Analysis of flood vulnerability in the Lawo watershed Soppeng Regency

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Abstract. The Lawo Watershed (DAS) is a watershed located in Soppeng Regency and every year during the rainy season it is prone to flooding. Other factors that cause flood vulnerability are slope, rainfall, soil type, altitude, and inappropriate land use. This study aims to determine the distribution of the level of flood vulnerability in the Lawo watershed, Soppeng Regency. The type of research used is descriptive quantitative. The method of making maps uses overlays and scoring between variables. Each variable will be given a score by giving weights and values according to the classification. Variables that have gone through the scoring stage will be overlaid with other variables using the ArcGIS application so as to produce a map of the level of flood vulnerability. The data analysis technique used descriptive method. The result of the research is a map of the level of flood susceptibility with four levels of vulnerability. There are two dominant levels of flood vulnerability in the Lawo watershed, namely not prone to flooding and prone to flooding. The flood-prone level is located downstream of the Lawo watershed with an area of 13,172 ha or 34.33% of the total watershed area, while the non-flood prone level is located in the upstream part of the watershed with an area of 13,923 ha or 36.28% of the total watershed area. The dominant factor that causes flooding in the Lawo watershed is the slope and land use. Most of the area of the Lawo watershed has a slope of 0-8% with a presentation of 57.22% of the total watershed area, and 32.97% of land use is in the form of rice fields and swamp shrubs.

1. Introduction
Flood is one of the natural disasters that often occurs in various areas, both urban and rural areas. The National Disaster Management Agency (BNPB) said that from 2015 to September 2019, floods took second place in the list of natural disasters that often occur in Indonesia. The condition of the various morphological forms of Indonesia and having many rivers, causes Indonesia to experience frequent floods every rainy season. Flood is a condition where a land is submerged by puddles because the volume of water increases due to heavy rains, overflows of river water or a broken river embankment.

The causes of flooding in Indonesia generally occur due to deforestation without reforestation, garbage disposal in river flow, and construction of houses on riverbanks [1]. These factors will result in a decline in the function of the watershed and can cause severe flooding. The phenomenon of critical watersheds can cause the ability to decrease the watershed, during the rainy season there will be floods and during the dry season there will be drought because they cannot store water reserves [2]. The increase in watershed damage can be seen from an increase in flood disasters, especially in downstream areas due to the large amount of sedimentation carried from the upstream due to extreme changes in land use.
The Lawo River Basin with an area of 38.372 ha is one of the watersheds in South Sulawesi which has serious problems to be addressed due to the ever-increasing and uncontrolled forest degradation and transformation. The forms and patterns of degradation that occur are very diverse, including: a decrease in vegetation density, a change in the type of vegetation cover of land, impermeability, namely the change of cultivated land to watertight residential areas and conversion of forest land to non-forest designations [3].

The classification of flood-prone areas can use a Geographic Information System (GIS). GIS can provide a comprehensive picture of spatial data phenomena, in terms of location, linkages with other spatial phenomena and changes over time to spatial phenomena [4]. Data that can be used to support map making can be in the form of data on slope, altitude, soil type, land use, and rainfall.

The increasing number of forest conversion to non-forest land and the number of flood occurrences in Soppeng Regency, especially in the Lawo watershed that occurs every year, has prompted researchers to conduct research with the aim of mapping flood-prone areas.

2. Method
This type of research is descriptive quantitative. Researchers describe the characteristics of flood vulnerability in the Lawo watershed of Soppeng Regency by using the geographic information system (GIS) as a means of processing data. Quantitative descriptive data are the numbers obtained from the calculation process. The object of this research is the flood disaster that occurred in the Lawo watershed. The research subject is a map obtained from related agencies in Soppeng.

The data used in this research is secondary data. Secondary data is obtained through data analysis studies, archives, books and other forms of documentation owned by related agencies. Rainfall data from 2010 to 2019 were obtained from the Pompengan Jeneberang River Basin. The variables used to measure the level of flood vulnerability consist of six variables, namely, slope, soil type, rainfall, altitude, land use and distance from rivers. The classification of slopes in the Lawo watershed is presented in the following Table 1.

| Slope  | Description | Information  | Score |
|--------|-------------|--------------|-------|
| 0-8%   | Flat        | Very Prone   | 5     |
| 8-15%  | Sloping     | Vulnerable   | 4     |
| 15-25% | Slightly Steep | Enough Prone | 3     |
| 25-45% | Steep       | Less Prone   | 2     |
| >45%   | Very Steep  | Not Prone    | 1     |

