Identification of flood prone areas based on Geographic Information System (GIS): a case study of Buntulia District, Pohuwato Regency, Gorontalo Province

by Sri Maryati

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Identification of flood prone areas based on Geographic Information System (GIS): a case study of Buntulia District, Pohuwato Regency, Gorontalo Province

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Abstract. This study aims to identify flood-prone areas in the Buntulia district. The types of data used in this study are primary data and secondary data. Data analysis techniques used to determine flood-prone areas are scoring and overlaying of three parameters, namely, slope maps, rainfall maps, and land use maps. The results of this study are to determine flood-prone areas based on Geographic information systems (GIS) in Buntulia District, Pohuwato Regency, Gorontalo Provinsi. To find out the number of flood-affected areas, it is carried out using a mapping of flood-prone areas, so that it is divided into four levels of flood vulnerability, namely the very vulnerable level of 1275 hectares (2.93%), the vulnerable level of 4493 hectares (10.35%), moderate level vulnerable area of 21406 hectares (49.31%), and the level of the non-vulnerable area of 16221 hectares (37.37%).

1. Introduction
Natural disasters in Indonesia have a high potential impact on infrastructure damage, economic losses, and casualties. The disaster that occurred is a serious concern. The increasing risk of disasters causes concern. Geographically, Indonesia is located in the ring of fire, increasing the risk of volcanic eruptions, storms, floods, hurricanes, earthquakes, and tsunamis. The increase in geological and hydrometeorological disasters impacts the environment, life, and economy [1,2].

Disaster events in Indonesia show an increase in its symptoms, such as extreme rain or rain with high intensity. A flood is an event where the water in the channel increases and exceeds its carrying capacity. Floods that occur have distinctive characteristics. There are various floods, namely upstream, extreme rain, postal, and flash floods. Flash floods occur due to high rainfall, with flooding events in about 5-6 hours. In addition, flash floods and heavy rains can trigger landslides [1].

One of the impacts of the flood is the inundation of residential areas and agricultural land. Other impacts of floods include economic losses and infrastructure damage. Floods are natural disasters that are usually caused by both natural and human factors. One of the factors causing the flood disaster in the Buntulia Sub-district comes from careless management of waste by the community. Land use that is not following conservation regulations has resulted in reduced vegetation in the Buntulia Sub-district that triggers the incidence of the flood.

Natural disasters hit almost all regions in Indonesia, one of which is Gorontalo Province. Gorontalo Province has five districts and one municipality, Boalemo District, Bone Bolango District, Gorontalo District, Gorontalo Utara District, Pohuwato District, and Gorontalo Municipality. Every district and municipality in Gorontalo Province has an area often hit by floods during the rainy season.

Based on Statistics Indonesia in Pohuwato District (2018), Buntulia District is a flood susceptible area. Buntulia District consists of seven villages, namely Buntulia Utara, Taluduyunu, Hulawa, Buntulia Tengah, Karya Indah, Sipatana, and Taluduyunu Utara. Three villages in Buntulia Sub-district that often experience floods are Taluduyunu, Hulawa, and Karya Indah. These areas are very susceptible to flood during the rainy season. Buntulia Sub-district is traversed by two major rivers, the Taluduyunu River and the Botudulanga River, which flow into Tomini Bay. Most of the economic activities of the Buntulia Sub-district community are in the form of plantations and mining. The expansion of rural activities, including industry, economy, settlements, and the hydrological cycle, has resulted in several areas becoming susceptible to floods.

According to the community, the flood in Buntulia District overflowed up to 50 centimeters when high rainfall occurs within 1-2 hours, inundating several villages around the riverbanks. One of the efforts to overcome the impacts of the flood is understanding the causes of flood and flood susceptible areas that depend on the area's climatological, hydrological, and physical characteristics.

An area is classified as susceptible to flood if it has high rainfall intensity, low soil capacity or water-saturated soil, impermeable surface, and damaged forest conditions [3]. One of the disciplines that enable to map in flood studies is Geographic Information Systems (GIS), which is applied to identify and map flood susceptible areas.

2. Methods

2.1 Study Location

This study was conducted in Buntulia Sub-district, Pohuwato District, Gorontalo Province, with 434.08 Km^2. Buntulia Sub-district administratively consists of seven villages namely, Buntulia Tengah, Buntulia Utara, Hulawa, Karya Indah, Sipatana, Taludyunu, and Taluduyun Utara, which are shown in Figure 1.

