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# Flood Vulnerability Assessment and Mitigation Strategy of Unda Watershed Using Geographic Information System

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**--------------------------------------------------------*ABSTRACT*---------------------------------------------------------**
*From 2017 until 2021, floods occurred in the Unda Watershed. To provide information related to flood disasters in the Unda Watershed, a mapping of vulnerable areas is needed. Flood hazards can be identified quickly, easily, and accurately through the Geographical Information System using the overlay method. This research can be used as the initial basis for decision-making for flood disaster mitigation strategy according to the location and level of vulnerability so that the negative impact of flooding in the Unda Watershed can be minimized. This research uses an overlay method with scoring between existing parameters, where a scoring process carries out each parameter by giving the weight and value according to each classification which is then overlaid. Based on the results of the overlay map of precipitation, slope, soil type, and land use, the vulnerability values in the Unda Watershed were obtained. The criteria for very low vulnerable are 0.53% of the total area of the Unda Watershed, 28.76% low vulnerable, 51.24% moderately vulnerable, 19.13% high vulnerable, and 0.34% very high vulnerable. The area's most vulnerable to flooding are dominant in the downstream area of the Unda watershed.*

***KEYWORDS:*** *Flood; Geographic Information System; Mapping, Mitigation; Vulnerability*

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## I. INTRODUCTION

A flood is an event of sinking the land by water. This phenomenon often occurs in various countries, including Indonesia [1]. A flood is a type of hydrometeorological disaster that occurs due to the volume of water that increases drastically to exceed the capacity of a channel or water flow[2]. Floods can affect our environment and in most vulnerable areas of the world, can cause damage, including loss of human life, damage to property and crops, disruption of transportation and utility services, and other damage arising from the disruption of economic activity [3].

Flood incidence globally is estimated to account for 43% of the total number of natural disasters and 47% of all weather-related disasters. Floods also affected 2.3 billion people in 1995-2015, with total damage of USD 662 billion. Currently, about 800 million people worldwide live in flood-vulnerable areas, and about 70 million of them are on average affected by flooding each year [4]. There have been 1,125 flood disasters in Asia from 1990 to 2010, which caused more than 6.76 million deaths and 132 million USD economic losses [5]. Flood vulnerable areas are areas that are vulnerable to or tend to be flooded. Meanwhile, the level of flood vulnerability can be determined based on the parameters that affect the occurrence of flooding.

The Unda Watershed is one of the potential watersheds in Bali Province with the Perennial river flow type. According to Bali-Penida watershed management bureau [6], the critical area of the Unda Watershed is 17.27 $km^2$ of critical potential, 8.72 $km^2$ of semi-critical, 95.95 $km^2$ of critical, and 100.85 $km^2$ of very critical. A large amount of critical land in the Unda Watershed causes flooding in the rainy season and drought in the dry season. In 2017, the water flow from the Unda River overflowed up to the road, almost even entering several residents houses [7]. Then in 2018, the Unda River in Klungkung Regency overflowed again due to heavy rains. The occurrence of a series of floods in a relatively short time and recurs every year requires more significant efforts to anticipate them to minimize losses [8].

Flood management is one of the efforts to maintain the safety and welfare of the community around watersheds, which are included in flood-prone areas. Flood vulnerability assessment is essential in risk management and flood damage assessment. Mapping the level of flood vulnerability is one form of flood vulnerability assessment that needs to be done as a basis for making appropriate mitigation policies to reduce these negative impacts.

Geographical Information System (GIS) techniques have been used successfully in flood vulnerability assessments [9][10]. Flood hazards can be identified quickly, easily, and accurately through the Geographical

Information System using the overlay method of flood parameters. High precipitation, topography, river morphology and slopes, and soil types will cause the area to be prone to flooding [11].

The aim of this research was to analyze the level of flood vulnerability using parameters of precipitation, slope, soil type, and land use for flood mitigation planning purposes using a geographic information system. This research purposes as an initial basis for decision-making for flood disaster mitigation efforts according to the location and level of vulnerability so that the negative impact of flood disasters in the Unda Watershed can be minimized.

## II. RESEARCH MATERIALS AND METHODS

**Study Area**

The Unda watershed is one of the watersheds located in the province of Bali. It is the second-largest watershed after the Ayung watershed in Bali Province, with an area of 230.91 $km^2$, as seen in Figure 1. The Unda watershed has upstream on Mount Besakih and downstream on Gunaksa Beach. Currently, the problems that often occur in the Unda watershed are sedimentation and flooding [12].