Source: [5]

Table 1 shows the classification of slopes divided into 5 parts. The highest score is on a slope of 0-8% while the lowest score is on a slope of > 45%. Soil type classification can be seen in the following Table 2.

| Soil Type                     | Description    | Information    | Score |
|-------------------------------|----------------|----------------|-------|
| Aluvial, Planosol, Hidromorf, Laterik | Slow          | Very Prone    | 5     |
| Latosol                       | Slightly Slow | Vulnerable    | 4     |
| Tanah Hutan Coklat, Tanah Mediteran | Moderate     | Enough Prone  | 3     |
| Andosol, Laterik, Grumosol, Podsol, Podsolic | Rather fast | Less Prone    | 2     |
| Regosol, Litosol, Organosol, Renzina | Fast        | Not Prone     | 1     |

Source: [5]
Table 2 shows that the highest score is on soil types that have slow infiltration, and low scores on soil types that have fast infiltration. The classification of the distribution of rainfall in the Lawo watershed can be seen in the following Table 3.

| Rainfall | Description | Information    | Score |
|----------|-------------|----------------|-------|
| >3000    | Very wet    | Very Prone     | 5     |
| 2501-3000| Wet         | Vulnerable     | 4     |
| 2001-2500| Moderate    | Enough Prone   | 3     |
| 1501-2000| Dry         | Less Prone     | 2     |
| <1500    | Very Dry    | Not Prone      | 1     |

Source: [6]

Table 3 shows that the greater the rainfall intensity the greater the score, and the smaller the rainfall intensity, the smaller the score. The land use classification in the Lawo Watershed can be seen in the following Table 4.

| Land Use         | Information     | Score |
|------------------|-----------------|-------|
| Settlement       | Very Prone      | 5     |
| Rice field / pond| Vulnerable      | 4     |
| Field / Moor     | Enough Prone    | 3     |
| Shrubs           | Less Prone      | 2     |
| Forest           | Not Prone       | 1     |

Source: [7]

Table 4 shows that residential land use has the greatest level of vulnerability compared to other land uses such as rice fields, shrubs and forests. The altitude classification can be seen in Table 5.

| Altitude (mdpl) | Description | Information    | Score |
|-----------------|-------------|----------------|-------|
| <20             | Very low    | Very Prone     | 5     |
| 20 – 75         | Low         | Vulnerable     | 4     |
| 75 – 130        | Moderate    | Enough Prone   | 3     |
| 130 – 200       | High        | Less Prone     | 2     |
| >200            | Very high   | Not Prone      | 1     |

Source: [7]

Table 5 shows that the higher a place is, the lower the flood hazard level. Classification of distance from the river can be seen in the following Table 6.

| Distance from river (m) | Information | Score |
|-------------------------|-------------|-------|
| 0 – 50                  | Very Prone  | 5     |
| 50 – 100                | Vulnerable  | 4     |
| 100 – 250               | Enough Prone| 3     |
| 250 – 500               | Less Prone  | 2     |
| >500                    | Not Prone   | 1     |

Source: [8]
The technique for making a flood hazard map consists of 2 stages, namely:

2.1. Data processing
2.1.1. Attribute analysis. Providing information is done to edit the open attribute Table. The attribute analysis process consists of 2 stages, namely, scoring and weighting. The score for each parameter is in accordance with the classification Table that has been made. The more vulnerable in this parameter class, the higher the score. The weighting is done for each parameter. The greater the influence of the parameters on flood hazard, the greater the weight and the smaller the effect of the parameters on flooding, the smaller the weight. The classification of parameter weights is presented in the following Table 7.

| Parameter          | Weight |
|--------------------|--------|
| Slope              | 25     |
| Type of soil       | 15     |
| Rainfall           | 10     |
| Land Use           | 20     |
| Altitude Place     | 15     |
| Distance from river| 10     |

Source: [8]

2.1.2. Overlay. This analysis was carried out using the tumpeng stacking / overlaying technique of maps that already had scores and weights in the Table attributes. The overlay process is carried out by combining six flood hazard parameters. After the overlay process is complete it will produce a flood hazard map.