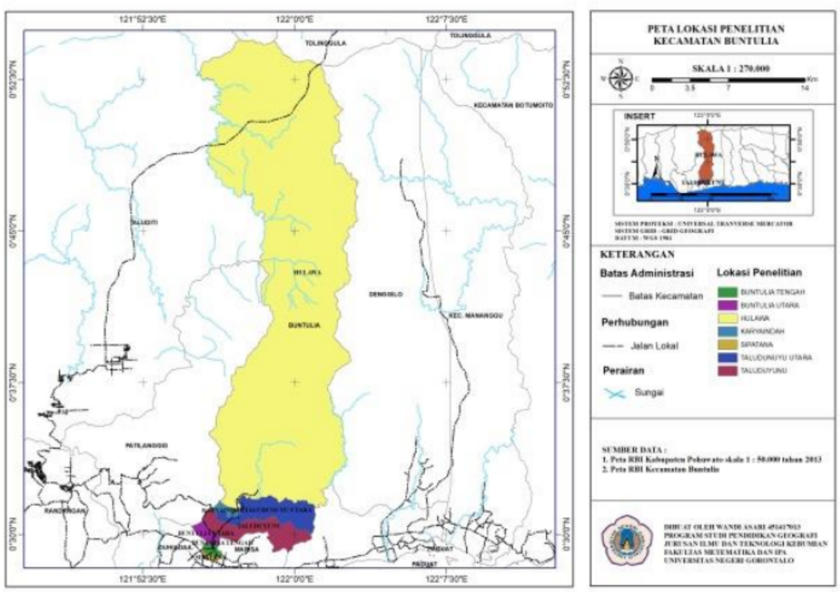

Figure 1. Study Location Map

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2.2 Types of Data
This study used primary and secondary data

2.2.1 Primary Data
a. Community perception of flood
b. Community interviews about flood susceptible issues
c. Community interviews about flood characteristics that include return period (frequency of flooding), inundation depth, and duration of inundation.

2.2.2. Secondary Data
a. Slope map to classify slope classes in each area in the study location.
b. Rainfall map to classify rainfall in the study location.
c. Land use map to classify land in the study location.

Table 1. Types and Sources of Data

No	Types	Sources	Purpose
1	Slope	DEMNAS Imagery of Pohuwato District	classify slope classes in each area in the study location
2	Rainfall	Meteorological, Climatological, and Geophysical Agency of Bonebolango	classify rainfall in the study location
3	Land Use	Geospatial Information Agency	classify land in the study location

(Source: Author)

2.3 Data analysis method
The method used to determine flood susceptible areas was scoring on each variable and direct interviews with the community in the study location. The scoring method for each variable resulted from multiplying and adding the factors and variables used to determine the flood susceptible area by subtracting the highest and lowest values with the previously determined hazard class. Meanwhile, observation is a method of collecting data systematically through observation and recording the phenomenon in the study. Researchers conduct direct observations on the study location and interacted intensely with the community during data collection

2.3.1. Score and Weighting
The distribution of flood susceptible areas was determined by scoring the value of each parameter. These parameters were slope, rainfall, and land use that were given a different score according to the influence of the parameter on the effect of a flood. The score value was adjusted to the conditions and effects of flooding. The scoring was defined as giving a score to each class. According to Suherlan (2001)[4], the scoring was based on the impact of the class on the magnitude of the flood. Table 2 shows the weighting factors for the classification of flood susceptible areas in the Buntulia Sub-district.

Table 2. Rating of Flood Susceptible Classification

No	Parameter	Skor	Bobot
1	Slope	1-5	30
2	Rainfall	1-5	30
3	Land Use	1-5	30

Based on Table 2 each parameter was given a score of 1-5, and each parameter was given a weight of 30 because each parameter had an equal effect. In determining flood susceptible areas, each score and weight were summed to obtain the highest and lowest values used as the reference in dividing the number of classes and class intervals of flood susceptibility.