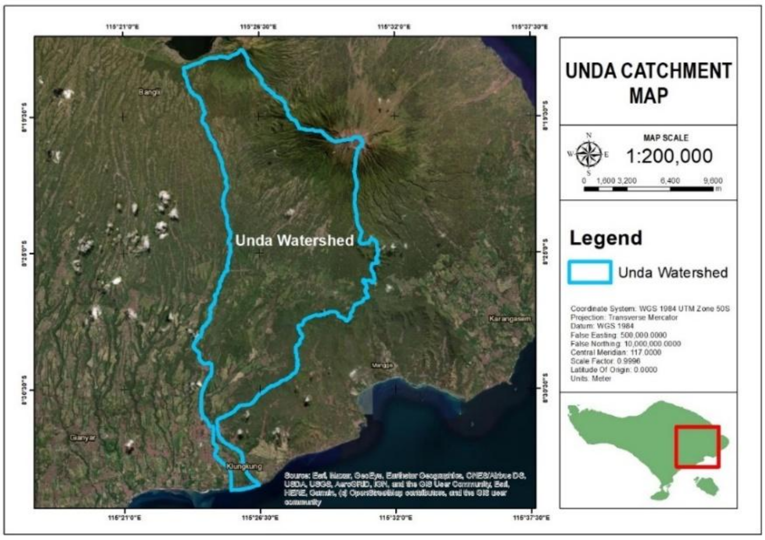


**Figure 1.** Unda Catchment Map

**Research Tools and Materials**

The tool used in data processing in this research is QGIS 3.10. This tool is used to generate slope data from DEM data. The data used in this study are Digital Elevation Model (DEM) data obtained from the National DEM built from several data sources, including IFSAR data (5m resolution), TERRASAR-X (5m resolution), and ALOS PALSAR (11.25 m resolution), by adding mass point data resulting from stereo plotting. The spatial resolution of DEMNAS is 0.27-arcsecond, using the vertical datum EGM2008. In addition to DEM data, this research used Watershed catchment data, precipitation data from 2014 until 2018, and land use obtained from Bali-Penida watershed management bureau. Furthermore, soil type data is obtained from digitizing soil maps of the Environmental Research Center Udayana University.

**Data Analysis Method**

The flood vulnerability map of the Unda Watershed was obtained from an overlay analysis with the help of a geographic information system (GIS). Geographical Information Systems can be one of the approaches for planning and decision making for disaster mitigation in vulnerability areas [13]. To obtain the slope map, a slope analysis was carried out from the DEM data, and then from the slope data, it was classified according to Table 1. Then the map of soil types, precipitation, and soil types was also classified according to Table 2-4. After all, maps have been classified, and it is continued by overlaying the map to obtain an overlay map of flood vulnerability. After overlaying with the help of QGIS 3.10, it was continued by multiplying the score for each parameter by the weight of each parameter according to Table 5. After obtaining the total weight multiplied by the score for each parameter, the total value was classified according to Table 6 to obtain the level of vulnerability. Then after getting the level of vulnerability, it can be suggested that mitigation strategies can be done.

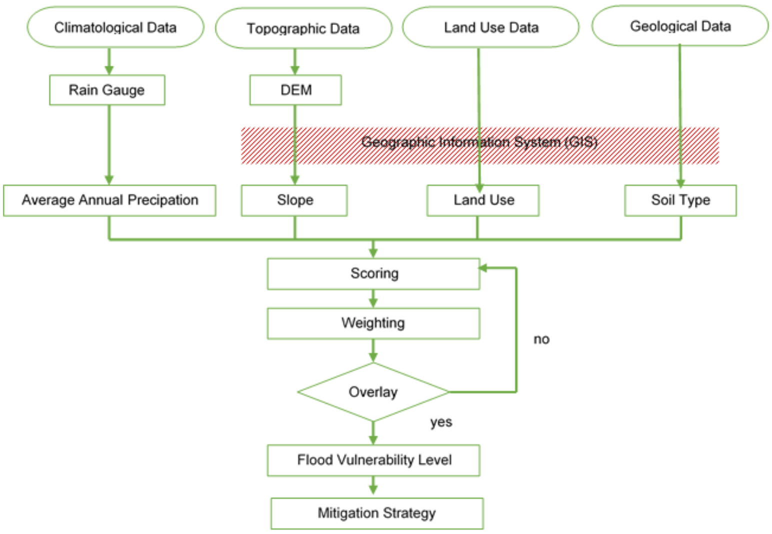


**Figure 2.** Data Analysis Framework

**Slope Scoring**

The slope is the percentage ratio between vertical (land height) and horizontal (flat land length)—the flatter the slope, the more potential for flooding, and vice versa. The steeper the slope, the safer it will be from floods.

