Analysis of the landslide susceptibility map using frequency ratio method in sub-sub-Watershed Mamasa

Rizki Amaliah¹, Andang Suryana Soma¹, Baharruddin Mappangaja¹, and Friska Mambela²

¹Forestry Department, Hasanuddin University, Makassar, Indonesia
²Student of Forestry Faculty, Hasanuddin University, Indonesia

Email : s_andangs@unhas.ac.id

Abstract. Landslides that often occur in the Subs watershed of Mamasa increase the sedimentation rate so that the Bakaru hydropower plant becomes less than optimal. The contributing factors to landslide susceptibility are land closure, lithology, curve, slope direction aspect, slope, precipitation, fault distance, and river distance. The research aims to determine the most influential erosion causative factor in Mamasa Sub-watershed by building a landslide susceptibility map using the frequency ratio method. The most significant factor is land closure, with a value of 2.03, indicating a high probability of landslide events. The model's success rate and prediction rate's success rate were expressed fairly well with 0.754 and 0.752. Based on the insanity map, the Region is very high and high at 23.74% and 12.52%; insanity is moderate, low, and very low consecutively at 27.44 %, 23.77, and 12.33%.

1. Introduction
The phenomena of global climate change encourage natural disasters, such as landslides. Due to extreme weather changes, which enable natural disasters, a few losses occur of natural disasters, namely landslides. According to Nandi (2007), the impact caused by landslides such as land damage, loss of land change, disruption of ecosystem balance, the land becomes critical cause the underground water reserves are depleted [1]. Soil landslides can cover other land such as rice fields, gardens, and other productive land and cause casualties. Land that is carried during a landslide can also cause sedimentation on the reservoir.

The upstream Mamasa Watershed is one of the watersheds that often occurs landslide. Mamasa Watershed is a multifunctional watershed which is a source of raw water for the people who live in the vicinity, as a source of irrigation for rice fields, and as a Hydroelectric Power Plant (PLTA), namely the PLTA in Bakaru. Landslides that often occur in the upstream sub-watershed Mamasa can harm the community and cause sedimentation in the Hydroelectric Power Reservoir (PLTA) in Bakaru [2]. The presence of sedimentation can cause less than optimal function of the Hydroelectric Reservoir (PLTA) in Bakaru.

According to Buchori and Joko (2012), the factors that cause landslides are divided into natural and human factors. Nature factors include slope, rainfall, geology [3]. While the human element is related to all the actions taken that change nature's conditions, thereby increasing the potential for landslides to occur. Rudiyanto (2010) also added the factors that cause landslides: soil texture, soil permeability, effective soil depth, density hills, groundwater table depth, slope, land use, species soil, and rainfall [4].
To find out the factors of landslide occurrence, used one method of the frequency ratio. According to Nusantara and Setianto (2015), the ratio frequency method is based on the occurrence of landslides with factors affecting the landslide [5]. Based on this description, it is necessary to conduct a study to knowing the level of vulnerability to landslides in the Mamasa sub-watershed to see the factors that most influence the occurrence of landslides using the frequency ratio method.

2. Methods

2.1. Tools and materials
The tool used in this study was a laptop with a geographic information system software application ArcMap 10.3 and SPSS (Statistical Product and service solutions. The materials used in this research are: Mamasa Sub-watershed map, Citra time-series image from Google Earth Pro, Citra Landsat 8. image 2013, geological map, Earth curvature data, slope and distance determination from rivers, Slope direction from Digital Elevation Model (DEM) National, Meteorological, Climatological, and Geographical Agency rainfall data (BMKG) and RBI 1: 50,000 maps as base maps.

2.2. Data collection
There are two types of data collected. The first is landslide inventory and data collection landslide factors. Landslide inventory activities are carried out by interpreting remote sensing images based on spectral characteristics, shape, and contrast [6]. This study using digitized time-series image data from Google Earth Pro from 2014 – 2019 and processed on ArcMap 10.3. Next, the causative factors variables in this study such as (1) slope, (2) distance from drainage/water channel/river, (3) distance from fault/fault, (4) lithology, (5) land cover, (6) rainfall, and (7) curvature (8) aspects of slope direction.

2.3. Data analysis
The data analysis used is a quantitative method, namely the method ratio frequency. If the ratio is greater than 1.0, then the relationship between the event's landslides and their causal factors is higher. If the ratio is less than 1.0, then the relationship between landslide events and the causal factors is low in depth. Score frequency ratio is calculated by the formula [6]:

\[ Fr = \frac{P_{xcL} \times (nm)}{\sum P_{n} \times L_{pm}} \]

Where: \( Fr \) is the ratio frequency; \( P_{xcL} \) is the number of pixels with the ground landslide in class \( n \) of parameter \( m \) (nm); \( Pixel \) is the number of pixels in class \( n \) of parameter \( m \) (nm); \( P_{n} \times L \) is the total pixels of parameter \( m \), and \( P_{n} \) is the total pixels of the area.

