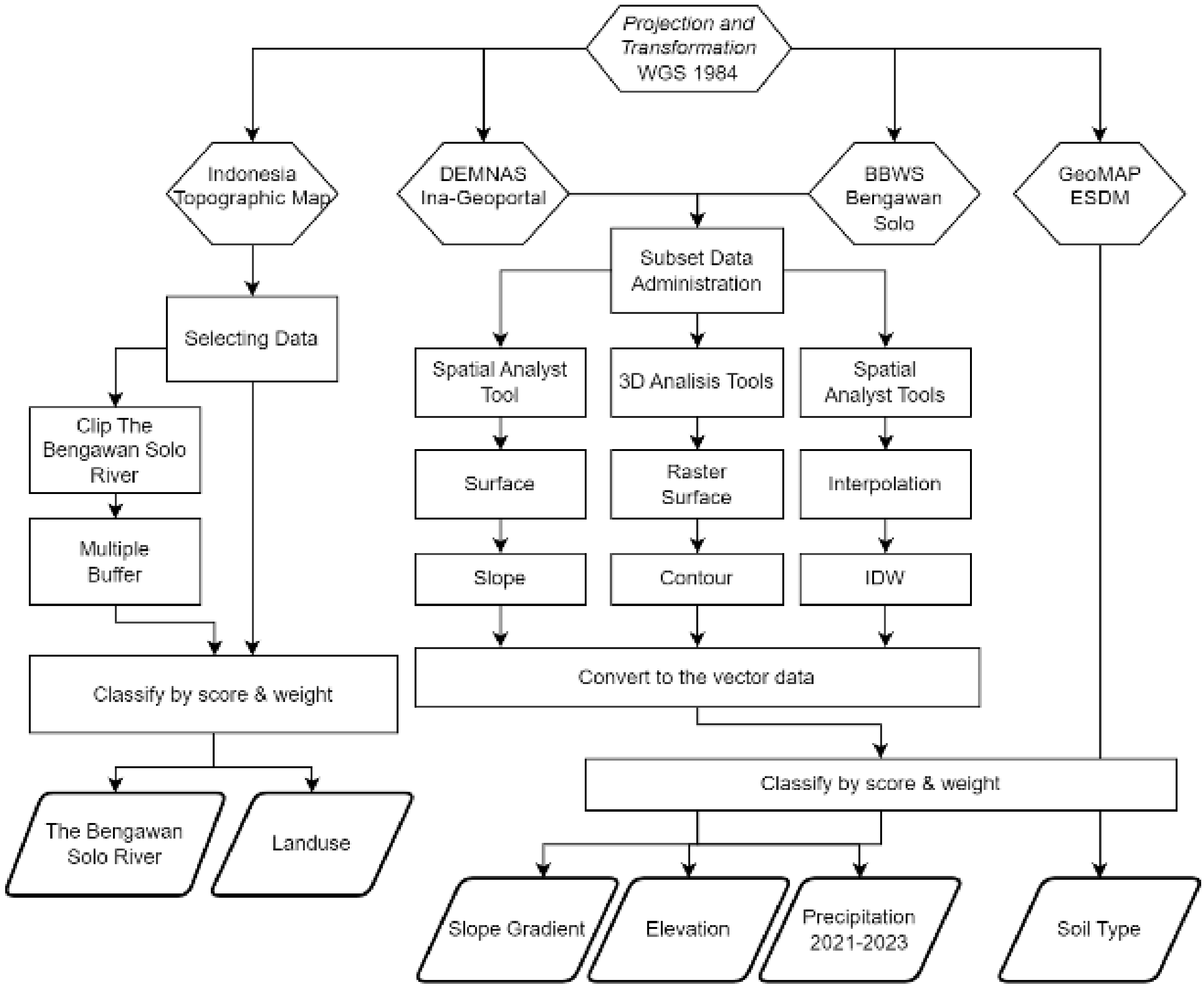

Figure 4. Flow of Data Processing

3. RESULTS AND DISCUSSION

3.1 Data Result

3.1.1 Precipitation

Heavy rainfall throughout the year can increase flood vulnerability in Sukoharjo Regency. High rainfall dominates the entire Sukoharjo Regency area. Most of the Sukoharjo Regency experiences rainfall exceeding 4 classes, classified as Very Light (<1500 mm/year), Light (1500 - 2000 mm/year), Moderate (2001 - 2500 mm/year), and Heavy (2501 - 2800 mm/year) *(refer into **Table 9** and **Figure 5**).*

The 2021–2023 rainfall map for Sukoharjo Regency shows a clear north-to-south precipitation gradient. The highest totals (2.501–2.800 mm) concentrate along the northern border, immediately south of Surakarta City. Moving southward, a broad central swath records moderate rainfall (2 001–2.500 mm), forming an almost elliptical band across the regency's midsection. Beyond this, the southern and southwestern peripheries receive lower rainfall (1.500–2.000 mm), while the lowest values (<1.500 mm) appear in a small zone at the extreme northwest corner.

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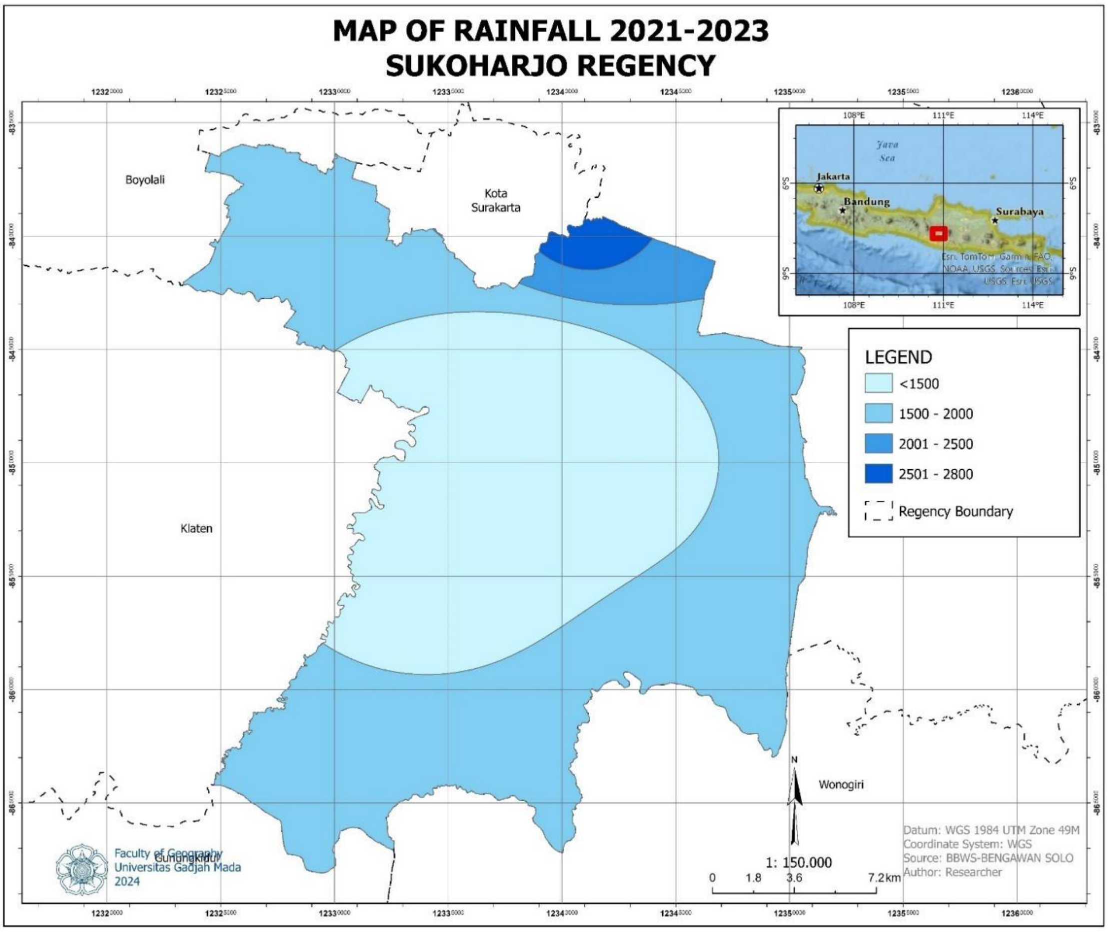