**Table 1**. Slope Classification

| No | Slope (%) | Description | Score |
|---|---|---|---|
| 1 | >45% | Very Steep | 1 |
| 2 | 25% - 45% | Steep | 2 |
| 3 | 15% - 25% | Slightly Steep | 3 |
| 4 | 8% - 15% | Sloping | 4 |
| 5 | <8% | Flat | 5 |

Source: [14]

**Precipitation**

Precipitation is the amount of rainwater that falls in an area within a specific time. The precipitation required for the flood control design is the average precipitation throughout the area concerned, not the precipitation at a certain point which is usually called regional precipitation. Precipitation in a specific watershed will become runoff (Yulianur Bc, Azmeri, and Khairuddin, 2019), so that it becomes one of the parameters to predict the potential for flooding that occurs. The higher the precipitation, the more potential for flooding, and vice versa.

**Table 2**. Precipitation Classification

| No | Average Annual Precipitation (mm/year) | Description | Score |
|---|---|---|---|
| 1 | <1000 | Very Light Rain | 1 |
| 2 | 1000-1500 | Light rain | 2 |
| 3 | 1500-2000 | Moderate rain | 3 |
| 4 | 2000-2500 | Heavy rain | 4 |
| 5 | >2500 | Very Heavy Rain | 5 |

Source: [14]

**Soil Type Scoring**

Soil type is used as a parameter of flood vulnerability (Lincoln, Zogg, and Brewster, 2016; Kusmiyarti, Wiguna, and Ratna Dewi, 2018). The type of soil in an area is very influential in water absorption or what we usually refer to as the infiltration process. Infiltration is the process of vertically flowing water in the ground due to gravitational potential—the greater the soil infiltration, the smaller the flood-vulnerable level. In determining the flood hazard in an area, the precipitation factor is crucial because high precipitation intensity can cause flooding [18].

**Table 3**. Soil Type Classification

| No | Soil Type | Infiltration Rate | Score |
|---|---|---|---|
| 1 | Regosol, Litosol, Organosol | Very sensitive | 1 |
| 2 | Andosol, Lateric, Grumosol, Podsol, Podzolic | Sensitive | 2 |
| 3 | Brown Forest Land, Mediterranean Land | Medium Sensitivity | 3 |
| 4 | Latosol | A little sensitive | 4 |
| 5 | Alluvial, Planosol, Gray hydromorph, Lateric Groundwater | Not sensitive | 5 |

Source: [19]

**Land Use Scoring**

Land use will affect the flood vulnerability of an area. Land use will play a role in the amount of runoff water resulting from rain that has exceeded the infiltration rate. Land heavily planted with vegetation means much rainwater will be infiltrated, and the runoff will take more time to get to the river so that the possibility of flooding is less than in areas that are not planted with vegetation.

**Table 4**. Land Use Classification

| No | Land Use | Score |
|---|---|---|
| 1 | Forest | 1 |
| 2 | Plantation, shrubs | 2 |
| 3 | Agriculture, rice fields, moor | 3 |
| 4 | Settlements, mixed gardens, yard plants | 4 |
| 5 | Open land, rivers, reservoirs, swamps | 5 |

Source: [14]

**Overlay**

An overlay is an essential procedure in GIS (Geographical Information System) analysis. An overlay can place one map graphic on top of another map graphic and display the results on a computer screen or a plot. In short, an overlay overlays a digital map on another digital map and its attributes and produces a combined map of both that has the attribute information of the two maps. An overlay is a process of unifying data from different layers [20].

**Table 5**. Weight of each Parameter

| No | Parameter | Weight | Score | Max. Score |
|---|---|---|---|---|
| 1 | Slope | 4 | 1-5 | 20 |
| 2 | Soil Type | 2 | 1-5 | 10 |
| 3 | Land use | 2 | 1-5 | 10 |
| 4 | Precipitation | 3 | 1-5 | 15 |

Source: [17] with modification.