2.2. Vulnerability Level Analysis
The value of flood hazard is obtained by adding up the scores of the 6 parameters using the following equation:

\[ K = \sum_{i=1}^{n} (W_i \times X_i) \]

Information:
\[ K \] = the value of vulnerability 
\[ W_i \] = Weights for the parameter to – i 
\[ X_i \] = parameter class score to-i 
\( n \) = lots of data

| Classification      | Score  |
|---------------------|--------|
| Not Prone           | 100 – 199 |
| Enough Prone        | 200 – 299 |
| Vulnerable          | 300 – 399 |
| Very Prone          | 400 – 499 |

Source: [8]
3. Result and discussion

3.1 Slope

The slope of the slope is the angle formed between the vertical distance of the land and the horizontal distance of the land, in percentage units or degrees. The slope of the slope is a factor that has an influence on the size of an area entering the flood-prone zone. The slope in the Lawo watershed can be seen in the following Figure 1.

Figure 1 shows that the flat slope (0-8%) has the widest distribution of 21,957.19 ha (57.22%) with a total score of 125. The flatter an area is, the greater the potential for flooding, this is because falling rainwater will flow to a lower or flatter area.

| Slope    | Score (S) | Weight (W) | Total (SxW) | Large (ha)   | Percentage (%) |
|----------|-----------|------------|-------------|--------------|----------------|
| 0-8%     | 5         | 25         | 125         | 21,957.19    | 57.22          |
| 8-15%    | 4         | 25         | 100         | 527.08       | 1.37           |
| 15-25%   | 3         | 25         | 75          | 2,769.70     | 7.22           |
| 25-45%   | 2         | 25         | 50          | 8,784.56     | 22.89          |
| >45%     | 1         | 25         | 25          | 4,334.34     | 11.30          |

Source: Secondary data processed in 2020

Table 9 shows that the slope of 0-8% has the widest distribution of 21,957.19 ha (57.22%) with a total score of 125. The flatter an area is, the greater the potential for flooding, this is because falling rainwater will flow to a lower or flatter area.

3.2 Soil type

Soil is a layer of earth formed by weathering of the parent rock material and formed as a result of interaction with the climate, living beings, and the parent material. Soil type will have a relationship with soil texture. Soil texture will affect the process of water infiltration. Infiltration is the process of water flow into the soil [4]. The more finely textured ground, then the slower the rate of water into the ground. The type of soil in the Lawo watershed can be seen in the following Figure 2.
Figure 2 shows that the dominant type of cambisol soil in the Lawo watershed area. Cambisol soil is another soil that shows hydromorphic properties within a depth of 50 cm from the surface, does not have a characteristic horizon (unless > 50 cm of new material is buried) other than A horizon, H horizon, B horizon cambic, calcic or gypsic. The results of scoring and weighting for soil types can be seen in Table 10.

![Map of Lawo Watershed Soil Types](image)

**Table 10.** Soil Type Classification Score.

| Soil Type | Infiltration  | Score (S) | Weight (W) | Total (SxW) | Large(ha) | Percentage (%) |
|-----------|---------------|-----------|------------|-------------|-----------|----------------|
| Alluvial   | Slow          | 5         | 15         | 75          | 215.11    | 0.56           |
| Gleisol    | Slow          | 5         | 15         | 75          | 11,290.90 | 29.42          |
| Kambisol   | Rather fast   | 2         | 15         | 30          | 26,293.26 | 68.52          |
| Mediteran  | Moderate      | 3         | 15         | 45          | 573.61    | 1.49           |
| Amount     |               |           |            |             | 38,372.87 | 100            |

Source: Secondary data processed in 2020

Table 10 shows that the distribution of gleisol soil types that are prone to flooding has an area of 11,290.90 ha or 29% of the total area of the Lawo watershed with the largest number of values being 75. Kambisol soil has a rather fast infiltration sensitivity level, while for alluvial soil types and gleisols are sensitive to slow infiltration.

3.3 Rainfall
Rainfall is the amount of water that fell from the sky in an area within a certain time. The higher the average rainfall, the higher the potential danger of flooding, and vice versa. The lower rainfall, the more secure from the threat of flooding. Distribution of the average rainfall in the watershed Lawo during the years 2010 - 2019 are presented in the following Figure 3.
Figure 3 shows that most of the Lawo watershed area has an average rainfall of 1,985.41 mm / year. The results of the scoring and weighting of the rainfall parameters can be seen in the following Table 11.

| Rainfall (mm/year) | Score (S) | Weight (W) | Total (SxW) | Large (ha) | Percentage (%) |
|-------------------|-----------|------------|-------------|------------|----------------|
| 2,082.47          | 3         | 10         | 30          | 2,770.16   | 7.22           |
| 1,985.41          | 2         | 10         | 20          | 35,602.71  | 92.78          |
| Amount            |           |            | 38,372.87   | 100        |

Source: Secondary data processed in 2020

Table 11 shows that rainfall of 1,985.41 has an area percentage of 92.78%. This rainfall is included in the dry category, so the Lawo watershed when viewed from the rainfall factor has a less prone level of flood vulnerability.