2.3.2. Total Score of the Summation
After all the parameters in determining flood susceptibility are overlaid, the next step is the summation of the total scores to obtain the total value of all overlaid parameters. The equation used to calculate the total score in determining flood susceptibility [5] was:

Flood susceptibility = 30(CH) + 30(KL) + 30(PL)

where: CH = Rainfall
KL = Slope Class
PL = Land Use
30,30,30, = Weighting Factor/Weight

The weighting factor for each parameter was given the same value, namely 30, because each parameter had an equal effect. In rainfall, a weighting factor of 30 was given with an influence on flood susceptibility; the higher the rainfall, the greater the incidence of flooding. The slope was given a weighting factor of 30. This physical land parameter has a significant effect on flood susceptibility. The steeper the slope in heavy rain, the rain always flows to low areas until it reaches plain areas. Land use is an influential factor in flood susceptibility. It has a weighting factor of 30 since excessive land use can cause the surrounding vegetation to decrease, harming the environment, and causing flood susceptibility.

2.3.3. Class Interval Determination
The number of classes used in this study was 4 (four). The score of each physical parameter had been multiplied by the weighting factor. The level of flood susceptibility is obtained if the value of flood susceptibility is high. The score is the result of the sum of the highest scores of each parameter—the lower the flood susceptibility score, the lower the flood susceptibility level. The flood susceptibility score for each parameter can be seen in Table 3.

Table 3. Flood Susceptibility Criteria

No	Class Interval	Class Interval
1.	90-157	Non-susceptible
2.	158-224	Moderately Susceptible
3.	225-291	Susceptible
4.	292-358	Very Susceptible

(Sumber: Author's Calculation Result)

The formula used to determine the class interval class is: :

$$\text{Class Interval} = \frac{\text{Highest Score} - \text{Lowest Score}}{\text{Number of Classes}}$$

$$\text{Class Interval} = \frac{358 - 90}{4} = 67$$

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After the overlay, the determination of the total score was beneficial in determining the number of flood susceptibility classes and the flood susceptibility class intervals. The class interval was used to classify the overlay results into the level of flood susceptibility. The number of classes and class intervals can be calculated using the Sturges equation, as follows:

$$k = 1 + 3.3 \log n$$

Source : [6]
where:
k = number of classes n = number observation

$$R = \text{Maximum Value} - \text{Minimum Value}$$

where: R = the difference between the largest and the smallest data

$$i = \text{range} : \text{class}$$

The value of an area's susceptibility to flooding is determined from the total score of each flood parameter. Areas that are very susceptible to flooding will have a high total score and vice versa. After obtaining the flood susceptibility value, the map is analyzed using overlay analysis. The results of the analysis are presented in the form of a flood susceptibility map.

3. Results And Discussions

3.1 Results

Analysis of the level of susceptibility to flooding was the output of this study. Analysis of the level of susceptibility to flooding was carried out to provide information to the surrounding community to be more careful and alerted to the flood potential. Analysis of the level of flood susceptibility was carried out by combining the three parameters used in this study, namely the slope class, rainfall, and land use in Buntulia Sub-district. The rainfall data were obtained from the Meteorological, Climatological, and Geophysical Agency of Bonebolango District in the form of rainfall data from 2016-2020. The slope data were obtained from the DEMNAS Imagery of Pohuwato District, and the land use data were obtained from the Geospatial Information Agency. Each data was georeferenced and then digitized to obtain new information in the form of vector data.

After the data for each parameter became vector data, it was overlaid using union overlay analysis before being scored and weighted. The score given for each parameter ranged from 1,2,3,4,5. The higher the score, the higher the level of susceptibility. The weighting was based on the effect of the parameters on the flood potential.

3.1.1 Slope

Table 4. Score and Weight of Slope

Slope Class	**Slope%**	**Score**	**Weight**	**Weight x Score**	**Area (Ha)**	**Area %**
Flat	0-8%	5	30	150	1521	3.50%
Plain	8-15%	4	30	120	2283	5.26%
Moderately Steep	15-25%	3	30	90	4410	10.16%
Steep	25-45%	2	30	60	14031	32.32%
Very Steep	>45%	1	30	30	21163	48.75%
	Total				**43408**	**100.00%**

Slope class is an essential parameter in analyzing the level of susceptibility to flooding with a weight of 30%. The very steep slope class with a slope of >45% dominates the Buntulia Sub-district area with an area of 21163 Ha or about 48.75% of the total area of the Buntulia Sub-district. Areas with a very steep slope have a high flood potential.