The arithmetic method used in the overlay process can be addition, multiplication, and power. For making the flood vulnerability map, the arithmetic method used in the overlay process of the flood vulnerability parameters is a method of multiplying the values and weights of each flood vulnerability parameter. Making the value of the flood vulnerability class interval aims to distinguish the flood vulnerability classes from one another. The formula used to create interval classes is as follows.

$$Ki = \frac{Xt - Xr}{k} \quad (1)$$

$$Ki = \frac{55 - 11}{5} = 8.8 \quad (2)$$

Where:

Ki = Interval class
Xt = Highest data (total score if all parameters get the highest score)
Xr = Lowest data (total score if all parameters get the lowest score)
K = the number of classes decided

A comparative approach determines the interval value by looking at the maximum and minimum values for each mapping unit. The interval class is obtained by finding the difference between the highest and lowest data and dividing by the number of classes desired. Flood vulnerability in this study is divided into five classes of vulnerability levels: very high vulnerable, highly vulnerable, moderately vulnerable, low vulnerable, and very low vulnerable.

**Table 6**. Flood Vulnerability Classification

| No | Vulnerability Level | Score |
|---|---|---|
| 1 | Very Low Vulnerable | 11 - 19.8 |
| 2 | Low Vulnerable | > 19.8 - 26.6 |
| 3 | Moderately Vulnerable | > 26.6 - 37.4 |
| 4 | High Vulnerable | > 37.4 – 46.2 |
| 5 | Very High Vulnerable | > 46.2 - 55 |

Source: Result Analysis (2021)

## III. RESULTS AND DISCUSSION

### The slope of Unda Watershed

Based on the data that has been obtained, to determine the slope of the data required is the Digital Elevation Model (DEM) data. The DEM data was then analyzed with the slope menu in QGIS. Then after getting the results of the slope analysis, the results are reclassified by creating five classes for five categories of slope and giving the percentage of each slope. After calculating it into five classes, the raster data is converted back into vector data (shapefile) using the raster to polygon feature. Based on the slope classification, the results are presented in Figure 3.

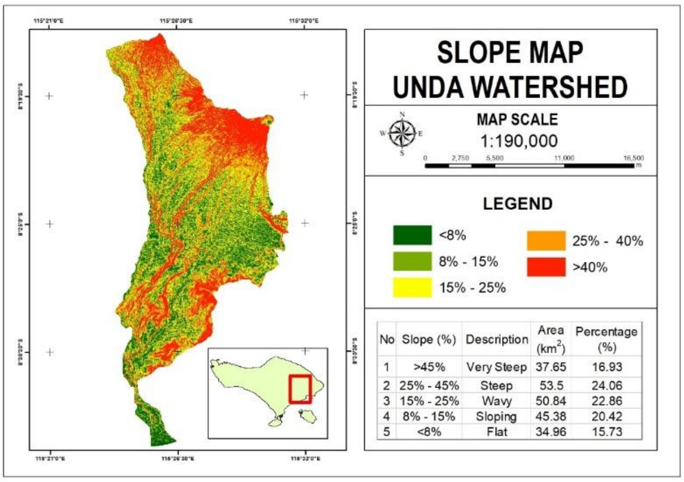


**Figure 3.** Slope of Unda Watershed
Source: Result Analysis (2021)

The flat area has a percentage of 15.73% of the Unda Watershed area. A flat area is an area that has a great potential for flooding because this area can become a water storage area when it rains [21], [22]. The slope significantly affects flooding because if the location is in the steep or very steep category, the risk posed is small, even in heavy rain. After all, the water will immediately flow to find a lower area. Even so, areas with the category of steep and very steep are not immune from the threat of flooding due to other physical factors. Most of the flat areas in the Unda Watershed are downstream. It will increase the risk of frequent flooding in the downstream area.

### Precipitation of Unda Watershed

Precipitation in a specific watershed will become runoff. The precipitation data for the last five years from 2014-2018 in the Unda Watershed from three rain gauge show that the average precipitation that falls in the Unda Watershed ranges from 1846-2025 mm/year in the moderate to heavy category. Based on observation data and comparing to Table 2, the results are presented in Figure 4.

