# DETECTION OF FLOOD HAZARD POTENTIAL ZONES BY USING ANALYTICAL HIERARCHY PROCESS IN TUNTANG WATERSHED AREA, INDONESIA

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**ABSTRACT:**

Water resources play a crucial role in economic development, human health, and biodiversity. Mismanagement of water resources can lead to various disasters, with floods being one of the most frequent occurrences in river watershed. The rapid advancement of geospatial information systems enables the early prediction of flood hazard zones in the watershed by utilizing information about natural resources. This research focuses on determining flood hazard zones in the Tuntang Watershed through a combination of remote sensing, Geographic Information Systems (GIS), and the Analytic Hierarchy Process (AHP). Nine parameters are used to describe aquifer recharge zones, and each parameter is weighted according to its water characteristics and potential, determined through the AHP method based on expert opinions gathered in a Focus Group Discussion (FGD). The priority order obtained through AHP is as follows: precipitation, distance to the river, Land Use Land Cover (LULC), slope, Normalized Difference Vegetation Index (NDVI), elevation, curvature, Topographic Wetness Index (TWI), and soil type. The final flood hazard zone map is divided into five categories: very low, low, moderate, high, and very high. The results indicate that certain areas are very hazardous and present flood prone areas, namely Grobogan District with an area of 102.17 km2 (8.59 %), Demak with an area of 49.75 km2 (4.18%), and Semarang with an area of 45.23 km2 (3.80 %).

***Key-words:*** *Analytic Hierarchy Process, Multi-Criteria, Decision Making, Technical Geography, Geographic Information System*

## INTRODUCTION

The population's growth necessitates the development of facilities and infrastructure to meet increasing needs, resulting in land use changes, particularly in watershed (Anna, 2014). Watershed functions as a system with rainfall as the input, the watershed condition as the system structure, and river flow containing sediment and nutrients as the output. Understanding the Watershed characteristics is vital and serves as a fundamental basis for watershed management (Sriyana, 2011). Without sustainable watershed management to accompany population growth, it willinevitably lead to disasters (Sari, 2015). The periodic floods in the Tuntang Watershed result from channel construction and sediment accumulation, reducing the river's capacity to handle floodwaters (Safitri et al., 2017). Moreover, changes in land use for urban development, not only downstream but also upstream in the watershed, exacerbate the fluctuation of flood occurrences (Imanda & Andono, 2016). A significant flood disaster struck Tuntang Watershed, specifically Grobogan Regency, on January 8, 2020, impacting 8 regencies, 56 villages, and 26.67 km2 of rice fields, with an estimated loss of IDR 13 billion, which is a frequent scenario in Tuntang Watershed (Development Planning Agency at Sub-National Level of Grobogan District, 2021). Another recent flood in Semarang Regency on December 31, 2022, affected 147 residents, 44 houses, and 36 families (Regional Disaster Management Agency of Semarang City, 2022).

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The studies about monitoring flood frequency analyzed that there is repetition of the average flood discharge for 100 years in the Tuntang watershed (Maulana et al., 2017). Recurring flood discharges from year to year using the Harpers method, (2015) = 305.58 m3/s, (2010) = 468.43 m3/s, (2000) = 607.46 m3/s, (1985) = 827.76 m3/s, and (1935) = 1,035.57 m3/s.

Numerous studies have been conducted on flood hazard modeling using different methods and techniques. However, the use of Analytical Hierarchy Process (AHP) - Ordered Weighted Averaging (OWA) with 9 parameters in modeling has received relatively less attention. Some previous research related to flood modeling, such as the study by (Upwanshi et al., 2023), focused on mapping and delineating groundwater potential zones using remote sensing, GIS, and AHP in Mulshi Taluka, Pune district, India. Other studies conducted by Murtiono & Paimin (2016) and Azoune & Cherrared (2022) extensively investigated the complex characteristics of Tuntang Watershed and AHP-FMEA method for integrated river watershed management purposes. Building upon the findings of Jumadi & Priyana (2016), the development of a web-based GIS for surface water modeling could be a valuable plan for future flood hazard zoning modeling in Tuntang Watershed using AHP.

The general objective of this research is to identify flood hazard zones using AHP method in Tuntang Watershed. Specifically, this study aims to create a map of the 9 parameters that influence flood hazards and analyze the relationships between these parameters based on their respective weights. Conducting this research is crucial considering the frequent and recurring floods that occur in the downstream areas of Tuntang Watershed (in Semarang and Demak) every year. By mapping flood hazard zones using the AHP method, this study will provide valuable information about the level of hazard in the upstream, middle part of watershed, and downstream areas of Tuntang Watershed.

## 2. STUDY AREA

Tuntang Watershed is located between 110°15' 50"E - 110°33' 20"E and 06°51' 25"S - 07°26'40"S, with its main river stretching 139 km (Abiy et al., 2023). Tuntang Watershed is situated in the eastern part of the administrative region of Semarang City. It comprises five administrative regions, namely Demak Regency, Semarang Regency, Grobogan Regency, Salatiga City, and Boyolali Regency (Murtiono & Paimin, 2016). Below are the administrative map (**Fig. 1**) and a table showing the area and percentage for these five regions within Tuntang Watershed (**Tab. 1**).

**Table 1.**
**Area and percentage of administrative regions in Tuntang Watershed.**

| No. | Regency/City | Area of Tuntang Watershed ($km^2$) | Percentage (%) |
|---|---|---|---|
| 1 | Demak | 851.50 | 39.28 |
| 2 | Semarang | 658.43 | 30.38 |
| 3 | Grobogan | 555.73 | 25.65 |
| 4 | Salatiga | 57.03 | 2.64 |
| 5 | Boyolali | 44.61 | 2.05 |

*Source: Ministry of Environment and Forestry, 2016.*

The Tuntang Watershed has unique hydrological conditions with eight sub-watershed forms differently shaped. The largest administrative area is Demak Regency. Tuntang is the main river in the watershed system, along with two other secondary rivers, the Senjoyo River with an area of 120 $km^2$ and the Bancak River with an area of 140 $km^2$. There are eight subwatersheds that pass through Tuntang Watershed, such as: Senjoyo, Bencak, Tuntang Hilir, Temuireng, Blorong, Rowopening, Jajar, and Tuk Bening (Murtiono & Paimin, 2016). In the last 30 years there have been changes in increasing rainfall and discharge in the Tuntang watershed. For this study, monthly rainfall data were compiled for 11 stations around Tuntang Watershed (**Fig. 1.**). Almost all stations had some periods of data gaps ranging from a few days to several years, the gaps being filled by CHIRPS data with neighboring stations having highly correlated precipitation records. However, many stations still have other limitations that make them unsuitable for analysis. The temporal scope of data from the past to the present of annual rainfall for the last 30 year ago (**Table 2.**).