3.4. Land use

Land use is a manifestation of human activity in utilizing its natural environment to meet needs in supporting life and success [9,10]. Human activities on earth are dynamic, so every year there will be changes in land use on the earth's surface. The distribution of land use in the Lawo watershed is presented in the following Figure 4.
Figure 4 shows that the dominant land use in the Lawo watershed is dryland agriculture mixed with shrubs and rice fields and secondary dryland forest. The distribution of secondary dryland forest is located in the upstream part of the watershed, rice fields are located in the downstream part of the watershed, while dryland mixed bush agriculture is located between secondary dryland forest and rice fields. The results of the scoring and weighting of land use parameters can be seen in Table 12.

### Table 12. Land Use Classification Score.

| Land Use                      | Score (S) | Weight (W) | Total (SxW) | Large (ha) | Percentage (%) |
|-------------------------------|-----------|------------|-------------|------------|----------------|
| Secondary Dryland Forest      | 1         | 20         | 20          | 9,853.46   | 25.68          |
| Plantation Forest             | 1         | 20         | 20          | 206.75     | 0.54           |
| Dry Land Mixed Shrub Farm     | 2         | 20         | 40          | 13,572.47  | 35.37          |
| Open Land                     | 3         | 20         | 60          | 44.84      | 0.12           |
| Dryland Agriculture           | 3         | 20         | 60          | 259.47     | 0.68           |
| Shrubs                        | 2         | 20         | 40          | 835.72     | 2.18           |
| rice field                    | 4         | 20         | 80          | 11,011.29  | 28.70          |
| Settlement                    | 5         | 20         | 100         | 949.12     | 2.47           |
| Thicket Swamp                 | 4         | 20         | 80          | 1,639.74   | 4.27           |
| **Amount**                    |           |            |             | 38,372.87  | 100            |

Source: Secondary data processed in 2020

Table 12 shows that the Lawo watershed, 35% of its area, is dominated by dryland mixed with shrubs. In addition, there are rice fields with a total weight of 80 which dominate the Lawo watershed with an area of 11,011.29 ha (28.7%) of the total watershed area. The large area of rice fields increases the potential for flooding in the Lawo watershed. The vegetation in the rice fields is not strong enough to withstand the flow of surface water and increase the occurrence of erosion. The forest area in the Lawo watershed is 9,853.46 ha or 25.68%. The existence of forests can reduce the risk of flooding in the Lawo watershed.
3.5. Altitude

Altitude is the elevation level location measured from the lowest point is sea level. Altitude is one of the factors or parameters to measure the danger of flooding. The elevation of the Lawo watershed is shown in the following Figure 5.

![Figure 5. The Lawo Watershed Elevation Map.](image)

Figure 5 shows the widest distribution of altitude in the Lawo watershed, with an altitude of more than 200 m spread over the upper watershed. The results of the scoring and weighting of the altitude parameters can be seen in Table 13.

| Place Altitude | Score (S) | Weight (W) | Total (SxW) | Large (ha) | Percentage (%) |
|----------------|-----------|------------|-------------|------------|----------------|
| 0 - 20 Meter   | 5         | 15         | 75          | 8,551.60   | 22.29          |
| 21 - 75 Meter  | 4         | 15         | 60          | 7,855.84   | 20.47          |
| 76 - 130 Meter | 3         | 15         | 45          | 3,068.82   | 8              |
| 131 - 200 Meter| 2         | 15         | 30          | 2,593.90   | 6.76           |
| > 200 Meter    | 1         | 15         | 15          | 16,302.71  | 42.48          |
| **Amount**     | **38,372.87** | **100**    |             |            |                 |

Source: Secondary data processed in 2020

Table 13 shows that the Lawo watershed is dominated by an altitude of > 200 meters with an area of 16,302.71 (42.48%) of the total watershed area. The higher a place, the lower the level of vulnerability to flooding. Surface water flow will move from a high surface to a low surface due to gravity and water will tend to pool in that place before heading to the sea or lake.