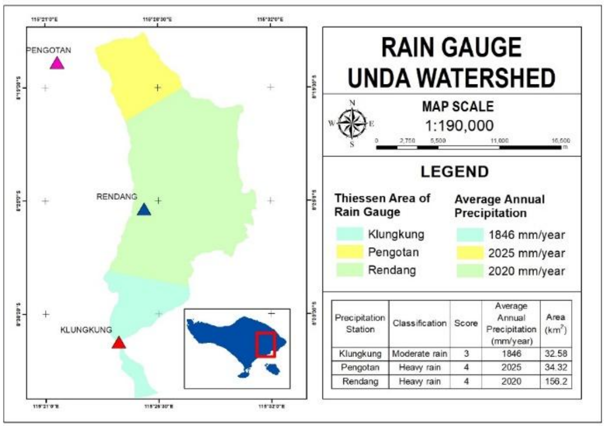


**Figure 4.** Precipitation Rate of Unda Watershed
Source: Result Analysis (2021)

**Soil Type of Unda Watershed**

The soil type map shows that the Unda Watershed has four types of soil, namely Yellowish Brown Regosol, Reddish Brown Latosol and Litosol, Regosol Humus, Gray Regosol. The Unda Watershed is dominated by gray regosol soil, where the percentage of this type of soil reaches 58% of the total area of the Unda Watershed. Regosol Humus and Gray Regosol dominate the upstream part, while Yellowish Brown Regosol and Reddish-Brown Latosol and Litosol dominate downstream.

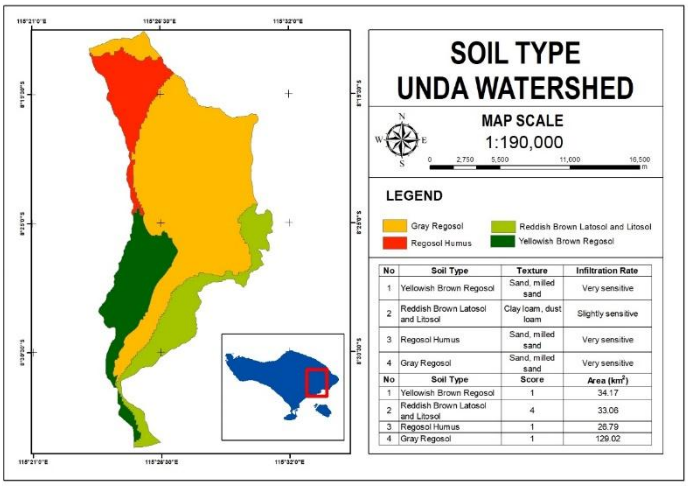


**Figure 5.** Soil Type of Unda Watershed
Source: Result Analysis (2021)

Based on the soil type classification table, the level of soil sensitivity to water infiltration in the Unda Watershed gets a low score so that rainwater can be assumed to be well absorbed, but for the downstream part, it gets a high score so that rainwater is not adequately absorbed and becomes runoff water causing local flooding. The concretization process or the amount of construction is also the cause of the difficulty of water being absorbed properly.

**Land Use of Unda Watershed**

The land use of the Unda Watershed is still dominated by Forest and Garden/ Plantation with a percentage of 20.98% and 29.74%, which are primarily found in the upstream part of the Unda Watershed, while in the middle and downstream parts are dominated by irrigation and settlements with a percentage of 15.59% and 8.85%. The greater the score for the type of land use, the easier it is to produce surface runoff so that it has a great potential for flooding. Many studies have shown that the larger impervious surface areas created by urbanization increase stormwater volume, discharge rate, and the flow of pollutants into waterways (Dela Rama-Liwanag et al., 2018; Sun et al., 2019).

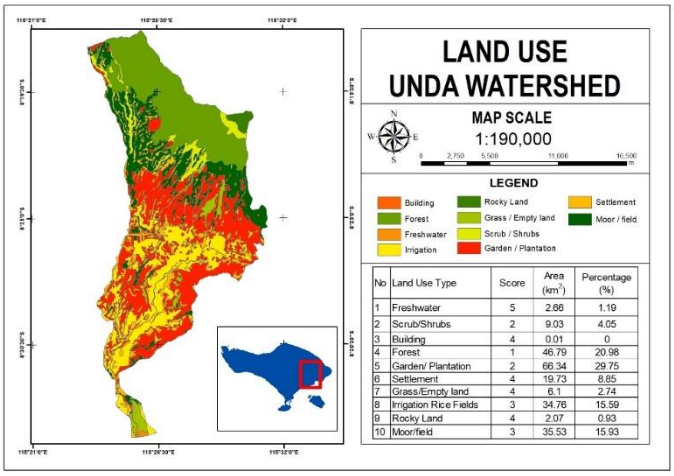


**Figure 6.** Land Use of Unda Watershed
Source: Result Analysis (2021)

**Vulnerability Level of Unda Watershed**

Flood hazard is a condition that describes whether an area is affected by the flooding based on natural factors that affect flooding, including meteorological factors such as rainfall intensity and watershed characteristics (slope, soil type, and land use). With a geographic information system with overlay analysis, the value of the level of vulnerability is calculated [25].