Figure 5. Map Distribution of Precipitation 2021-2023

Table 10. Classification of Result Scoring and Weighting Precipitation

No.	Precipitation (mm)	Description	Score	Weighting	Area (Ha)
1.	< 1500	Very Light	1	15	19.4
2.	1500 - 2000	Light	3	45	27.6
3.	2001 – 2500	Moderate	5	75	1.47
4.	2501 - 2800	Heavy	7	90	0.72
				Total	49.3

3.1.2 Soil Type

Alluvial soil is found in most parts of Sukoharjo Regency. Alluvial soil has very low infiltration capacity, resulting in poor water absorption, covering an area of 24.3 hectares. Meanwhile, Latosol is widely spread in the eastern part of Sukoharjo Regency, covering an area of 11.6 hectares. Latosol soil is also very low in water absorption. Lithosol and regosol soils dominate the northern and southern regions of Sukoharjo with significant coverage. Regosol is distributed in the northwest part of Sukoharjo District. In general, lithosol and regosol soils have very high infiltration rates, with a total area of 13.2 hectares in **Figure 6**.

Regosol and Lithosol have a score of 1 with a weight of 10, indicating they are less sensitive to flooding. Meanwhile, Latosol has a score of 7 with a weight of 70, meaning this soil is moderately sensitive to flooding. Alluvial soil has a high score of 9 with a weight of 90, making it highly sensitive to flooding. (Refer to **Table 10**).

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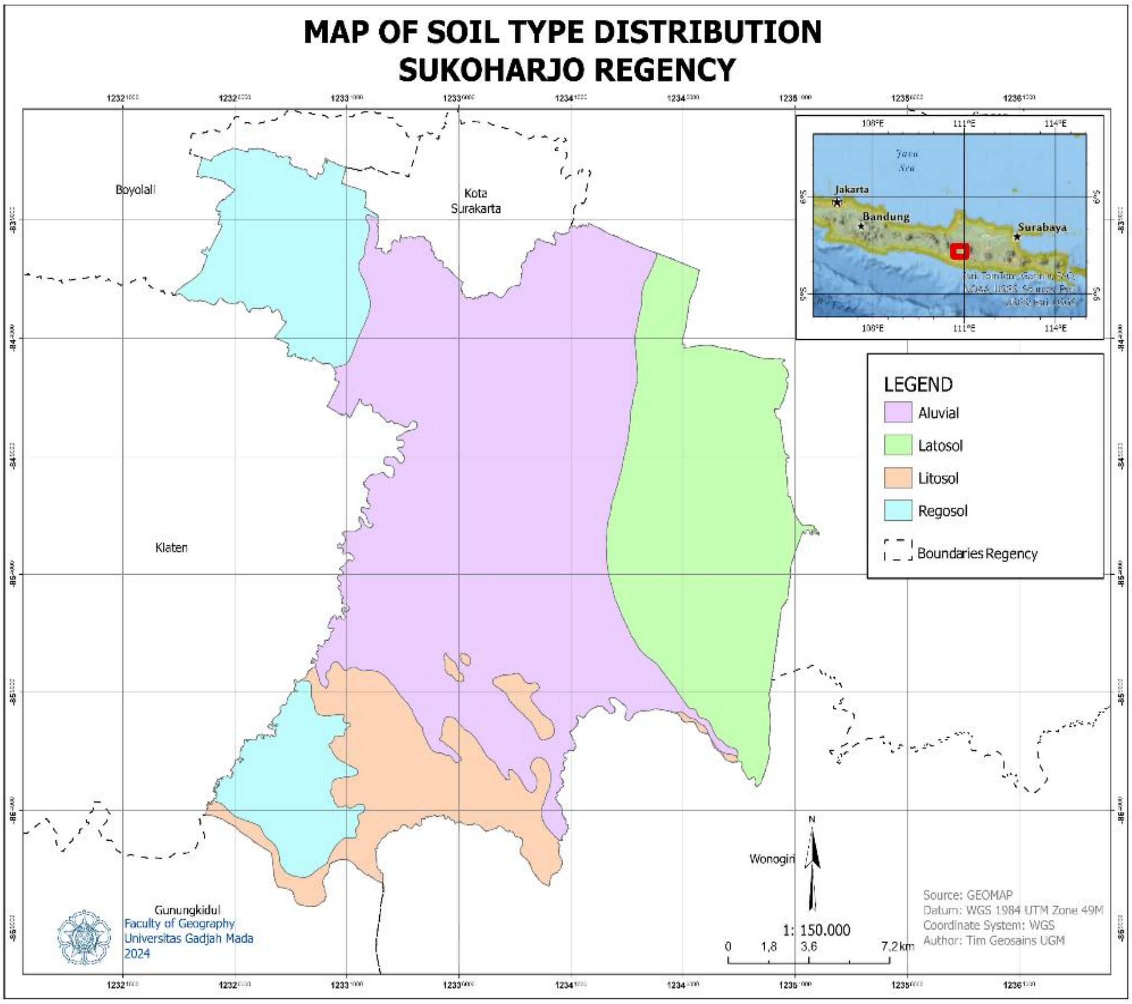

Figure 6. Map Distribution of Soil Type Sukoharjo Regency

Tabel 11. Classification of Result Scoring and Weighting Soil Type

No.	Soil Type	Score	Infiltration	Weighting	Area (ha)
1.	Regosol, Lithosol	1	Highly Sensitive	10	13,2
2.	Latosol	7	Insensitive	70	11,6
3.	Alluvial	9	Highly Insensitive	90	24,3
				Total	49,3

3.1.3 Slope Gradient

The data above shows the distribution of slope gradients (refer to **Figure 7**). The distribution of slope areas is associated with a region's elevation. Spatially, the southern and eastern parts of Sukoharjo Regency have relatively varied slopes. In contrast, the northern and western parts exhibit less variation, although there are slope changes along the Bengawan Solo River.

The percentage of slope inclination will influence the scoring and weighting results. Slopes with an inclination of less than 8% have a score of 9 and a weight of 135, covering an area of 37.6 hectares, dominating Sukoharjo Regency. Areas with slopes of 8-15% have a score of 7, a weight of 70, and cover an area of 8.37 hectares. Slopes of 16-25% get a score of 5, a weight of 50, and cover 2.22 hectares. Steeper slopes, ranging from 26-45%, get a score of 3 and a weight of 30, covering

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0.86 hectares. Slopes with an inclination of more than 45% are considered to have minimal influence on flood vulnerability and are assigned a score of 1 and a weight of 10, covering an area of 0.26 hectares **Table 11**.