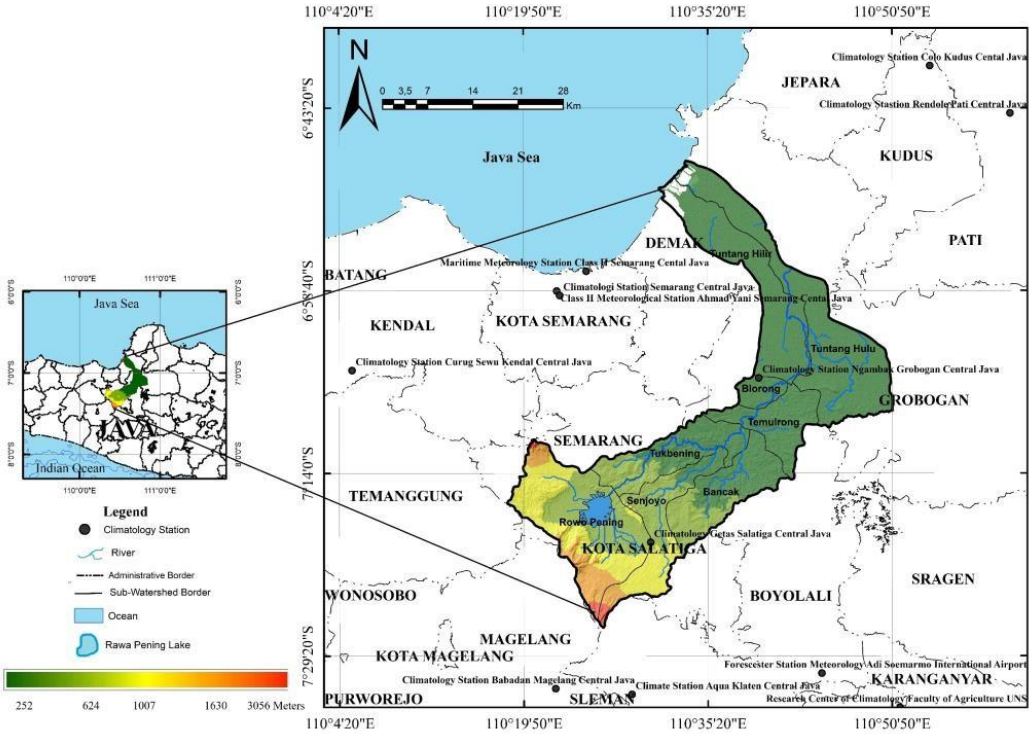


**Fig. 1.** Location of Tuntang Watershed Area on a map of Central Java, Indonesia.

**Table 2.**

**Properties of annual rainfall data around Tuntang Watershed year 1992-2022.**

| Year of Record | Annual Mean (mm/year) | Minimum (mm/year) | Maximum (mm/year) |
|---|---|---|---|
| 1992 | 1,195.14 | 1,154.18 | 1,236.90 |
| 2002 | 1,196.35 | 1,154.33 | 1,239.92 |
| 2012 | 1,196.34 | 1,154.32 | 3,989.92 |
| 2022 | 1,274.00 | 1,228.98 | 1,321.20 |

*Source: CHRIPS Analysis, 2023.*

## 3. DATA AND METHODS

### 3.1. Parameters of Flood Hazard Analysis

The data in this study consist of 9 parameters that influence floods. The study primarily utilized secondary data from various sources and institutions. **Table 3.** presents the required data and sources forthis research. The offline forum group discussion (FGD) was also conducted to determine the levelof importance or weight of each parameter. Ten respondents were interviewed, representing experts from various fields in physical and technical geography. These experts assessed the importance of the 9 parameters by comparing them to each other using AHP technique. The obtained weights will follow the overall weight result from the AHP Calculator. Ultimately, this expert judgment will determine the ranking of each parameter in relation to its influence on floods in the Tuntang Watershed. Other methods that might be used for future research are AHP and FMEA (Azoune & Cherrared, 2022). In this case, AHP was used only up to the stage of detecting flood hazard zones based on mathematical and psychological technique. To reach the risk stage, management understanding methods such as Failure Mode, Effect and criticality Analysis (FMEA) are needed.

**Table 3.**

**Data and sources used in the study.**

| No | Data | Sources | Function |
|---|---|---|---|
| 1 | Shapefile data of the Tuntang Watershed and its surroundings | Ministry of Environment and Forestry (KLHK) | Research area boundary |
| 2 | Shapefile data of river network | Geospatial Information Agency (BIG) | Parameters distance to river |
| 3 | Topographic Map of Indonesia Scale 1:25,000 sheet Semarang and Surrounding Area | Geospatial Information Agency (BIG) | Land use parameter |
| 4 | Landsat 8 Remote Sensing Image, Recorded in 2022 | United States GeologicalSurvey (USGS) | NDVI Parameter |
| 5 | ASTER DEM data scene of Semarang and its surroundings | United States GeologicalSurvey (USGS) | Elevation, slope, curvature, and TWI parameters. |
| 6 | Soil type data | Indonesian Center for Agricultural Land Resources Research and Development (ICALRD) | Soil type parameter |
| 7 | Average rainfall data | Climate Hazards Group InfraRed Precipitation withStation data (CHIRPS) | Precipitation parameter |
| 8 | Expert Judgement | Offline FGD | Hazard assessment |

## 3.2. AHP calculation

Spatial decision support system is one of the machine learning techniques based on Artificial Intelligence (AI) (Sànchez-Marrè, 2022). The AHP is one of the tools in spatial decision support systems developed for complex multi-criteria evaluation (Sugumaran et al., 2011). Previously, the widely used multi-criteria weighting method was the Weighted Linear Combination (WLC). However, one of the weaknesses of WLC is the potential bias in effectively assigning weights (Malczewski, 1998). In an effort to reduce user bias, AHP was developed in the 1980s by Saaty (1987) and can help determine the level of influence of each parameter on specific phenomena (Sugumaran et al., 2011).

In the process of determining objective weight scales in this research, OWA is used to integrate AHP. AHP serves as a global tool to construct the hierarchical structure of location decision problems, while OWA is employed to analyze the entire process and prioritize each alternative (Meng et al., 2011). The OWA operator, driven by linguistic metrics, provides a general framework for generating local AHP aggregates (Malczewski, 1998). The overall priority scores, Ri, for the alternative of i is calculated using the following equation.

$$\mathrm{Ri} = \sum_{j=1}^{n} WjXij \tag{1}$$

where *Wj* represents the combined aggregate weight of goal weight and attribute weight.

The weights are calculated through the multiplication of relative weight matrices at each hierarchy level. *Xij* denotes the standardized attribute value for the alternative of *i* (Malczewski, 1998; Meng et al., 2011). The weight determination in this research adopts the importance scale developed by Saaty (1987), comprising 9 scales of intensity in the importance table (**Table 4**.).

**Table 4.**

**Fundamental scale of importance intensity used in this research (Saaty, 1987).**

| Intensity of importance on an absolute scale | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance of one overanother | Experience and judgement slightly favorone activity over another |
| 5 | Essential or strong importance | Experience and judgement strongly favor one activity over another |
| 7 | Very strong importance | An activity is strongly favored and its dominance demonstrated in practice |
| 9 | Extreme importance | The evidence favoring one activity over another is of the highest possible order ofaffirmation |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgements | When compromise is needed |
| Reciprocals | If activity i has one of the above numbers assigned to it when compared with activity j, the j has the reciprocal value when compared with i | |
| Rationales | Rations arising from the scale | If consistency were to be forced by obtaining a numerical value to span the matrix |

## 3.3. Validation of AHP Models

The first step of the AHP method uses pairwise comparison which the value will be normalized to obtain the value used in the weighting of each parameter. The ranking results based on the criteria (**Fig. 2a.**) generated a pairwise comparison matrix (**Fig. 2b**) to validate whether the normalized relative weights align with geographical conditions and flood hazard causes at the research location (Yolanda et al., 2019). After obtaining the decision matrix, eigenvectors and consistency ratio (CR) are determined. The study involved 36 comparisons of variables we have, resulting in a principal eigenvalue of 9.557, which was then normalized through 5 iterationsto obtain the relative weights in the eigenvector solution. The obtained consistency ratio is 4.8%, calculated from the maximum λ (or an estimated value). Although the CR value is relatively high (> 0.1) (Saaty, 1987; Yolanda et al., 2019), it falls into the "good" category according to the AHP calculator. Experts have different perceptions of the priority between one parameter and another due to differences in the variation of flooding that occurs in the Tuntang watershed. In this case, the focus group discussion determined the closest weight from several experts (**Fig. 2.**). Nevertheless, all experts agree that parameters such as rainfall intensity and distance from settlements to the river carry significant weight when associated with frequency of flood hazard.