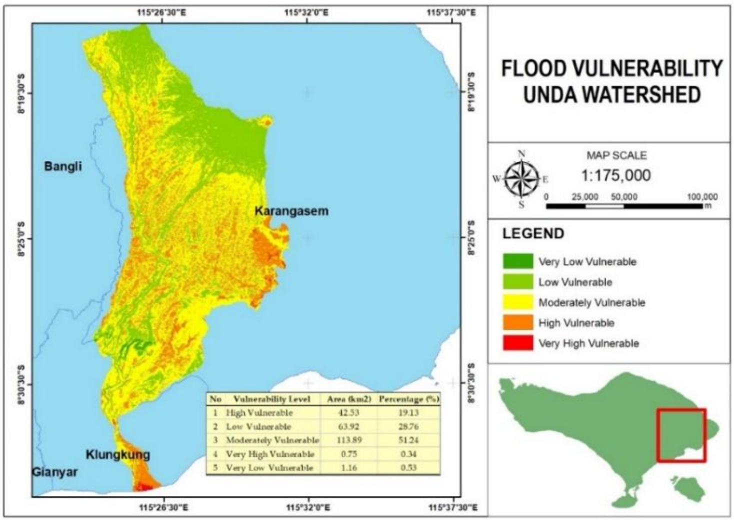


**Figure 6.** Flood Vulnerability Level in Unda Watershed
Source: Result Analysis (2021)

Based on the results of the overlay map of precipitation, slope, soil type, and land use, the vulnerability values in the Unda watershed were obtained. The criteria for very low vulnerable are 0.53% of the total area of the Unda Watershed, 28.76% low vulnerable, 51.24% moderately vulnerable, 19.13% high vulnerable, and 0.34% very high vulnerable. The area's most vulnerable to flooding are dominant in the downstream area of the Unda watershed. The downstream area of the Unda watershed has many built buildings, the slope of the land tends to be flat, and the type of soil whose infiltration rate is rather sensitive, rainwater is not adequately absorbed and becomes runoff.

**Mitigation Strategy for Vulnerability Area of Unda Watershed**

To reduce the negative impact of flood hazards, mitigation efforts are needed. Flood disaster mitigation efforts are divided into two:

1. Structural mitigation is a strategy undertaken to minimize disasters, such as by constructing a special fund to prevent flooding and making technical engineering for disaster-resistant buildings and waterproof building infrastructure.

2. Non-structural mitigation is a strategy carried out in addition to structural mitigation, such as by area planning and insurance. In this non-structural mitigation, we expect more advanced technological developments. The hope is for technology that can predict, anticipate, and reduce the risk of a disaster.

Based on the mapping results of the level of flood vulnerability of the Unda watershed in the upstream part of the Unda watershed, the mitigation strategy that can be carried out is sufficient with non-physical strategies. Meanwhile, in the downstream part, it is essential to physically handle flooding, which can be in the form of flood protection buildings combined with non-physical mitigation such as reforestation and environmental care activities, so that in the future, there will be no more flooding like the existing conditions [7], [8], [12].

## IV. CONCLUSION

Based on the results of the overlay map of precipitation, slope, soil type, and land use, the vulnerability values in the Unda watershed were obtained. The criteria for very low vulnerable are 0.53% of the total area of the Unda Watershed, 28.76% low vulnerable, 51.24% moderately vulnerable, 19.13% high vulnerable, and 0.34% very high vulnerable. The area's most vulnerable to flooding are dominant in the downstream area of the Unda watershed. Based on the mapping results of the level of flood vulnerability of the Unda watershed in the upstream part of the Unda watershed, the mitigation strategy that can be carried out is sufficient with non-physical strategies. Meanwhile, in the downstream part, it is essential to physically handle flooding, which can be in the form of flood protection buildings combined with non-physical mitigation such as reforestation and environmental care activities, so that in the future, there will be no more flooding like the existing conditions.

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