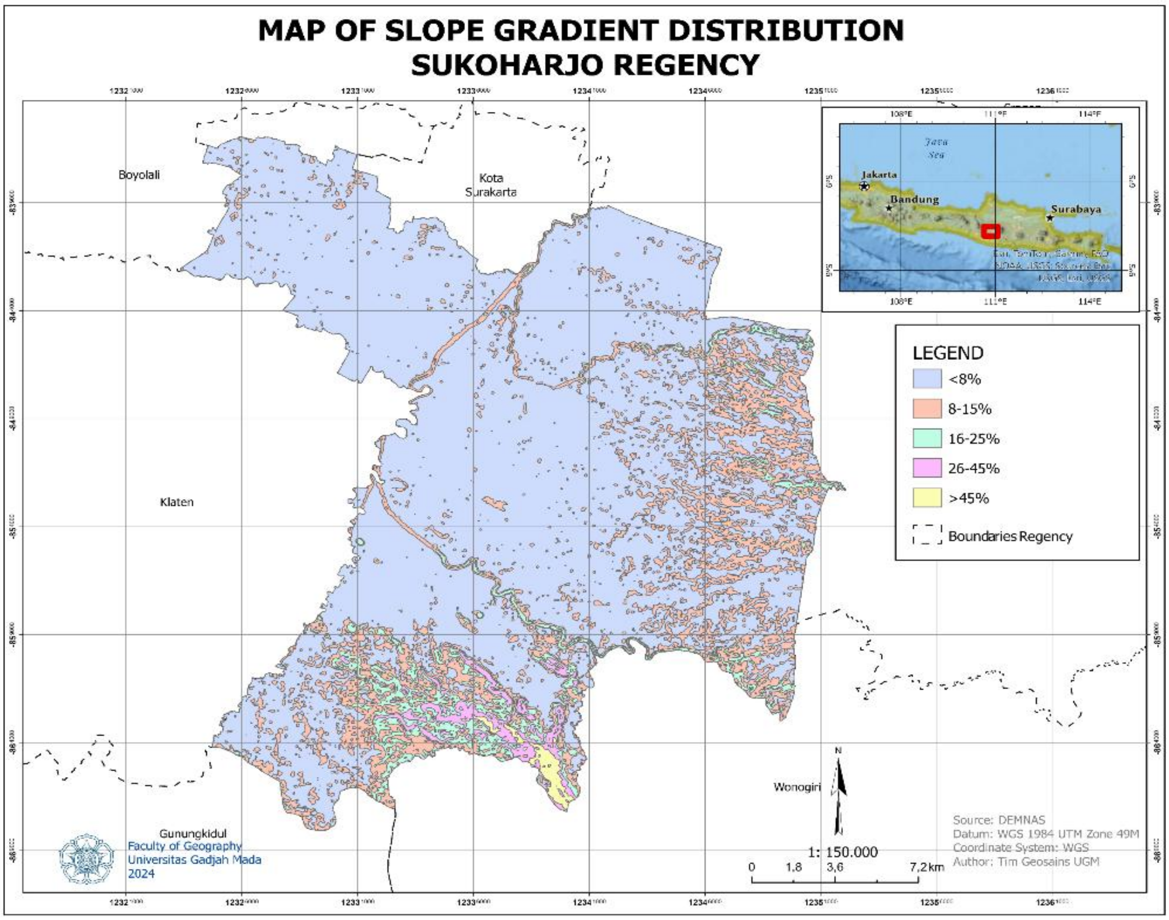

Figure 7. Map Distribution of Gradient Slope Sukoharjo Regency

Table 12. Classification of Result Scoring and Weighting Slope Gradient

No	Gradient Slope (%)	Score	Description	Weighting	Area (Ha)
1.	>45%	1	Very Steep	10	0,26
2.	26-45%	3	Steep	30	0,86
3.	16-25%	5	Moderately Steep	50	2,22
4.	8-15%	7	Gentle	70	8,37
5.	<8%	9	Flat	90	37,6
				Total	49,3

3.1.4 Elevation

The result of spatial distribution elevation in Sukoharjo Regency is depicted in Figure 8. The central region includes areas with elevations between 51-100 meters above sea level (masl), covering 16.4 hectares. In the western and eastern regions, elevations of 101-200 masl are spread over 31.1 hectares, while the southern part shows elevations above 200 masl, covering 1.7 hectares, located near the western border of Wonogiri Regency at **Table 12.**

Surface height affects the occurrence of flooding. The data in **Table 11** shows that the classification score 5 has an elevation of 50-100 masl with a weighting result of 100. An elevation of 101-200 masl has a score of 3 with a weighting result of 60. An elevation > 200 masl has a smaller score, namely 1 with a weighting result of 20 which is caused by the water flowing into lower land.

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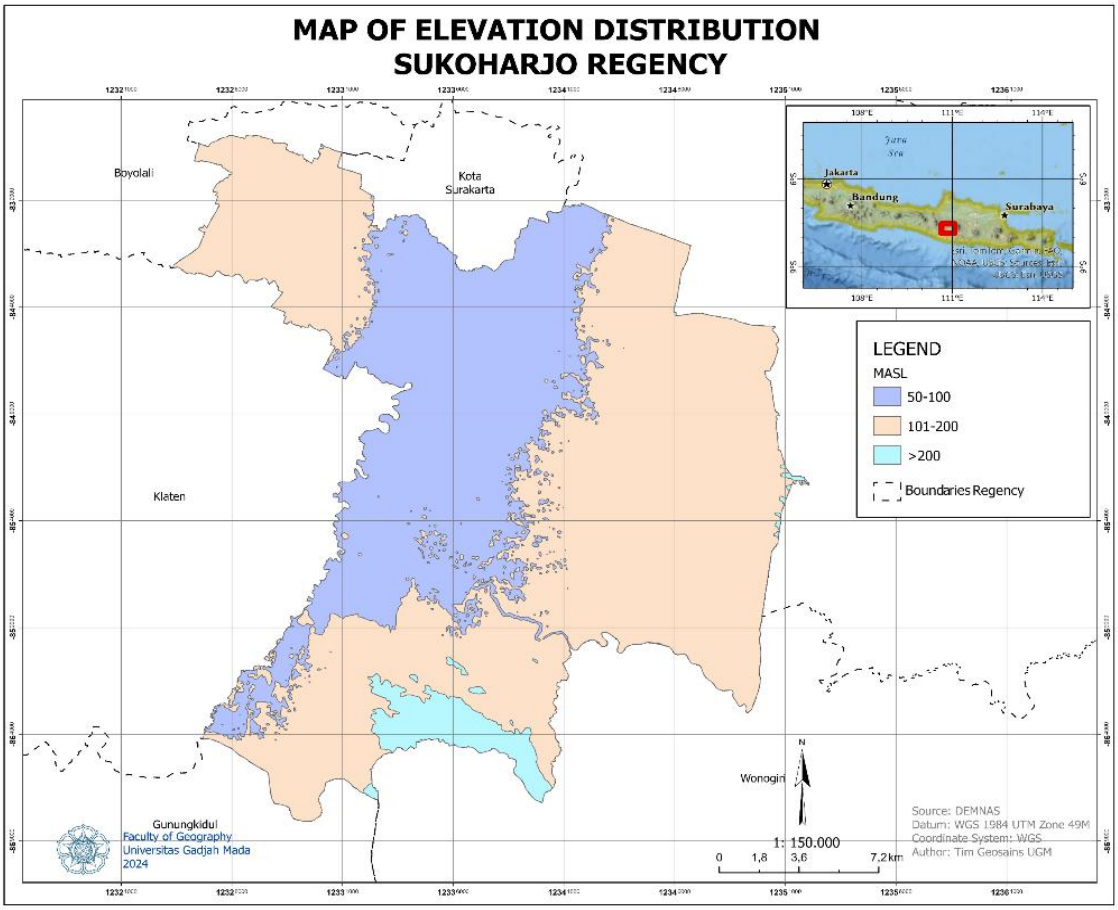