In general, the morphological description of the Buntulia Sub-district administrative area consists of mountainous land, hills, and lowlands. The description of the morphology of the Buntulia Sub-district is based on the results of field observations. This description is also supported by the results of slope class mapping using the DEMNAS Imagery of Gorontalo in 2020. Class parameters are the most critical parameters in analyzing the flood potential. The slope class classification in this study used DEMNAS Imagery of Gorontalo in 2020.

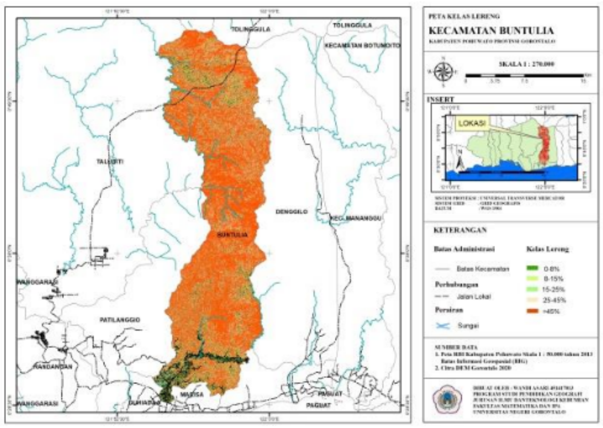

Figure 2. Slope Map of Buntulia Sub-district

3.1.2 Rainfall

Table 5. Rainfall Score and Weight

Description	Rainfall (mm/year)	Score	Weight	Weight x Score	Area (ha)	Area %
Very wet	>3000mm	0	0	0	0	0
Wet	2501mm-3000mm	3	30	90	4350	10.02%
Moderate/humid	2001-2500mm	3	30	90	7451	17.16%
Dry	1501mm-2000mm	2	30	60	16452	37.90%
Very dry	<1500mm	1	30	30	15155	34.91%
	Total				**43408**	**100.00%**

Rainfall is the most critical parameter in the level of susceptibility to flooding, with a weight of 30%. The prediction is that if the rainfall is high, the potential for flooding is higher. The rainfall in Buntulia Sub-district was in 2001-2500 mm/year, which is included in the moderately humid category. Rainfall in Buntulia Sub-district can be classified in the range of 2001-2500 mm/year that makes it categorized as moderate/humid with an area of 10.02%, with the prediction that if high rainfall occurs, it can cause flooding.

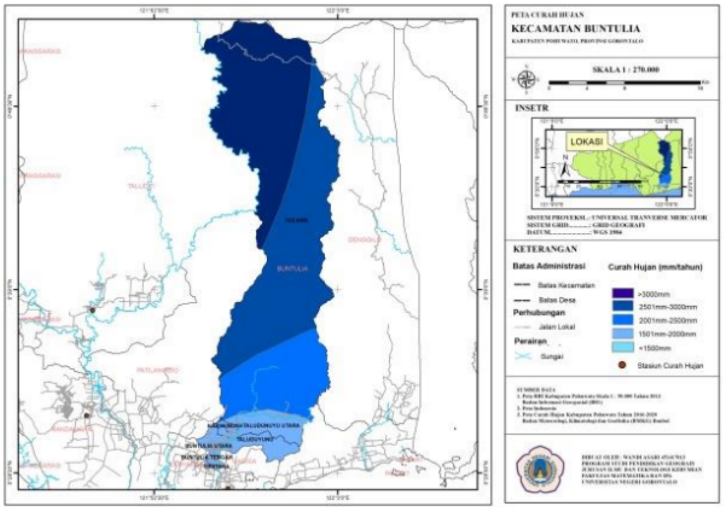

Figure 3. Rainfall Map of Buntulia Sub-district

3.1.3 Land Use

Table 6. Land Use Score and Weight

Land Use	Score	Weight	Weight x Score	Area (ha)	Area %
Forest	1	30	30	39498	90.99%
Sand	1	30	30	2	0.004%
Plantation	4	30	120	803	1.85%
Settlement	3	30	90	96	0.22%
Ricefield	3	30	90	205	0.47%
Shrub	3	30	90	7	0.02%
Mine	3	30	90	130	0.30%
Bare Land	2	30	60	20	0.05%
Moor	4	30	120	2647	6.09%
	Total			**4340**	**100.00**

Land use parameters are essential parameters in determining the level of susceptibility to flooding with a weight of 30% with a prediction that massive land management by cutting down trees, and excessive land exploration has a high flood potential because the trees that hold water and prevent erosion are reduced. The table illustrates that moor and plantation dominate the land use with a percentage of 6.09% and 1.58% respectively of the total area of Buntulia Sub-district.