The second step is to classify each dimension into sub-categories and assign weights to each category. The maximum and minimum values for each class vary from 1 to 5. The seven factors are divided into five classes, while the curvature and soil factors are divided into three and four classes. Furthermore, from each class, the normalization is calculated to determine the weight of each class (Mujib et al., 2021). The Manual interval method used to determine classes for nine parameters. The final step is validation survey and analysis of the model results. **Fig. 3.** presents the flowchart of the GIS-based hydrological modeling approach to realize this study.

| Cat | | Priority | Rank | (+) | (-) |
|---|---|---|---|---|---|
| 1 | elevation | 7.7% | 6 | 1.8% | 1.8% |
| 2 | slope | 10.1% | 4 | 4.0% | 4.0% |
| 3 | curvature | 7.0% | 7 | 2.5% | 2.5% |
| 4 | TWI | 6.9% | 8 | 1.9% | 1.9% |
| 5 | NDVI | 8.2% | 5 | 5.0% | 5.0% |
| 6 | LULC | 10.3% | 3 | 4.4% | 4.4% |
| 7 | Distance to river | 22.3% | 2 | 9.2% | 9.2% |
| 8 | Precipitation | 25.4% | 1 | 7.5% | 7.5% |
| 9 | Soil | 2.1% | 9 | 0.7% | 0.7% |

**(a)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.20 | 0.33 | 5.00 |
| 2 | 1.00 | 1 | 3.00 | 1.00 | 1.00 | 1.00 | 0.50 | 0.33 | 6.00 |
| 3 | 1.00 | 0.33 | 1 | 1.00 | 1.00 | 0.33 | 0.50 | 0.33 | 5.00 |
| 4 | 1.00 | 1.00 | 1.00 | 1 | 1.00 | 1.00 | 0.20 | 0.20 | 3.00 |
| 5 | 1.00 | 1.00 | 1.00 | 1.00 | 1 | 0.50 | 1.00 | 0.20 | 3.00 |
| 6 | 1.00 | 1.00 | 3.00 | 1.00 | 2.00 | 1 | 0.33 | 0.33 | 5.00 |
| 7 | 5.00 | 2.00 | 2.00 | 5.00 | 1.00 | 3.00 | 1 | 1.00 | 9.00 |
| 8 | 3.00 | 3.00 | 3.00 | 5.00 | 5.00 | 3.00 | 1.00 | 1 | 7.00 |
| 9 | 0.20 | 0.17 | 0.20 | 0.33 | 0.33 | 0.20 | 0.11 | 0.14 | 1 |

**(b)**

**Fig. 2.** The resulting weights of priorities for the criteria based on pairwise comparisons - **a**; The resulting weights are based on the principal eigenvector of the decision matrix – **b.**

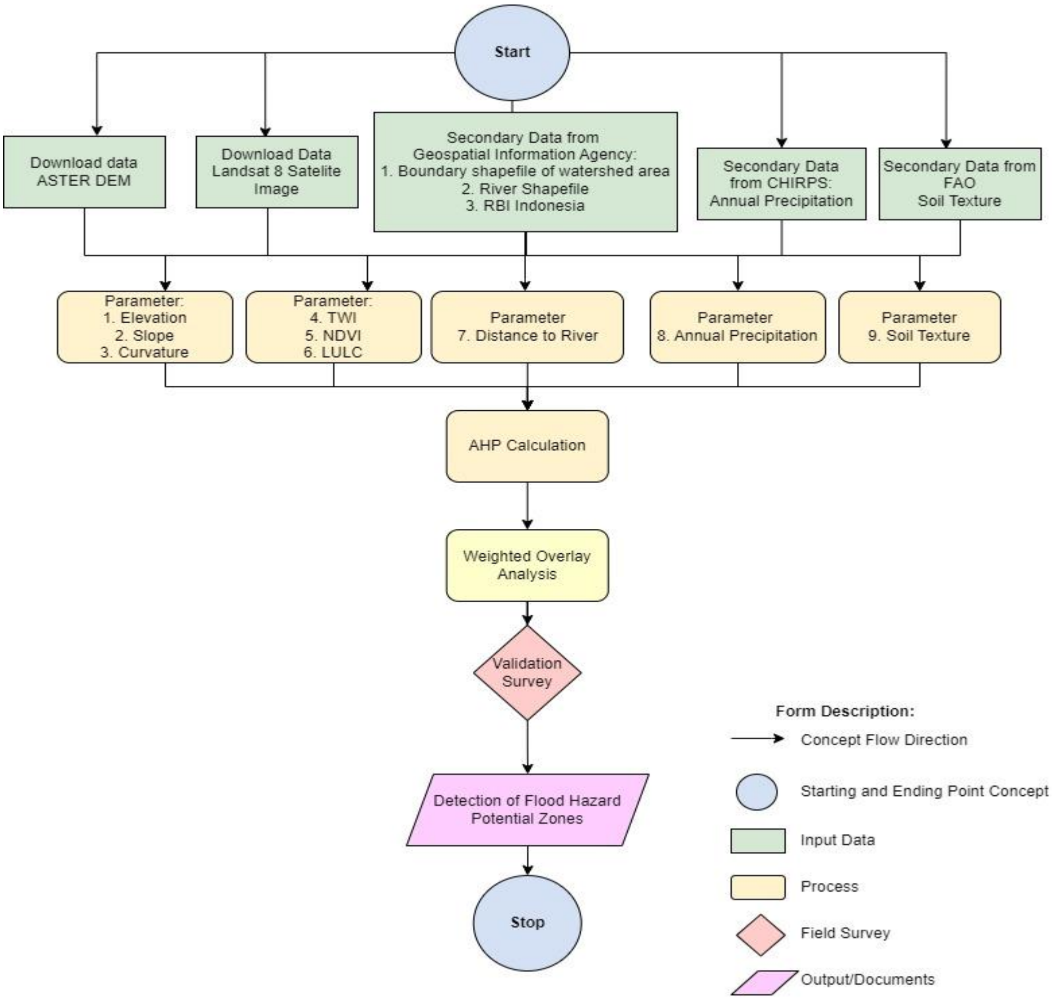


**Fig. 3.** Flowchart of research methodology.

## 4. RESULT

### 4.1. Flood Hazard Parameter Analysis

The weighting results of the 9 parameters were prioritized using the AHP calculator, as shown in **Fig. 2.** and **Fig. 4.** below. The contribution of each category in determining flood hazard areas is described in Table 5. Rate 1 is the level with the least impact on floods, rate 5 is the level with the most flood impact in this study. The top priority is precipitation from the annual rainfall data (CHRIPS), with a weight of 25.4%. Rainfall intensity and precipitation are directly proportional to the level of flood hazard. During the rainy season, high rainfall in the upstream area leads to an increased potential flood hazard downstream (Zhou et al., 2021; Negese et al., 2022; Sari, 2023). Precipitation holds the highest weight due to the average annual rainfall in the upstream of the Tuntang Watershed ranging from 1,000 mm/year to over 3,500 mm/year. The flood hazard classes determine from manual interval method based on the precipitation parameter are as follows: very high if the rainfall exceeds 3,500 mm/year, high for 3,000-3,500 mm/year, moderate for 2,500-3,000 mm/year, low for 2,000-2,500 mm/year, and very low for 1,000-2,000 mm/year.