Figure 8. Map Distribution of Elevation Sukoharjo Regency

Table 13. Classification of Result Scoring and Weighting Elevation

No.	Elevation (MASL)	Score	Weighting	Area (Ha)
1.	>200	1	20	1,7
2.	101-200	3	60	31,1
5.	51-100	5	100	16,4
			Total	49,3

3.1.5 Land Use

The distribution of land use in Sukoharjo Regency consists of various types, including water bodies (lakes, rivers, reservoirs), settlements, rice fields, cultivated land, shrubs, grasslands, plantations, and forests (vegetation). Land use in Sukoharjo Regency is dominated by rice fields. Other important land uses include buildings and residential areas. The land cover has a total area of 43.4. In addition, water bodies, including lakes, rivers, and reservoirs, have a total area of 0.44 hectares. The three land covers have a total area of 43.4. In addition, water bodies, including lakes, rivers, and reservoirs, have a total area of 0.44 hectares. Dry land/fields are almost spread in various corners with a total area of 2.5 hectares. Shrubs, plantations, and fields have a total area of 2.6. Forests have a total area of 0.25 hectares at Table 13 and **Figure 9**.

Forest areas have lower scores compared to residential areas and water bodies due to water absorption systems. Water bodies are assigned a score of 5 with a weighting of 225 because water absorption into the soil is insensitive. Settlements and rice fields receive a score of 7 with a weighting of 175 due to the decreasing water absorption areas, while cultivated land receive a score of 5 with a weighting of 125. Shrubs, grassland, and plantations are rated 3 score with a weight of

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75. Vegetation (forest) is rated 1 score with a factor of 25 because water is easily absorbed with high precipitation.

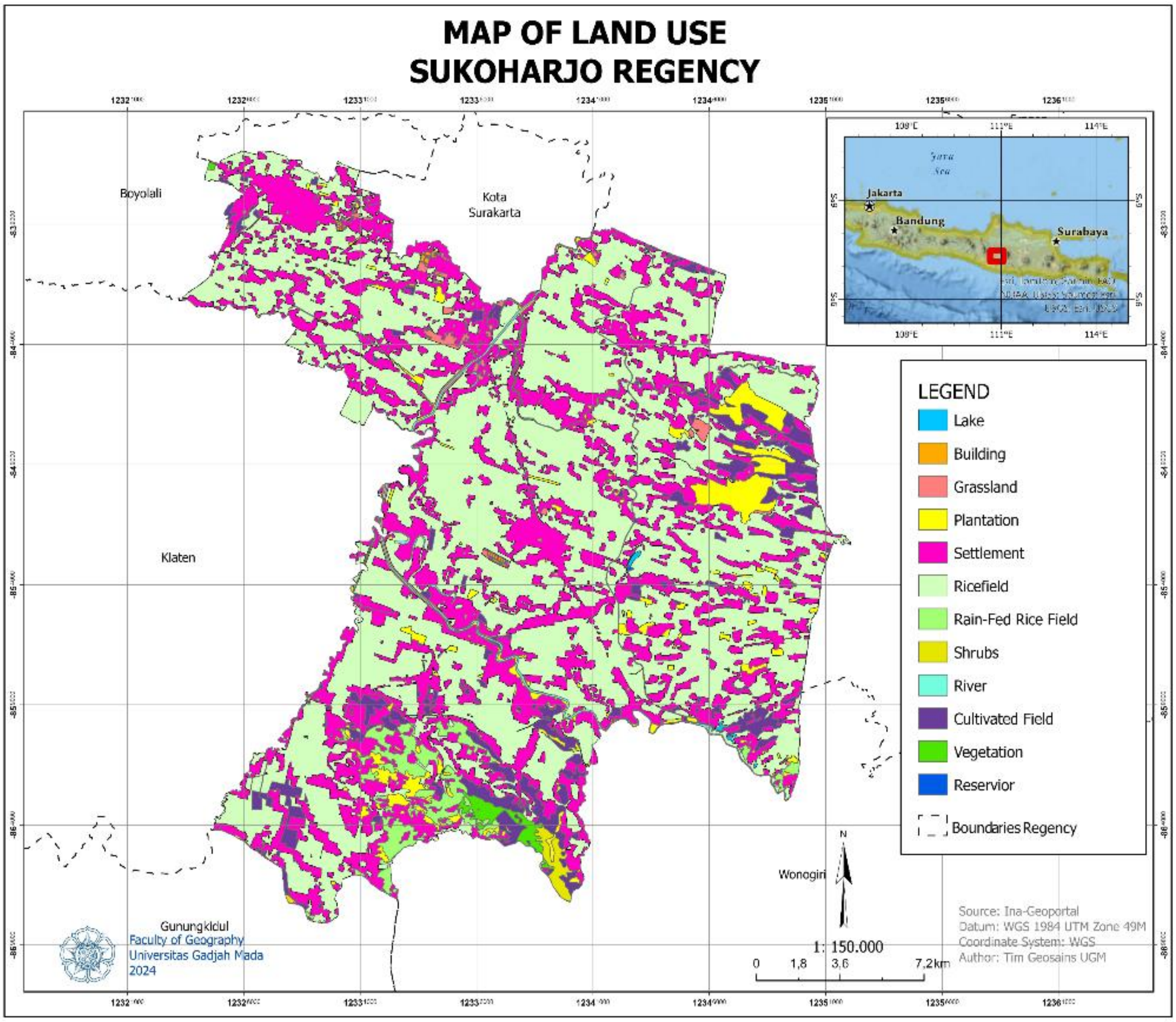

Figure 9. Map Distribution of Land Use Sukoharjo Regency

Table 14. Classification of Result Scoring and Weighting Land Use

No	Land Use	Score	Weighting	Area (Ha)
1.	Forest	1	25	0,25
2.	Shrubland, Plantation, Grassland	3	75	2,6
3.	Cultivated Land/Field	5	125	2,5
4.	Settlement, Rice Field	7	175	43,4
5.	Waterbody	9	225	0,44
			Total	**49,3**

3.1.6 River Buffer

The distance of the river to settlements or river buffers determines the level of flood vulnerability. The Bengawan Solo River crosses the Districts of Mojolaban, Grogol, Nguter, Tawangsari, Sukoharjo, and Bulu. Weighting of the area In **Table 13**, the distance of the Bengawan Solo River to the surrounding settlements gets 5 classifications in **Figure 10**.

The first distance of 0-25 meters has an area of 0.39 hectares with the highest score of 9 and a weighting of 180, the influence on the surrounding area is quite high. The distance of 26-50 meters

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has an area of 0.17 ha with a weighting of 140 which has a relatively high influence on flooding. At a distance of 51-75 meters from the river, the score is 5 with a weighting of 100, having a total area of 0.17 ha. The distance of 76-100 meters gets a score of 3 with a weighting of 60 which has an area of 0.16 ha. Distances of more than 100 meters have a less significant effect, with an area of 48.4 ha and a weighting result of 20 with a score of 1 at **Table 14**.