In general, the morphology of the Buntulia Sub-district consists of mountainous land, hills, and lowlands. This description is also supported by the results of land use mapping using the data obtained from the Geospatial Information Agency. Land use in Buntulia Sub-district was classified into nine land use classes: forest, plantation, settlement, rice field, shrubs, mine, bare land, dry land, and sand. Settlements, ricefields, plantations, and moor were scattered in Hulawa Village, Karaya Indah Village, Taluduyunu Utara Village, Taluduyunu Village, Buntulia Utara Village, Buntulia Tengah Village, and Sipatana Village. Meanwhile, mines, sand, shrubs, bare land, and forests were scattered in Hulawa Village, Taluduyunu Utara Village, and Taluduyunu Village. Land use located in rural areas and rivers is more susceptible to flooding.

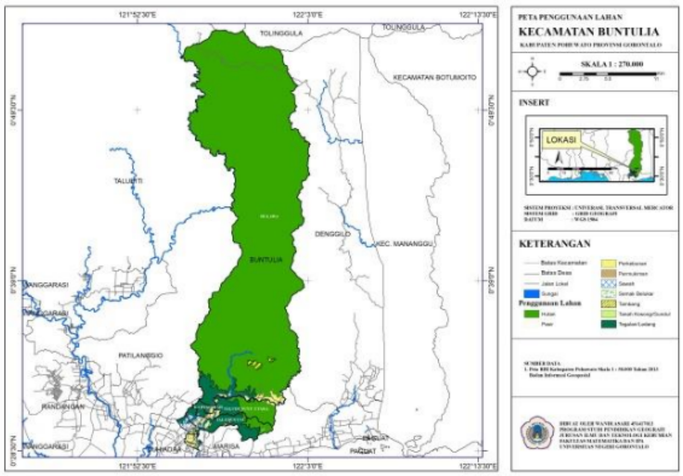

Figure 4. Land Use Map of Buntulia Sub-district

3.1.4 *Total Value and Map of Flood Susceptibility Level*

The total value was obtained from the sum of the scores and weights of each parameter after overlaying all the parameters used in the classification of the flood susceptibility map in the Buntulia Sub-district.

Table 7. Parameter Total Value

		Score	
No	**Parameter**	**Highest**	**Lowest**
1	Slope Class	150	30
2	Rainfall	90	30
3	Land Use	120	30
Total		**360**	**90**

Based on observations in seven villages in Buntulia Sub-district, three villages were identified as the place where floods occurred. Thus, the class was divided into several classes of susceptibility levels using the Sturges Equation.

$k = 1 + 3.3 \log n$
$= 1 + 3.3 \log 7$
$= 4$

where:
k = number of classes
n = number of observations
R = Maximum Value – Minimum Value
$= 360 - 90$

= 270
where : R = the difference between the largest and the smallest data
i = range : class
= 270 : 4
= 67
where: i = class interval

The susceptibility level analysis showed four categories: non-susceptible, moderately susceptible, susceptible, and very susceptible, with class intervals of 67.

Table 8. Flood Susceptibility Class

No	Class Interval	Class Category	Area (Ha)	Area %
1.	90-157	Non-susceptible	7272	16.75%
2.	158-224	Moderately Susceptible	26430	60.89%
3.	225-291	Susceptible	8326	19.18%
4.	292-358	Very Susceptible	1380	3.18%
Total			**43408**	**100.00%**

Table 9. Flood Susceptibility in the Buntulia Sub-district

Village	Flood Susceptibility Area (Ha)			
	Non-susceptble	Moderately Susceptible	Susceptible	Very Susceptible
Hulawa	15075	20296	3423	773
Karya Indah	7	62	75	83
Taluduyunu Utara	786	458	235	191
Taluduyunu	342	541	481	79
Buntulia Utara	3	30	188	66
Buntulia Tengah	2	8	58	53
Sipatana	6	11	30	30
Total	16221	21406	4493	1275
Area of the Buntulia Sub-district	43408			
Percentage (%)	37.37%	49.31%	10.35%	2.93%