The second priority is the distance from the river, accounting for 22.3% weight. If buildings are located at an unsafe distance from the riverbanks, the risk of flooding increases significantly (Aisha et al., 2019). The distance from the river parameter is closely related to the Land Use Land Cover (LULC) that occurs around the riverbanks in the Tuntang Watershed. The results of the Euclidean Distance with manual interval method based on the distance to river parameter are as follows: very high (0 m – 511.89 m), high (511.89 m – 1,044.25 m), moderate (1,044.25 m – 1,719.95 m), low (1,719.95 m – 2,702.78 m), and very low (2,702.78 m – 5,221.28 m). The distance from 0 – 511.89 m from river is the most expansive area and very prone to flooding. It covers about 73% of the total area.

The third priority is Land Use Land Cover, accounting for 10.3% weight. The main land use change, particularly from vegetation to built-up areas, leads to rainwater having a higher potential to become surface runoff instead of being absorbed by the soil surface (Kusumo & Nursari, 2016; Irza & Syabri, 2016; Yolanda et al., 2019). Land use changes, especially in forested areas, have significant impacts, particularly when the changes involve compacting the soil surface (reducing soil permeability), which in turn decreases infiltration rates and increases surface runoff (Asdak, 2017; Edial & Triyatno, 2008). The Tuntang Watershed exhibits various land covers, as observed from the latest data provided by the Geospatial Information Agency (BIG). These land covers include trees, flooded vegetation, crops, built areas, clouds, water, and bare ground. The flood hazard is high in areas covered by built-up areas. Flood hazard classes of LULC determine from **Table 5.** The largest area is crops in middle part of watershed, with 39.24% of the total area. It causes crops to be quickly affected by flooding. According to Sentinel satellite's classification calculations on ArcGIS Software, clouds affect the appearance in the study area by 21% of the total area (**Fig. 4c.**). The distribution of clouds is mainly located in the upstream part of the watershed.

The fourth priority is a slope, accounting for 10.1% weight. The slope gradient around the Tuntang Watershed ranges from 0 to 8% (low flow velocity), covering an area of 1,176.05 $km^2$, and it is very steep (21% - 65.62% with very high flow velocity), covering an area of 42.19 $km^2$. The watershed has an elongated shape, with sub-watersheds ranging from the $4^{th}$ to $6^{th}$ order, and a rectangular dendritic flow pattern (Sriyana, 2011; Rifani et al., 2014). Flood hazard classes determine from manual interval method based on the slope parameter are as follows: very high (0% - 2%), high (3% - 7%), moderate (8% - 13%), low (14% -20%), and very low (21% - 65.62%). Due to the variation in slope gradients across the 8 sub-watersheds of Tuntang, different types of floods occur. However, if the main focus is on the downstream areas with flat slopes or flood inundation, the slope classes have an inverse relationship with flood hazard classes. The high range slope class (3%-7%) covers about 46.24% which means the largest part of the total area. The very high flood hazard from slope values are distributed about 25.37 % of the study area.

The fifth priority is the NDVI (Normalized Difference Vegetation Index), accounting for 8.2%

weight. NDVI can indicate various parameters, including green leaf biomass, which can be estimated for vegetation distribution (Lestari et al., 2018). The NDVI values range between -1 and 1 (Gessesse & Melesse, 2019). The ratio between highly reflective near infraread (NIR) and highly absorbing red wavelengths in healthy and stressed plants that exhibit reduced NIR and increased red reflectivity. It is defined as:

$$NDVI = \frac{(\rho nir - \rho red)}{(\rho nir + \rho red)} \qquad (2)$$

The NDVI value has an inverse relationship with flood hazard classes. As the vegetation index value increases (approaching 1), indicating greener and denser vegetation cover, it enhances infiltration and reduces the flow rate of water. In this study, a higher vegetation index corresponds to a lower flood hazard class. The variation of NVDI value in this study is between 0.61-0.09. The flood hazard classes determined by the manual interval method (formula 2) based on the NDVI parameter are as follows: very low (0.61-0.33), low (0.33-0.27), moderate (0.27-0.20), high (0.20-0.10), and very high (0.10-0.09). The largest part of the total area (30.08%) is covered by the low range NDVI class (0.33-0.27). The high class NDVI values are distributed on about 5.42% of the study area.

The sixth priority is the location's elevation, accounting for 7.7% weight. The elevation in the Tuntang Watershed varies from the upstream areas to the outlet, which is the Java Sea. The elevation classes have an inverse relationship with flood hazard classes, meaning that lower elevations are more susceptible to flood disasters, especially flash floods or inundation events (Zevri, 2022). The variation of elevation value in this study area is between 1 m - 3,056 m. Flood hazard classes determine from manual interval method based on the elevation parameter are as follows: very high (1 m - 252.58 m), high (252.58 m - 623.98 m), moderate (623.98 m - 1,007.35 m), low (1,007.35 m - 1,630.33 m), and very low (1,630.33 m - 3,056 m). The elevation class with most significant area is very high class (1 m – 252.58 m) which covers about 62.15 % of the total area.

The seventh priority is the curvature, accounting for 7% weight. The curvature parameter is divided into concave, flat, and convex categories. It is used to describe its quantitative nature to understand erosion and runoff processes. Acceleration and deceleration affect the flow of water across the surface. Negative values indicate a concave upward surface, resulting in slower flow such as depressions and valleys. Positive values indicate a convex upward surface leading to faster flow such as hills and ridges. Values close to 0 represent flatness. Curvature has a minor effect on flooding, although it cannot be ruled out (Das, 2018; Mujib, 2021). The flood hazard classes determine from manual interval method based on the curvature parameter are as follows: very high/concave (<-0.1), moderate/flat -0.1 – 0.01), and very low/convex (>0.01). In this case, the concave curvature is classified into the highest or most hazardous class, with 23.01 % of the total area. The flat curvature has the largest area with 59.02% of the total area. The concave has the smallest area with 17.97 % of the total area.

The eighth priority is the TWI (Topographic Wetness Index), accounting for 6.9% weight. TWI is a method used to analyze soil moisture levels and areas of water runoff by assessing the wetness of the topography. The Tuntang Watershed exhibits varying levels of topographic wetness, with the lowest values having a TWI of 2.86 and the highest values reaching 22.47. According to Ballerine (2017), TWI is a valuable tool for understanding surface water flow and groundwater flow by applying principles from topography and hydrology. The results of TWI analysis can be used as one of the parameters to assess the and potential hazards of flood disasters. The variation of TWI value in this study is 22.47-2.83. Flood hazard classes determine from manual interval method based on the TWI parameter are as follows: very high (13.61-22.47), high (10.38-13.61), moderate (8.22-10.38), low (6.45-8.22), and very low (2.83-6.45). The low range TWI class (6.45-8.22) covers the largest area of about 40.65% of the total area. The high TWI values are distributed on about 3.44% of the study area.

The ninth priority is the soil type, accounting for 2.1% weight. In the study of the Tuntang Watershed, soil type has the smallest weight because of its low correlation with floods. Additionally, soils can be modified, for example, through the construction of irrigation channels and water management. Soil texture also plays a role in determining soil water dynamics, including infiltration rate, penetration, and water retention capacity (Taryono et al., 2001; Edial & Triyatno, 2008). The dominant soil types in the Tuntang Watershed are Cambisol, Mediteran, and Gleysol with a predominantly moderate flood hazard. It covered 83.04% of the entire study area. Low hazard is found around the reservoir area with Latosol soil type. In the downstream areas, there is Regosol soil type consisting of coarse grains originating from volcanic eruptions, resulting in low hazard. Podsolic and Andosol soils in some upstream and middle part of watershed areas fall into moderate hazard category. The very high flood hazard has latosol which covered the area about 1.17% of the total area.