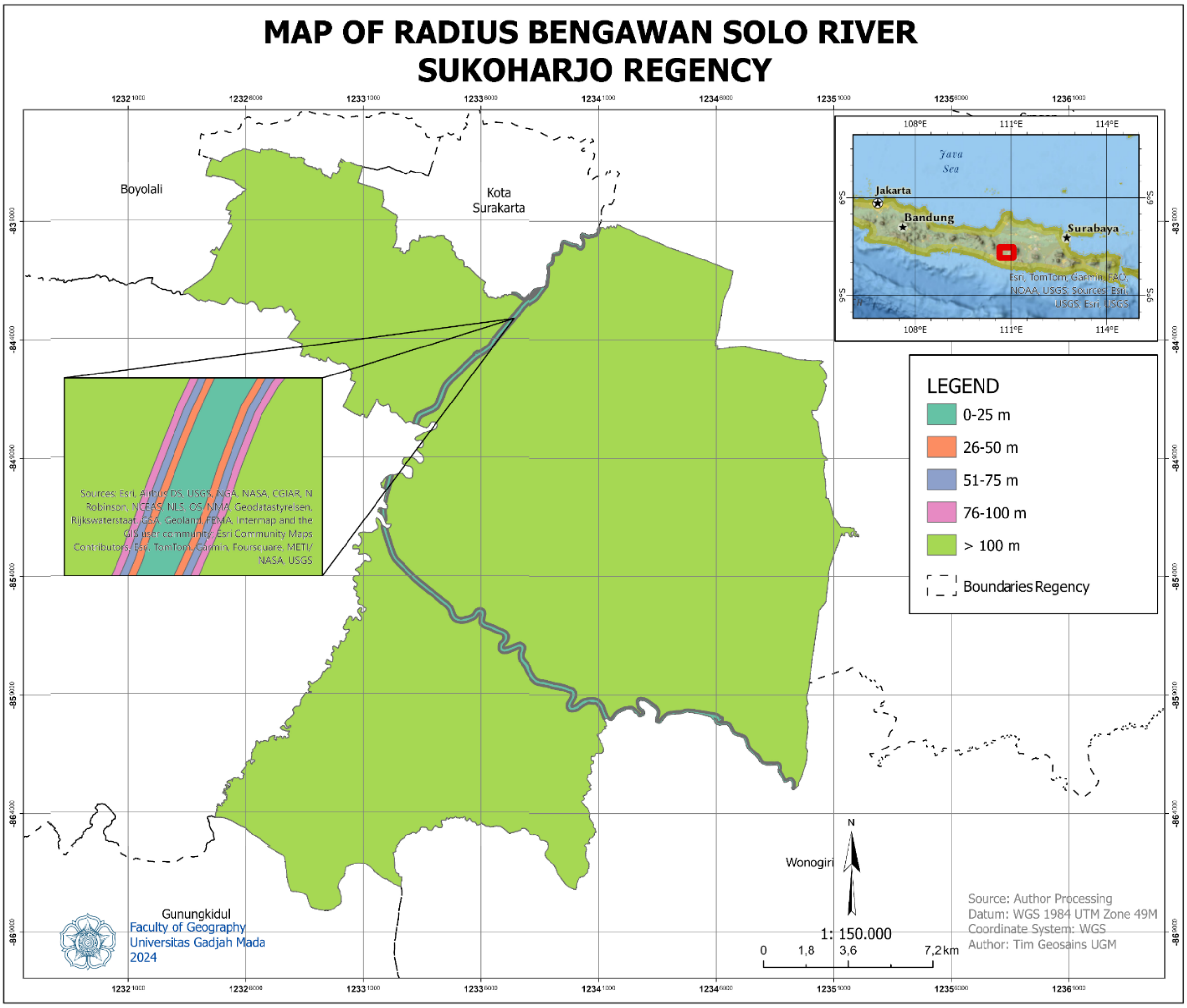

Figure 10. Map Distribution of River Buffer Sukoharjo Regency

Table 15. Classification of Result Scoring and Weighting River Buffer

No.	Distance (m)	Score	Weighting	Area (Ha)
1.	<100	1	20	48,4
2.	76-100	3	60	0,16
3.	51-75	5	100	0,17
4.	26-50	7	140	0,17
5.	0-25	9	180	0,39
			Total	**49,3**

3.2 Discussion

3.2.1 Result of Mapping Flood Disaster Area

The results of the flood vulnerability analysis show that the vulnerability levels are distributed across different regions. The eastern area is predominantly characterized by moderate to high vulnerability, while the western area exhibits a mix of low, moderate, and high vulnerability. Areas

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along the river particularly in the central region extending to the southeast are generally classified as having moderate to high flood vulnerability. Several interacting factors contribute to these patterns, with land use exerting the most significant influence due to its highest assigned weight, followed by elevation, especially within the buffer zone of the Bengawan Solo River in **Figure 11**.

The results of statistical data processing show that 31% of the total area of Sukoharjo Regency, or approximately 15.57 hectares, falls under the high flood vulnerability category. The largest proportion of the area is categorized as having moderate flood vulnerability, covering 18.04 hectares or 37% of the total area. Meanwhile, the low flood vulnerability area accounts for 15.73 hectares or 32% of the region. Further spatial distribution by sub-districts is detailed in **Table 17**, where Sukoharjo Sub-District contributes the largest area under high vulnerability (3.87 ha), followed by Mojolaban (2.87 ha) and Grogol (2.78 ha). On the other hand, sub-districts such as Gatak and Kartasura show very low areas under high vulnerability, with 0 and 0.01 ha, respectively.

In the high-vulnerability class, Gatak (0.00 ha) and Weru (0.00 ha) exhibit virtually no exposure, whereas Sukoharjo records the greatest high-vulnerability area at 3.88 ha. Mojolaban (2.87 ha), Grogol (2.78 ha), and Tawangsari (2.29 ha) also show comparatively large extents of high risk, suggesting concentrated flood susceptibility in these locales. In the moderate-vulnerability category, Gatak again marks the minimum area (0.01 ha), with Kartasura (0.05 ha) and Grogol (0.23 ha) retaining very small footprints. By contrast, Nguter (4.65 ha) and Bendosari (4.27 ha) record the highest moderate-vulnerability extents, indicating these sub-districts lie on the threshold between low and high flood risk.