The flood susceptibility class in Buntulia Sub-district was divided into 4, namely non-susceptible, moderately susceptible, susceptible, and very susceptible. All seven villages had different flood susceptibility classes. The very susceptible class was found in Hulawa Village with an area of 773 ha, Karya Indah Village with an area of 83 ha, Taluduyunu Utara Village with an area of 191 ha,

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Table 10. Flood Characteristics in the Buntulia Sub-district

No	Village	Flood Characteristics	
		Duration	**Depth (cm)**
1.	**Hulawa**	1-2 Jam	<50
2.	**Karya Indah**	2-6 Jam	<50
3.	**Taluduyunu Utara**	1-2 Jam	<50
4.	**Taluduyunu**	-	-
5.	**Buntulia Utara**	-	-
6.	**Buntulia Tengah**	-	-
7.	**Sipatana**	-	-

The flood characteristics in the Buntulia Sub-district had different durations and equal depth. Three villages were affected by the flood, and four villages were not affected by the flood. The villages affected by the flood were Hulawa, Karya Indah, and Taluduyunu Utara, with different durations and equal depth. Hulawa Village had a duration of 1-2 hours with a depth of <50 cm, Karya Indah Village had a duration of 2-6 hours with a depth of <50 cm, and Taluduyunu Utara Village had a duration of 1-2 hours with a depth of <50 cm. The villages not affected by the flood were Taluduyunu, Buntulia Utara, Buntulia Tengah, and Sipatana.

The overlay was conducted using union overlay analysis by involving spatial elements in the form of each parameter map and attribute. After the class and class interval were determined, the susceptibility area was calculated and mapped using three parameters, namely slope class, rainfall, and land use.

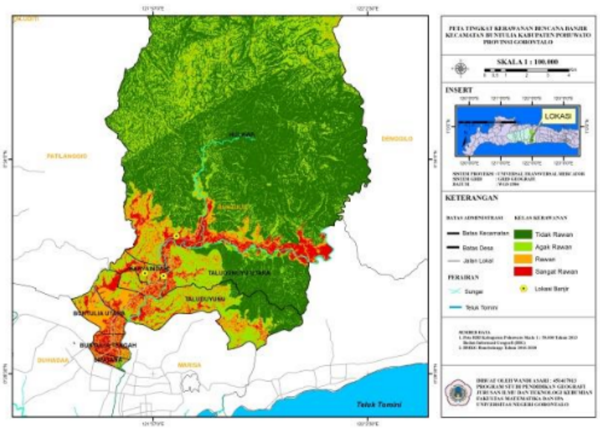

Figure 5. Flood Susceptibility Map

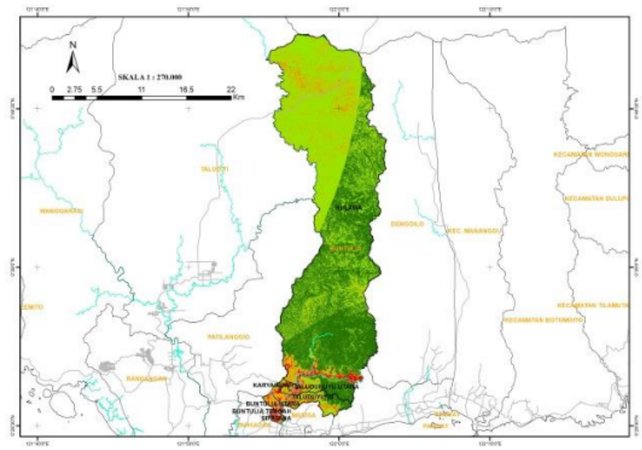

Figure 6. Flood Susceptibility Map

Thee Buntulia Sub-district is an area that is susceptible to flooding. The slope class is very steep with >45%, the rainfall was in the moderate/humid category with 2001-2500 mm/year, and the land use is dominated by moor with 6.09%, plantations with 1.85%, and mines with 130%. It is traversed by two major rivers, the Taluduyunu River and the Botudulanga River, flowing into Tomini Bay.