3.6. Distance from river

Rivers affect the occurrence of flooding. When the river's capacity is not able to accommodate the water discharge, the water will stagnate in the area around the river. The distance from the river in the Lawo watershed can be seen in the following Figure 6.
Figure 6 shows that the flow pattern of the Lawo River Basin is rectangular. The pattern of rectangular flow is the flow pattern found in areas that have structural faults, either in the form of the actual fault or just joints (cracks). This pattern is a right-angled flow pattern. The results of the scoring and weighting of the distance parameters from the river can be seen in the following Table 14.

| Distance from river (m) | Score (S) | Weight (W) | Total (SxW) | Large (ha) | Percentage (%) |
|-------------------------|-----------|------------|-------------|------------|----------------|
| 0 - 50                  | 5         | 10         | 50          | 2,480.27   | 6.46           |
| 51 - 100                | 4         | 10         | 40          | 2,299.30   | 5.99           |
| 101 - 250               | 3         | 10         | 30          | 6,394.78   | 16.66          |
| 251 - 500               | 2         | 10         | 20          | 8,587.72   | 22.38          |
| > 500                   | 1         | 10         | 10          | 18,610.80  | 48.50          |
| Amount                  |           |            |             | 38,372.87  | 100            |

Source: Secondary data processed in 2020

3.7. Flood Vulnerability
Maps that have gone through the scoring and weighting stages will be overlaid gradually so as to produce a flood vulnerability map. The results of the flood susceptibility map are presented in the following Figure 7.
Figure 7. Lawo watershed flood vulnerability map.

Figure 7 shows that in the Lawo watershed there are two levels of flood hazard that dominate, namely not prone to flooding and prone to flooding. The non-prone category is found in the upstream watershed area, while for the flood-prone area there is a downstream watershed area. The level of vulnerability in the Lawo watershed can be seen in Table 15.

| Level of vulnerability | Large (ha) | Percentage (%) |
|------------------------|------------|----------------|
| Not Prone              | 13,923.35  | 36.28          |
| Enough Prone           | 8,574.72   | 22.35          |
| Vulnerable             | 13,172.35  | 34.33          |
| Very Prone             | 2,702.45   | 7.04           |
| Amount                 | 38,372.87  | 100            |

Source: primary data processed in 2020

Table 15 shows that the non-flood-prone category has an area percentage of 36.28% and the flood-prone category is 34.33%. This category of not prone to flooding must be maintained both from the vegetation contained in it and other factors that cause flooding. For the category of flood-prone, the level of vulnerability will increase to become very prone to flooding if repairs or disaster migrations are not carried out immediately.

4. Conclusion
The distribution of flood-prone areas in the Lawo watershed is divided into four categories, namely very flood-prone, flood-prone, moderately flood-prone, and not flood-prone. The level not prone to flooding is the widest area with an area of 13,923.35 ha (36.28%) of the watershed area, while the flood-prone level has an area of 13,172.35 ha (34.33%), the level is quite prone to flooding with an area of 8,574.72 ha. (22.35%), and the level is very prone to flooding with an area of 2,702.45 ha (7.04%). Areas that are included in the flood-prone category are located in the lower reaches of the Lawo watershed while the area for the non-flood-prone category is located in the upstream part of the Lawo watershed.
References

[1] Prasetyo K and Hariyanto 2018 Indonesian Environmental Education (Bandung: PT. Rosdakarya Youth)
[2] Setyowati D L and Erni S 2014 Garang Hulu Watershed (Yogyakarta: Waves)
[3] Jeneberang Walanae Watershed Management Center 2012 Report on the Results of Identification of Damage to the Lawo Watershed in 2012 (Makassar)
[4] Budiyanto E 2016 Geographic Information System with Quantum GIS (Yogyakarta: Andi Publisher)
[5] Asdak C 2014 Hydrology and Watershed Management (Yogyakarta: Gadjah Mada University Press)
[6] Jeihan S 2017 Analysis of Flood Prone Areas in Sampang Regency Using Geographic Information System with Multi Temporal Data Method (Sepuluh Nopember Institute of Technology Surabaya)
[7] Darmawan K 2017 Analysis of Flood Vulnerability in Sampang Regency Using the Overlay Method with Scoring Based on Geographic Information Systems Undip Geod. J. 6
[8] Pratiwi H E 2020 Analysis of Flood Vulnerability in Lamongan Regency (Surabaya State University)
[9] Ritohardoyo S 2013 Use and Land Use (Yogyakarta: Waves)
[10] Barkey R A, Malamassam D, Mukhlisa A N and Nursaputra M 2020 Land use planning for floods mitigation in Kelara Watershed, South Sulawesi Province, Indonesia IOP Conference Series: Earth and Environmental Science vol 575 (IOP Publishing) p 12132