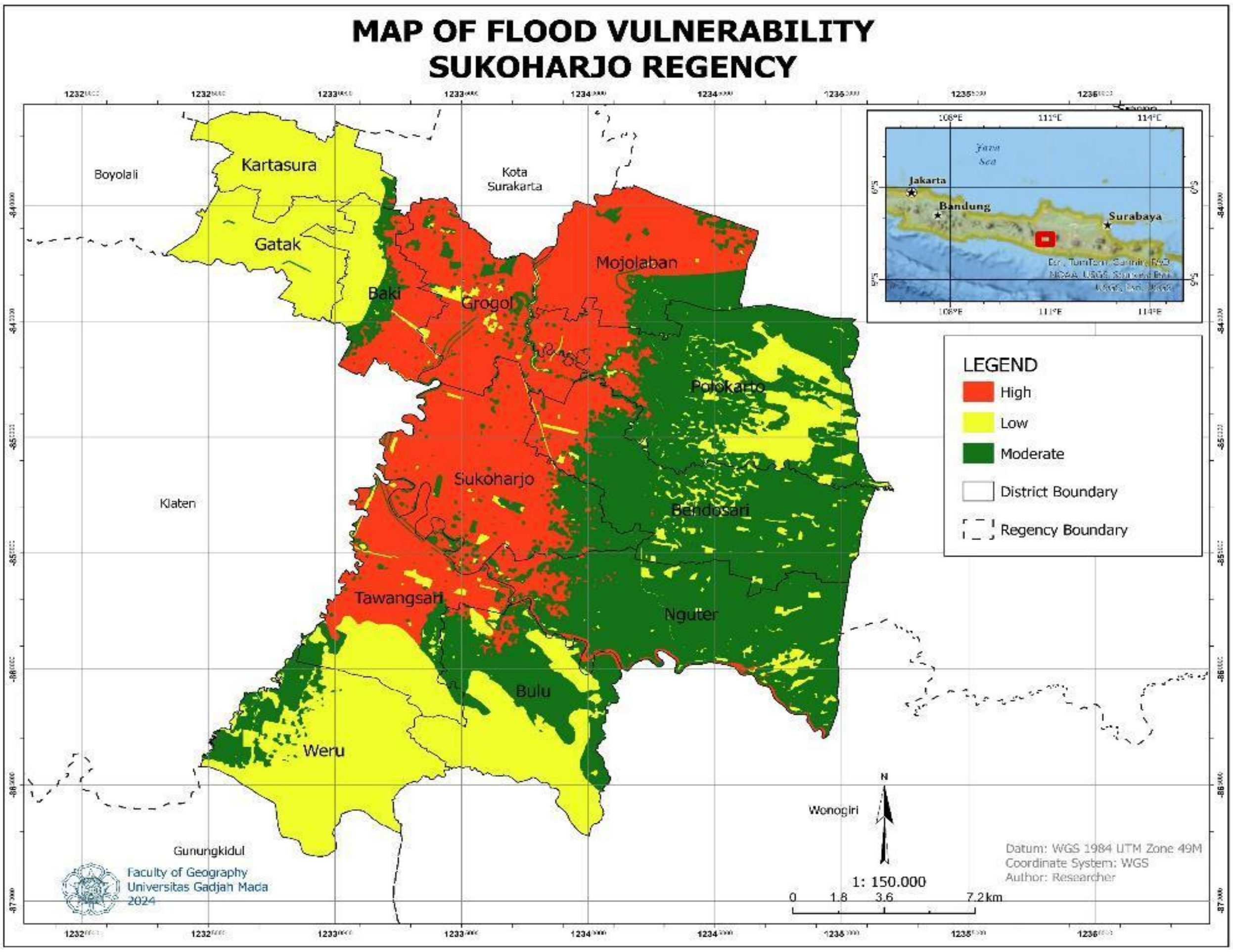

Figure 11. Map of Vulnerability Flood

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For low vulnerability, Mojolaban (0.03 ha) and Sukoharjo (0.05 ha) present the smallest areas, while Weru (3.84 ha) and Bulu (2.56 ha) register the greatest low-vulnerability land. This variation—from minimal to maximal exposure in each class—underscores localized variations in flood risk and highlights priority zones. These classifications are based on the weighted accumulation intervals as shown in Table 16**.** The divides of 49.30 ha study area into three vulnerability classes based on weighted-score intervals. The low-vulnerability class (130–410) encompasses 15.70 ha, representing 32 % of the total area. The moderate-vulnerability class (411–489) covers the largest portion at 18.04 ha, or 37 %. The high-vulnerability class (490–770) accounts for 15.50 ha, corresponding to 31 % of the study area.

Table 16. Interval and Area of Flood Vulnerability

No	Interval (Weight Accumulation)	Category of Vulnerability	Area (Ha)	Percentage (%)
1.	130 - 410	Low Vulnerable	15.7	32
2.	411 - 489	Moderate	18.04	37
3.	490 - 770	High Vulnerable	15.5	31
		Total	**49,3**	**100%**

Table 17. Result Area in Every Sub-District to The Flood Vulnerability

No.	Sub District	High (Ha)	Moderate (Ha)	Low (Ha)	
1.	Baki	1.058156	0.369686	0.857393	
2.	Bendosari	0.821386	4.274289	0.485143	
3.	Bulu	0.219561	1.857012	2.560481	
4.	Gatak	0	0.005495	2.023658	
5.	Grogol	2.781317	0.234391	0.127708	
6.	Kartasura	0.008801	0.049634	2.113879	
7.	Mojolaban	2.865412	0.899639	0.025278	
8.	Nguter	0.72222	4.654046	0.409354	
9.	Polokarto	0.937772	3.847743	1.966351	
10.	Sukoharjo	3.878667	0.762635	0.054317	
11.	Tawangsari	2.285618	0.414065	1.271421	
12.	Weru	0.000683	0.67325	3.837034	
	Total (Ha)	15.57	18.04	15.73	49.3
	Percentage(%)	31	37	32	100

This research has evaluated the model validity using 16 historical flood records from 2016 to 2024. Flood events were concentrated in the northern region and scattered across the central and southern areas (**Figure 12**). The assessment accuracy in Table 18 shows that this research accurately identified all 10 true high-vulnerability cases but overestimated high risk by classifying two moderate and two low cases as high. It correctly labeled only two of the four moderate cases and failed to detect both low-vulnerability locations. **Table 19** presents the overall performance metrics: the model achieved 75% precision (three out of four predicted vulnerable areas were correct), 62.5% recall (detecting approximately two-thirds of all actual vulnerable sites), and a 72.9% F_1-score,

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reflecting a balanced compromise between precision and recall. This model achieved 75% overall accuracy, indicating that its classification results are sufficiently or enough reliable to used.