The results of the flood susceptibility analysis, the Buntulia Sub-district was dominated by the very susceptible category with 2.93 % of the total area symbolized by red on the map, followed by the susceptible category with an area of 10.35% symbolized by brown on the map, moderately susceptible category with an area of 49.31% symbolized by light green, and the non-susceptible category with an area of 37.37% symbolized by dark green.

3.2 Discussion

3.2.1 Flood Susceptibility Analysis

Analysis of susceptibility to flooding is a way of determining the flood disaster suscep ibility of an area. The level of flood susceptibility in the Buntulia Sub-district is described through a map of the flood susceptibility level. In this study, analyzing the level of susceptibility to flooding used descriptive qualitative analysis methods and scoring. The use of this method was to make it easier for researchers to describe flood susceptible areas in Buntulia Sub-district.

The scoring method was used to give a value for each parameter for further processing to produce data on the level of susceptibility to flooding in the Buntulia Sub-district. The parameters used in determining the level of susceptibility to flooding were slope class, rainfall, and land use obtained from the Meteorology, Climatology and Geophysics Agency (BMKG), DEMNAS Imagery in 2020, and the Geospatial Information Agency (BIG). The attribute table of those data was georeferenced for further processing.

A field survey was conducted to obtain coordinate data of flood locations spread in three villages, namely Hulawa, Karya Indah, and Taluduyunu Utara. The field survey aimed to obtain direct information through observations and interviews with the local community. Field conditions can also determine the duration and the depth of the inundation and observe the potential losses experienced by the local community.

The parameters used in this study were slope class, rainfall, and land use. In terms of slope class, the Buntulia Sub-district is a very steep area with 48.75% of its area has a slope of > 45%. Water flowing from upstream will quickly flow downwards so that residential areas located in lowlands will be affected by floods. Then the rainfall in Buntulia Sub-district is in the range of 2001-2500 mm/year with moderate/humid rainfall. Thus, a fairly high amount of rain can cause flooding since the area is traversed by two large rivers that flow to Tomini Bay. The land use in Buntulia Sub-district is dominated by dry land, plantations, and mining sites. The use of dry land, plantations, and mining on a large scale can damage the vegetation that functions as a water reservoir and erosion barrier. The plantation covers 1.85%, the dry land covers 6.09%, and the mining sites cover 0.30% of the total area of the Buntulia Sub-district.

After each parameter was georeferenced, the attribute table was converted into vector data to assess each parameter. The assessment was given with intervals of 1,2,3,4, and 5. The higher the rating assigned, the higher the potential for susceptibility. The weights were given based on the effects of parameters on the potential for flood disasters. Each parameter was given a weight of 30% since all parameters have an equal effect.

After assigning values and weights to each parameter, the union overlay analysis was conducted to obtain data. Then, the values were summed to obtain the total value used as a class division for the level of flood susceptibility. Thus, four classes of flood susceptibility were obtained, namely non-susceptible, moderately susceptible, susceptible, and very susceptible. After obtaining the number of classes, the dissolve analysis was conducted to divide the susceptibility area by a total of 4 classes in the category of flood susceptibility.

The final result showed that there were four classes of flood susceptibility levels. Very susceptible with an area of 2.93% symbolized with red, susceptible with an area of 10.35% symbolized with brown, moderately susceptible with an area of 49.31% symbolized with light green, and non-susceptible with an area of 37.37% symbolized with dark green. The very susceptible category has a small area and only affected three villages, namely Hulawa, Karya Indah, and Taluduyunu Utara.

4 Conclusions

The level of flood susceptibility in the Buntulia Sub-district was classified into four categories, namely very susceptible with an area of 1275 ha (2.93%) which spread in Hulawa Village, Karya Indah Village, and Taluduyunu Utara Village, susceptible with an area of 4493 ha (10.35%) which extend in all villages in Buntulia Sub-district, moderately susceptible with an area of 21406 ha (49.31%) which spread in all villages in Buntulia Sub-district, and non-susceptible with an area of 16221 ha (37.37%) which extend in all villages in Buntulia Sub-district. The results showed that the areas affected by the flood disaster were Hulawa Village, Karya Indah Village, and Taluduyunu Utara Village.

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