**Table 5.**

**Classes of the factors and according weights.**

| **Factors** | **Class** | **Rate** | **Weight** |
|---|---|---|---|
| Precipitation (mm/year) | >3,500 | 5 | 25.4% |
| | 3,000-3,500 | 4 | |
| | 2,500-3,000 | 3 | |
| | 2,000-2,500 | 2 | |
| | 1,000-2,000 | 1 | |
| Distance to River (m) | 0-511.89 | 5 | 22.3% |
| | 511.89-1,044.25 | 4 | |
| | 1,044.25-1,719.95 | 3 | |
| | 1,719.95- 2,702.78 | 2 | |
| | 2,702.78- 5,221.28 | 1 | |
| LULC | Waterbody, flooded vegetation | 5 | 10.3% |
| | Low dense vegetation/ agriculture areas, urban/ other areas | 4 | |
| | Crops | 3 | |
| | Barren lands, bare ground | 2 | |
| | High dense vegetation/ forest/tree | 1 | |
| Slope (%) | 0-2 | 5 | 10.1% |
| | 3-7 | 4 | |
| | 8-13 | 3 | |
| | 14-20 | 2 | |
| | 21-65.62 | 1 | |
| NDVI | 0.10-0.09 | 5 | 8.2% |
| | 0.20-0.10 | 4 | |
| | 0.27-0.20 | 3 | |
| | 0.33-0.27 | 2 | |
| | 0.61-0.33 | 1 | |
| Elevation (m) | 1- 252.58 | 5 | 7.7% |
| | 252.58 - 623.98 | 4 | |
| | 623.98 – 1,007.35 | 3 | |
| | 1,007.35 – 1,630.33 | 2 | |
| | 1,630.33- 3,056 | 1 | |
| Curvature | Concave (< -0.1) | 3 | 7% |
| | Flat (-0.1 - 0.01) | 2 | |
| | Convex (>0.01) | 1 | |
| TWI | 13.61-22.47 | 5 | 6.9% |
| | 10.38 – 13.61 | 4 | |
| | 8.22-10.38 | 3 | |
| | 6.45-8.22 | 2 | |
| | 2.83 – 6.45 | 1 | |
| Soil | Other/ Latosol | 5 | 2.1% |
| | Podsolic, Andosol | 4 | |
| | Cambisol, Mediteran, Gleysol | 3 | |
| | Regosol | 1 | |