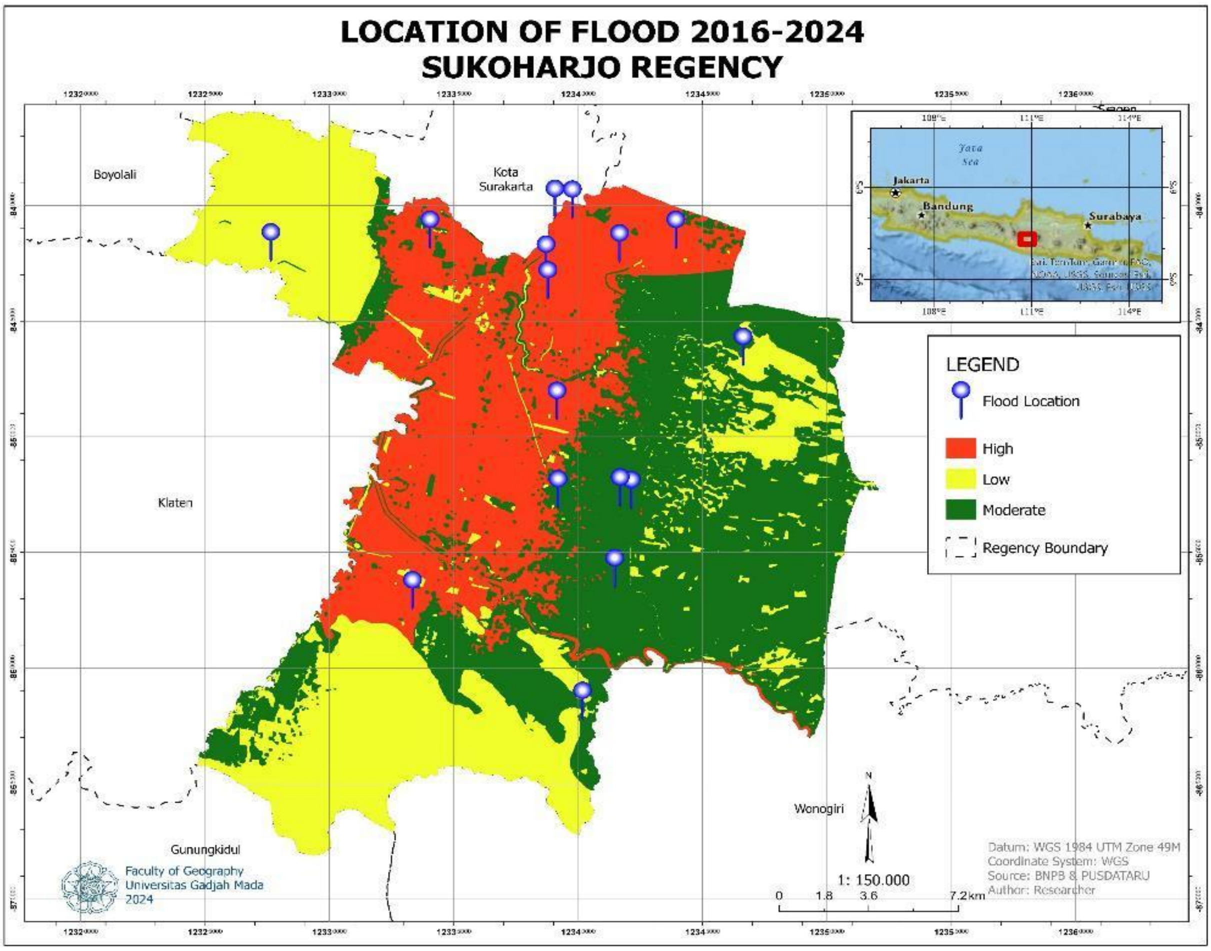

Figure 12. Flood location in the 2016-2024

Table 18. Result of Assessment Accuracy

	Predicted High Vulnerable	Predicted Moderate	Predicted Low Vulnerable	Total
Actual High Vulnerable	10	0	0	**10**
Actual Moderate	2	2	0	**4**
Actual Low Vulnerable	2	0	0	**2**
Total	**14**	**2**	**0**	**16**

Table 19. Result of Overall Accuracy Model

Parameter	Precision	Recall	f1	Overall Accuracy
VALUE (%)	75	62.5	72.9166667	75

3.2.2 Physical Aspect Determined of Distribution

Flooding occurs when water discharge cannot be conveyed downstream or infiltrated into the soil, resulting in surface accumulation. This behavior reflects fundamental of flood phenomenon, in which potential overland flow is generated by interactions between terrain variaton and infiltration capacity. Consequently, flood vulnerability is chiefly controlled by the area's topography and surface infiltration characteristics. Flood analysis in this research would be analyze with overland-flow

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concept. According to the overland-flow framework (Harisuseno and Bisri, 2017), physical factors on overland flow are primarily influenced by slope gradient, soil type, and land-use characteristics.

The first factor in the formation of overland flow is variations in the terrain of Bengawan Solo. In recent research, slope haven't been correlated with flood vulnerability because the location of research, in Demak, Central Java, haven't been variation topography (Putra, 2019). On other hand, topographic distribution in Sukoharjo is quite diverse. The elevation is lowest in the central part of Sukoharjo Regency, moderate in the southern, western, and eastern zones, and highest in the southern uplands. The slope parameter increases toward the south, particularly along the river's channel. Therefore, in the centre of Sukoharjo create basin ended in the Bengawan Solo River. These elevation and slope patterns regulate the upstream movement of water within the local hydrologic cycle in to the Bengawan Solo River.

The other factor is surface infiltration capacity by soil type and landuse. Although rainfall reach the ground to becoming overland flow, infiltration rates is also depend soil infiltration characteristics. The soil type factor is related to low potential by weight, but it created the pattern in along Bengawan Solo path in the center area of Sukoharjo. The domination of soil type is alluvial. Along that alluvial area, low infiltration is the result, then potentially created overland flow. On other hand, urban land-use dominate, where settlement areas are distributed across the Sukoharjo area, is highest weight. High proportions of impervious surfaces in these built-up zones reduce infiltration, while more permeable type soils water uptake and slow infiltration.

3.2.3 Mapping The Frequency of Flood by Mass Media Visualization

The utilization of mass media data provides a spatial distribution of flood events across Sukoharjo Regency. The visualization employs a village-level mapping unit, allowing detailed representation of localized flood occurrences. The analysis is based on flood frequency calculated over five years, covering the years 2019 to 2024.

The spatial distribution of flood frequency across Sukoharjo Regency from 2019 to 2024, aggregated by village units within each sub-district. The legend indicates five categories of flood frequency over the 5 years: 0 (no flood), 1, 2, 3, and 4 events. The highest frequencies (3–4 events) are concentrated in the northern part of Sukoharjo, particularly around the central-northern sub-districts near the boundary with Surakarta (Solo). This area is shown in shades of red and dark red. Moderate frequencies (1–2 events) are more widely distributed, appearing in villages in the central, northwestern, and southwestern parts of the regency, marked in light red to pink. In contrast, the eastern and southeastern parts of Sukoharjo show no recorded flood events within the period and are left unshaded, indicating a frequency value of 0 in **Figure 13**.

The accompanying table strengthens this spatial interpretation by providing year-specific flood occurrences for 28 villages across six sub-districts (**Table 20**). Gadingan and Laban in Mojolaban stand out with the highest recorded frequencies (4 floods), aligning precisely with the darkest areas on the map. Villages in Grogol, such as Tegalmade and Kadokan, follow with 3 floods, supporting the visual emphasis in the northern zone. Meanwhile, most villages listed such as those in Baki, Polokarto, and Tawangsari experienced only one flood event, indicating sporadic occurrences. Thus, the tabular data offers detailed temporal backing to the map's spatial overview.

Figure 13 illustrates the spatial correspondence between the model output (**Figure 11**) and flood frequency data. Both results indicate that areas near Surakarta City exhibit higher flood vulnerability. This condition is strongly influenced by land use factors, which are weighted significantly in the analysis. Previous studies (Putra et al., 2018) have shown that urban factors such as increased precipitation and extensive built-up areas contribute to the intensification of the Urban Heat Island (UHI) effect. Compared to Sukoharjo, Surakarta has a higher proportion of built-up land, which increases the UHI and subsequently increases the local precipitation, from the north to south

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of Sukoharjo. Therefore, excess rainfall in Surakarta City tends to exceed the infiltration capacity of the soil (permeability and porosity) leading to a higher potential for surface runoff and flood occurrences. This finding is also supported by previous GIS-based flood risk studies in different watersheds, such as Cisadane (Sebayang and Rosanti, 2022).

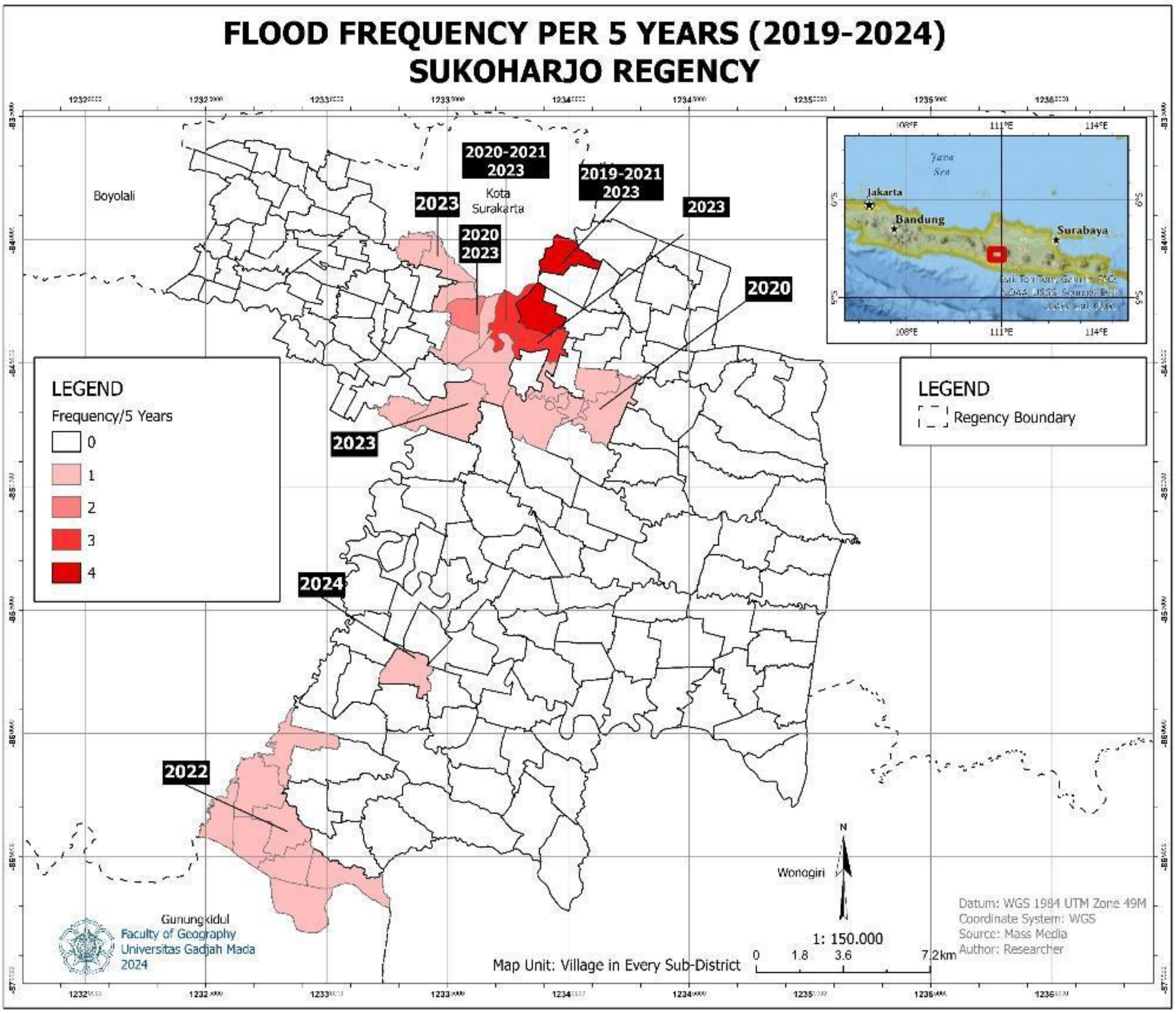

Figure 13. Visualize by Mapping Unit Sub-District from Reporting Media

Table 20. Frequencies of Flood

No	Sub District	Village	Years	Frequency/5 years
1	Baki	Ngrombo	2023	1
2	Grogol	Banaran	2023	1
3		Cemani	2023	1
4		Grogol	2023	1
5		Kwarasan	2023	1
6		Langenharjo	2023	1
7		Pandeyan	2020	1
8		Parangjoro	2023	1
9		Telukan	2023	1
10		Bakalan	2020	1

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11	Polokarto	Bugel	2020	1
12		Ngombakan	2020	1
13	Tawangsari	Kateguhan	2024	1
14	Weru	Grogol	2022	1
15		Jatingarang	2022	1
16		Karakan	2022	1
17		Karangtengah	2022	1
18		Karangwuni	2022	1
19		Krajan	2022	1
20		Tawang	2022	1
21		Tegalsari	2022	1
22	Grogol	Madegondo	2020 dan 2023	2
23		Kadokan	2020, 2021, dan 2023	3
24	Mojolaban	Tegalmade	2019, 2021, dan 2023	3
25		Gadingan	2019, 2020, 2021 dan 2023	4
26		Laban	2019, 2020, 2021 dan 2023	4
			Total Flood 5 Years	37

Source: *(Wicaksono, 2019, 2020, 2021); (Putra, 2022); (BPBD, 2023); (Takhrodjie, 2024)*

This spatial distribution is consistent with analytical predictions, which is in line with statistical-based flood susceptibility mapping methods integrating multivariate approaches (Tehrany et al., 2014). This study has limitations in using mass-media reports for flood mapping, as these data are not consistently aligned with official records from PUSDATARU and BNPB, primarily due to the complexity of flood types and their lack of transcription in the digital world. Moreover, media-based mapping relies on event frequency without any measurement, offering only descriptive insights. The last limitation is the insufficient number of samples in the flood history to represent the model.

4. CONCLUSIONS

This study has identified the spatial distribution of flood vulnerability in Sukoharjo. Statistically, 31% of the regency's area falls into the high vulnerability category, while the majority (37%) is moderately vulnerable, and 32% is classified as low vulnerability. Among all sub-districts, Sukoharjo, Mojolaban, and Grogol account for the largest high-vulnerability areas, whereas Gatak and Kartasura show minimal exposure. The model's performance was validated using 16 historical flood locations, resulting in an accuracy assessment with a Precision of 75%, a Recall of 65%, an F1-score of 72.9%, and an Overall Accuracy (OA) of 75%. This study identified key vulnerability factors contributing to overland flow in the Bengawan Solo River corridor. Two primary physical aspects were examined: terrain variation and surface infiltration capacity. Terrain variation, particularly slope, influences the formation of a basin-like area along the Bengawan Solo River, directing hydrological flow from upstream areas toward this central channel. Infiltration capacity is generally low due to dominant land use patterns and the prevalence of alluvial soils, which limit water absorption and increase the potential for surface runoff.

The mapping results based on media reports reveal a clear spatial pattern of flood frequency across Sukoharjo Regency. Higher flood frequencies (2–4 occurrences) are concentrated in the northern part of the region, particularly in the sub-districts of Grogol and Mojolaban. In contrast, lower flood frequencies are predominantly found in the southern areas. This spatial distribution aligns with the modeled flood vulnerability patterns (**Figure 11**), reinforcing the consistency between observed data and analytical predictions.

5. RECOMMENDATION

For future study, we recommend integrating mass-media monitoring into a web-GIS platform or Geo-AI that performs real-time updates via automated keyword searches (e.g., through Google) with using the flood frequency. Others recommend conducting more measurements or parameters in the flood analysis, such as maximum debit or C-coefficient (flow water). In addition, updating land-use parameters through manual image analysis will be the best way to improve accuracy.

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