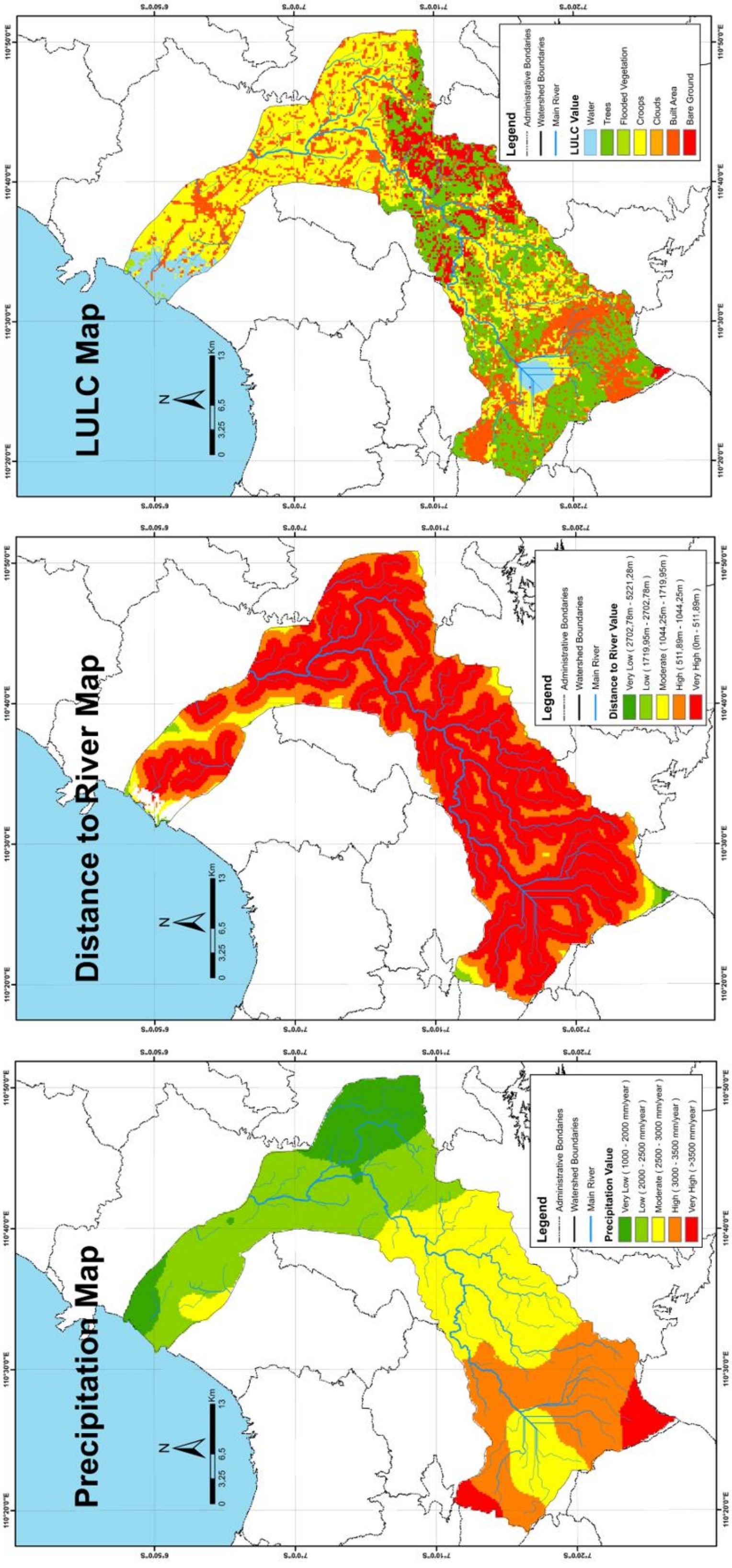


**Fig. 4.** Spatial parameter of flood hazard potential zones: precipitation-**a,** distance to river-**b,** LULC-**c.**

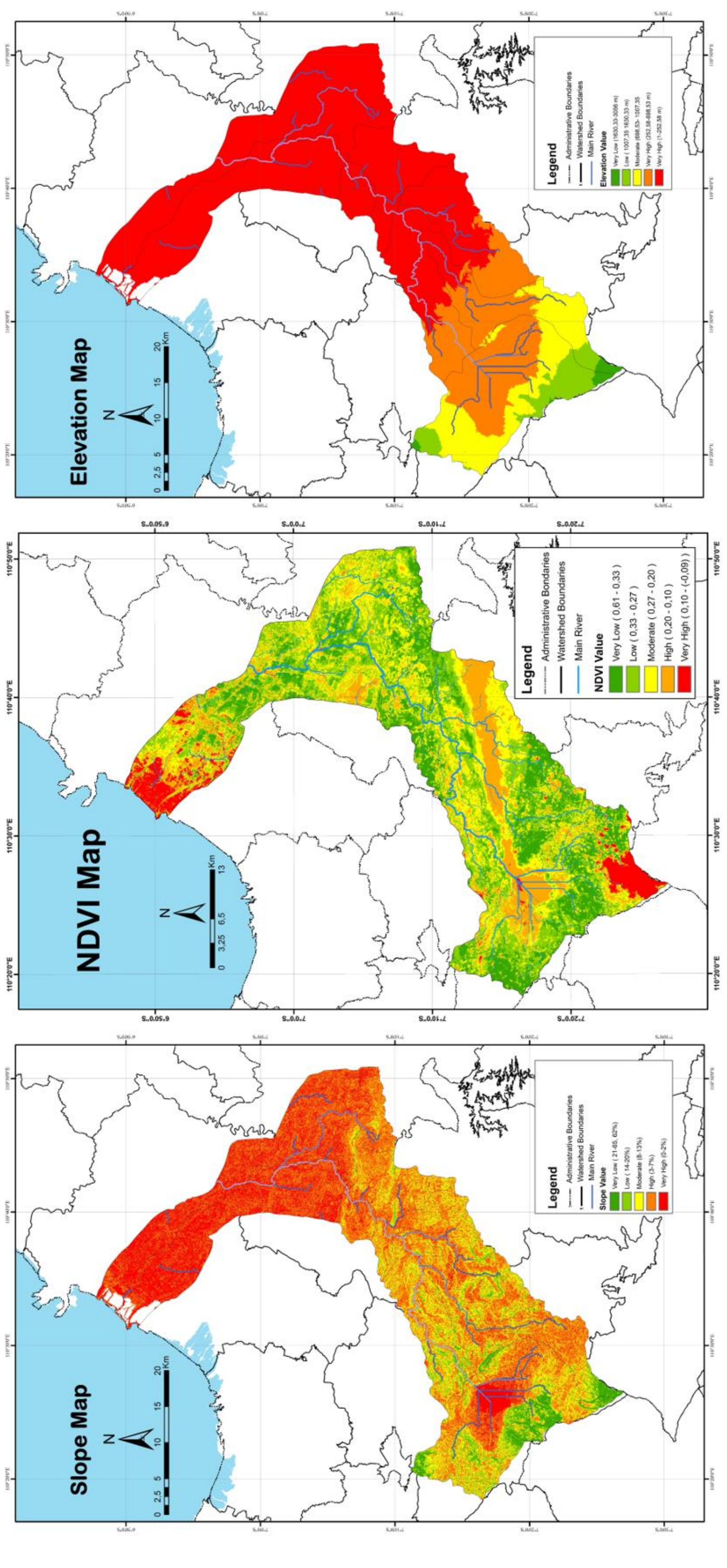


**Fig. 4.** Spatial parameter of flood hazard potential zones: slope– **d,** NDVI– **e,** elevation– **f.**

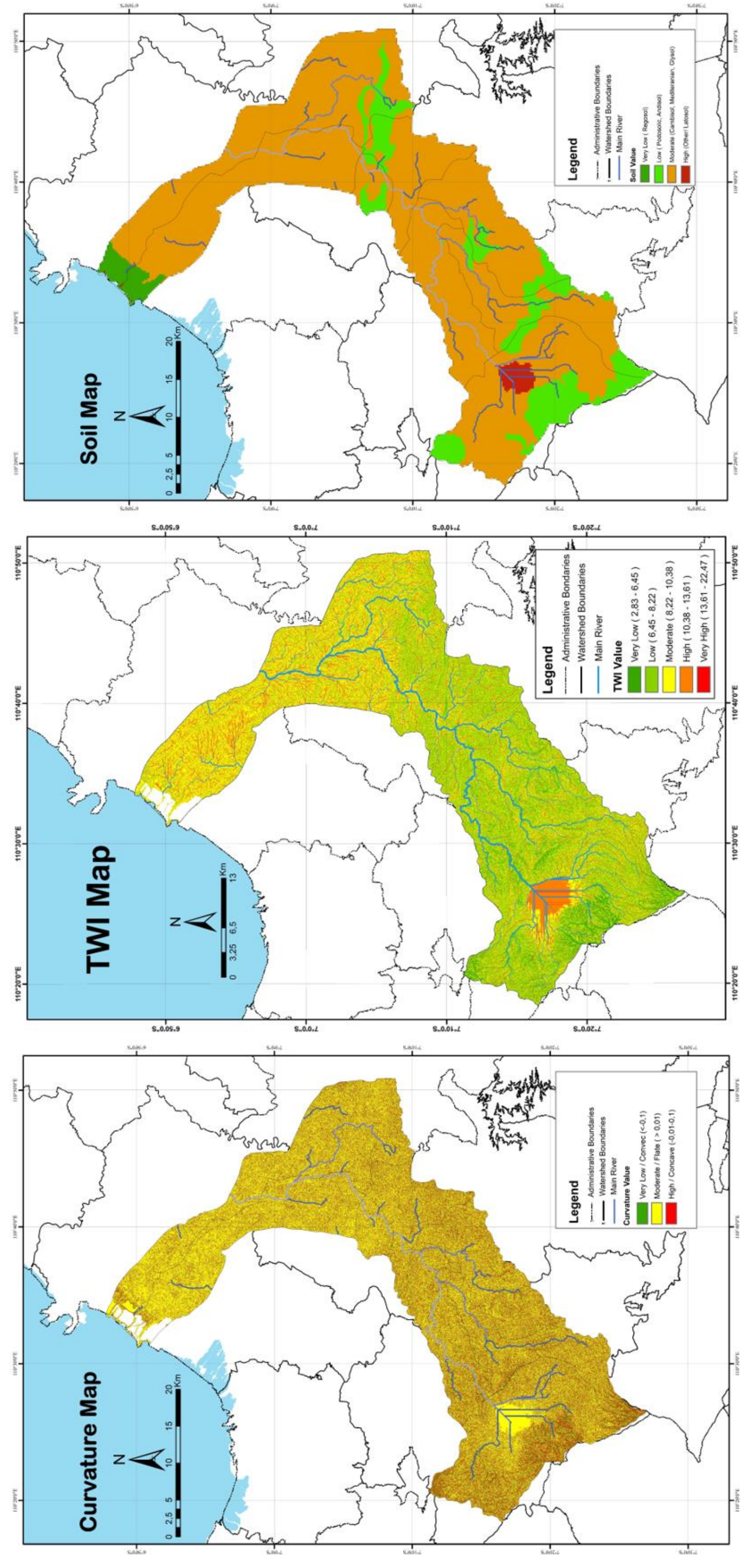


**Fig. 4.** Spatial parameter of flood hazard potential zones: curvature– **g,** TWI-**h,** soil– **i**.

### 4.2. Identification of Flood Hazard Potential Zones

This study identifies the most influential factors on floods using nine predetermined criteria. The selected parameters are tailored to the proximity and relevance to the geographical conditions of the Tuntang Watershed. Floods in the upstream areas of the watershed, accompanied by erosion and lack of infiltration areas, have influences for downstream areas such as Semarang and Grobogan. These findings highlight the need for caution, especially during the rainy season, as all activities along the watershed may be at risk of flood impacts in certain areas (Development Planning Agency at Sub-National Level of Grobogan District, 2021; Priyana et al., 2014; Safitri et al., 2017).

The findings indicate that the Tuntang Watershed has a high flood hazard, primarily in the upstream and middle part of watershed areas. Based on **Fig. 5.** and **Table 6**., the three largest locations with very low flood hazard (shown in dark green on the map) are Semarang covering 60.48 km$^2$ (5.09%), Grobogan covering 2.13 km$^2$ (0.18%), and Salatiga covering 2.13 km$^2$ (0.18%). Locations with lowflood hazard (light green on the map) are Semarang covering 107.70 km$^2$ (9.06%), Grobogan covering 38.04 km$^2$ (3.20%), and Demak covering 13.50 km$^2$ (1.14%). Locations with moderate flood hazard (yellow on the map) are Semarang covering 151.54 km$^2$ (12.75%), Grobogan covering 90.14km$^2$ (7.58%), and Demak covering 55.54 km$^2$ (4.67%). Locations with high flood hazard (orange on the map) are Grobogan covering 183.31 km$^2$ (15.42%), Semarang covering 148.75 km$^2$ (12.51%), and Demak covering 110.14 km$^2$ (9.26 %). Locations with very high flood hazard (red on the map) are Grobogan covering 102.17 km$^2$ (8.59 %), Demak covering 49.75 km$^2$ (4.18%), and Semarang covering 45.23 km$^2$ (3.80%). Areas with high and very high flood hazard require special attention, especially during the rainy season with rainfall exceeding 200 mm/month in the wet months.

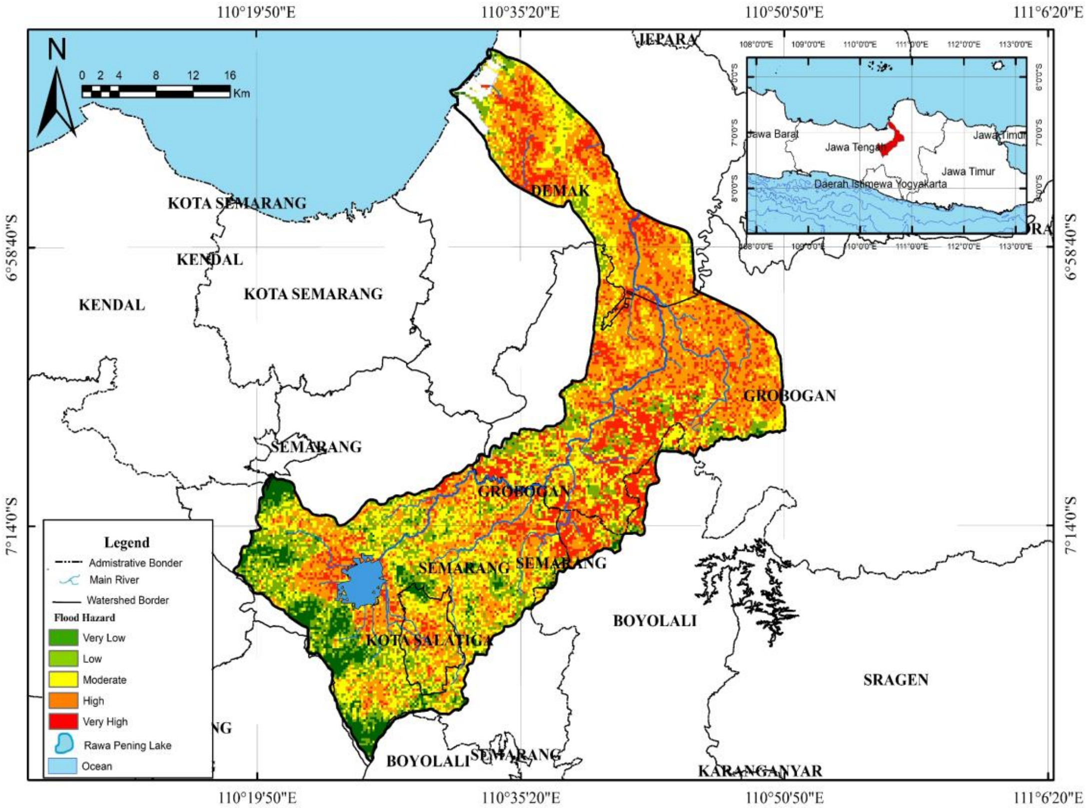


**Fig. 5.** Spatial distribution of flood hazard.

Table 6.

**Results of flood hazard modeling area using AHP.**

| Regency / City | Area of Classes | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WB | % | VL | % | L | % | M | % | H | % | VH | % | |
| **Demak** | | | 0.815 | 0.07% | 13.5 | 1.14% | 55.54 | 4.67% | 110.14 | 9.26% | 49.75 | 4.18% | **231.20** |
| **Grobogan** | | | 2.13 | 0.18% | 38.04 | 3.20% | 90.14 | 7.58% | 183.31 | 15.42% | 102.17 | 8.59% | **346.84** |
| **Semarang** | 0.26 | 0.02% | 60.48 | 5.09% | 107.7 | 9.06% | 151.54 | 12.75% | 148.75 | 12.51% | 45.23 | 3.80% | **511.22** |
| **Boyolali** | | | 1.69 | 0.14% | 5.24 | 0.44% | 9.67 | 0.81% | 11.24 | 0.95% | 19.67 | 1.65% | **46.62** |
| **Salatiga** | | | 2.13 | 0.18% | 6.96 | 0.59% | 18.31 | 1.54% | 20.51 | 1.73% | 5.11 | 0.43% | **53.04** |
| **Total** | | | **67.24** | **5.66%** | **171.44** | **14.42%** | **325.2** | **27.35%** | **473.95** | **39.86%** | **221.93** | **18.67%** | **1,188.92** |

*Note: WB – water body (km²), VL – very low hazard (km²), L – low hazard (km²), M – moderate hazard (km²), H –high hazard (km²), VH – very high hazard (km²).*

## 5. DISCUSSIOS

Upon examining **Fig. 5.**, it can be seen that in the upstream area of the Tuntang Watershed, there is already a natural lake called Rawa Pening (water body) that can serve as a natural reservoir in flood control efforts for the upstream area of the Tuntang Watershed. However, according to the research by Murtiono & Wuryanta (2016), there has been an increase in sedimentation every year, from 133.75 $m^3$ in 1993 to 149.22 $m^3$ in 2003. As a result of this eutrophication, the water storage capacity in Rawa Pening has decreased by around 16 million $m^3$ over a period of 28 years (Murtiono & Wuryanta, 2016). The changes in LULC from satellite images Sentinel-2A year 2012, 2017, and 2022 were presented on the **Fig. 6.**

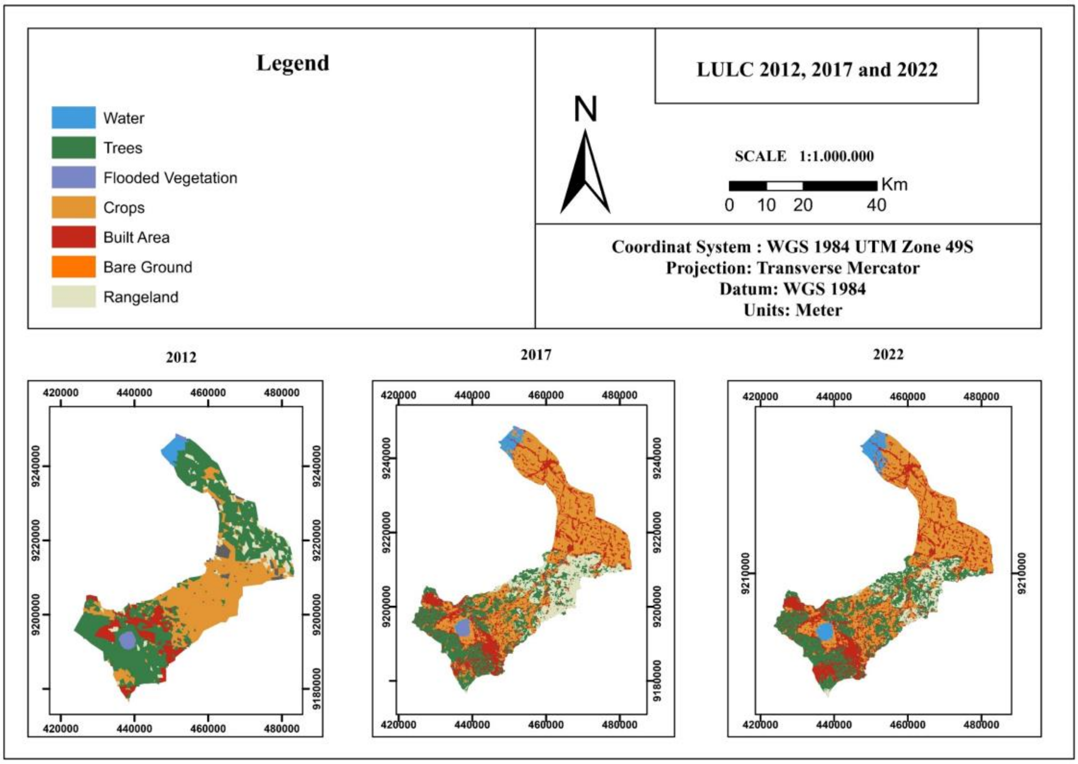


**Fig. 6.** LULC map changes between year 2012, 2017, 2022.

**Table 7.**
**LULC area changes between year 2012, 2017, 2022.**

| LULC | Area (km²) | | |
|---|---|---|---|
| | **2012** | **2017** | **2022** |
| Built Area | 107.17 | 258.73 | 292.97 |
| Trees | 595.72 | 289.16 | 352.15 |
| Water | 28.95 | 29.50 | 57.65 |
| Bare Ground | 29.91 | 0.25 | 0.01 |
| Rangeland | 75.13 | 176.99 | 96.83 |
| Crops | 449.53 | 531.55 | 497.47 |
| Flooded Vegetation | 19.34 | 14.19 | 32.94 |

*Source: Satellite image data of Sentinel-2A, 2023.*

Besides riverbed sediment conditions, LULC changes flood hazard occurrences in the Tuntang Watershed. According to Lusi & Afrizal (2015), flood disaster mitigation in a watershed can begin with regulations on land use and spatial planning around the watershed, enforced through both central and regional government legislation. **Fig. 6**. LULC change through Sentinel 2A satellite imagery for the last ten years, namely 2012, 2017, and 2022, shows a significant LULC change. The largest area ofchange is the built area, with an increase of 14.29% between 2012-2022. The appearance of the built area on the map is seen to lead to the north or downstream area of the watershed and around Rawa Pening Lake. Fluctuations in the upward change trend also occurred in crops and rangeland, which increased in 2017 and decreased in 2022. In addition, other changes in trees, water, and flooded vegetation were detected by Sentinel 2A data. In 2017, there was a significant reduction of 23.58% intree area, but it increased again by 4.84% in 2022. It is most likely related to trees growing and being detected by satellite imagery. Meanwhile, other significant changes were in water cover and flooded vegetation, which increased by 2.2% and 1.04% between 2012-2022.

In terms of climate, based on 30-year statistical observation in **Table 2.** (1992-2022) from 11 meteorological stations around the Tuntang watershed in **Fig. 1.** and CHRIPS data analysis, annual rainfall in the study area ranges from 1,154.18 mm/year to 3,989.92 mm/year. Cartographically, it can be seen in **Fig. 4a.** about the parameters for precipitation. The monthly rainfall intensity gradually increases from December to February (Murtiono & Paimin, 2016; Mujib et al., 2021). Dynamic changes such as LULC, urbanization, and increased household density in flood-prone areas will increase the likelihood of flood risk (Pelling, 2003). Land use in the study area is mainly crops, trees, and built areas (**Fig. 6.** and **Table 7.**). When linked to the average rainfall data for the last 30 years, there is an increase in water input into the watershed. It implies that LULC change and sediment significantly affect flood infiltration and runoff. Flood is also directly caused by heavy rainfall, which affects runoff volume, filling or even overflowing the drainage canal network, leading to very high discharge downstream and outlet of the watershed (Youssef, 2009; Mujib et al., 2021). The results of rainfall weighting based on focus group discussion shows a high percentage level because rainfall influences the infiltration process of the soil, which makes soil cavities that should be dry and filled with water.

The results of distance to river has a weight of 22.3% (**Fig. 4b.**). It shows a distance to river almost comparable to rainfall. The almost comparable weighting results were determined by expert judgment by taking opinions from experts and previously published research to support the FGD process (Saaty, 1987; Das, 2018; Upwanshi et al., 2023). The proximity of the river causes runoff that cannot be accommodated when the water discharge rises due to the small water boundaries in the flood hazard area, which causes a high volume of accumulation of water sent from higher slopes.

**Table 8.**
**Correlation between annual rainfall and discharge of Tuntang Watershed.**

| | | Annual Rainfall | Discharge |
|---|---|---|---|
| **Annual Rainfall** | Pearson Correlation | 1 | -.495 |
| | Sig. (2-tailed) | | .505 |
| | N | 4 | 4 |
| **Discharge** | Pearson Correlation | -.495 | 1 |
| | Sig. (2-tailed) | .505 | |
| | N | 4 | 4 |

*Source: Data Processing with SPSS, 2023.*

The correlation results in **Table 8**. show a significant level at 0.505, indicating that the two variables, rainfall from **Table 2.** and the discharge of Tuntang Watershed year 1935-2015 (Maulana et al., 2017), do not have a significant relationship. The N value of only four variables affects the significance value. The analysis further indicates that the correlation is insignificant for upstream, middle part of watershed, and downstream meteorological stations. The correlation value is at -0.495, meaning rainfall has a moderate correlation with the increase in Tuntang watershed discharge. The two variables had a negative relationship where annual rainfall greater than discharge. Hence, high rainfall does not significantly affect the increase in water discharge in the Tuntang watershed. In this case, other factors affect the intensity of flooding in the Tuntang watershed besides rainfall, including the distance to the river and significant LULC in the catchment zone. The results of this study show that rainfall, distance to the river, and land use change have significant weights in flood hazard analysis. In addition to the three most significant influential factors from the AHP results through FGDs, it is still necessary to conduct an in-depth study of 6 other factors that have a smaller portion in flood disasters in the Tuntang watershed, including slope, NDVI, elevation, curvature, TWI, and soil.

## 6. CONCLUSIONS

This study successfully comprehensively modeled flood hazard zones in the Tuntang Watershed. The uniqueness of the research and its innovative character lie in the multi-criteria analysis AHP method used. Nine parameters influencing flood hazard were weighted based on expert assessments. The research identified five hazard zones: very low, low, moderate, high, and very high. AHP seem to be more efficient, particullary for modelling flood hazard with large area (**Fig. 5.**). According to the results, the highest priority has precipitation, distance to the river, LULC, Slope, NDVI, elevation, curvature, TWI, and soil, contributing to periodic floods in some administrative areas (**Fig.4.**). Factors such as high rainfall in the upstream areas, proximity to rivers, land use and land cover changes, and slope variations play significant roles in influencing water level fluctuations. A decision support tool must be supported by survey or field visit. Based on the modeling results, administrative areas falling under the category of very high hazard are Grobogan, Semarang, and Demak.

Preventive measures and flood disaster mitigation are necessary to reduce the impact of material and human losses in these regions. In other hand, it would be important to combine other methods, interm of watershed management. Flood prevention in the upstream and middle part of the Tuntang Watershed can be achieved through flood disaster mitigation. The mitigation process requires the involvement of various stakeholders, including the government, experts (academics), and communities living along the Tuntang Watershed, especially those residing in high and very high-hazard zones. In addition, proper, and secure evacuation routes and shelters should be prepared to minimize both material and non-material losses during flood events.

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