Create Landslides Susceptibility Index (LSI) or vulnerability index landslides, all the factors that cause landslides will be mapped in raster map form of the FR values then summed using the following equation (Soma et al., 2019):

\[ LSI = Fr_1 + Fr_2 + \ldots + Fr_n \]

where \( Fr_1, Fr_2, \) and \( Fr_n \) is the ratio frequency raster map for the factors cause of landslides.

2.4. Data validation
This validation shows how well the model predicts landslides. The results of this validation will produce prediction accuracy values based on AUC (Area Under Curve). Each LSI class has calculated the percentage of the number of landslides and the cumulative percentage. The rate change curve is created with the LSI Value as the x-axis and the cumulative percentage of landslide events as the y-axis [5]. The classification of landslide validation results can be grouped into five value ranges according to Rasyid.
et al. (2016), namely 0.5 – 0.6 declared failed. 0.6 – 0.7 is considered bad. 0.7 to 0.8 is quite good, 0.8 – 0.9 is good, 0.9 – 1 is very good.

3. Result and discussion

Inventory of landslides from the year google earth pro image series 2014 to 2019 resulted in 1,165 polygon landslide events. Results The data has previously been processed into raster data with a total number of 4,783,620 pixels. The landslide pixel is divided into two data: data training with 70% with 7,432 pixels and 30% validation data with 3,168 pixels from the map of landslide distribution from 2014 to 2019. Factors landslides used include land cover, slope, slope, curvature, lithology, distance from the fault, distance from the river, and rainfall can be seen in Figure 1.

![Figure 1. Map of Factors Causing Landslide.](image)

3.1. Land cover

Land cover is one of the factors that can cause landslide occurrence. 9 (nine) types of landsat eight have been processed land cover that can be identified: primary dryland forest, secondary dryland forest, settlements, shrubs, plantations, rice fields, water bodies, open land, and dry land mixed with shrubs (DFWBS). Calculation of the ratio frequency value for each land cover can be seen in Figure 2.
The land cover factor shows that primary dryland forest has the value the frequency ratio is 2.03, which indicates the probability of landslides high. In addition to primary dryland forest, shrubs and agricultural land dry mixed bush have a value > 1, indicating a high probability of landslide occurrence. The high value of the frequency ratio was in agricultural land dry mixed with bushes due to human activities (agriculture). Meanwhile, secondary dryland forests, settlements, plantations, rice fields, bodies of water, and open land have a value of <1, indicating a high probability of low risk of landslides.

3.2. Lithology
Lithology affects the occurrence of landslides based on the type of the rocks. The rocks found in the research location are dominated by Neogene consisting of igneous rock. Igneous rocks that makeup are breakthrough rocks (Tmpi) consisting of intrusive granitic batholiths by granite. The graph of the ratio frequency value in each Lithology class shown in Figure 3.
properties is in line with [7], which says impermeable rocks water is prone to landslides that are generally found in the mountains and in supported by steep slopes.

### 3.3. Curvature

The curvature of the earth is one of the factors that cause landslide occurrence. The curvature of the land is divided into three classes, namely, Convex, Flat and Concave.

![Figure 4. Graph of the ratio frequency value in each Curvature class.](image)

The graph above (Figure 4) shows that flat areas have the lowest values (0.82) <1, indicating a low probability of landslides. Score the highest frequency ratio in convex areas with a value >1, showing the risk of landslides. Because of heavy rainfall, convex slopes contain more water and retain this water for a longer time [8].

### 3.4. Aspect of slope direction

The direction of the slope has an indirect influence on landslides' occurrence because the direction of the slope will determine the amount of sunlight that will affect the weathering of rocks if combined with rainfall, which will make rocks easily weathered that can cause landslides.

![Figure 5. Graph of the ratio frequency value in each class Slope Direction.](image)
The slope direction that has a high effect on landslide susceptibility with frequency ratio values > 1 are southeast, south, east, and northeast (Figure 5). Due to the direction of the slopes of the southeast, south, east often exposed to sunlight the sun which causes the weathering of rocks. The direction of the slope others such as Flat, north, southwest, west, and northwest have a value < 1 means low landslides.

3.5. Slope
The slope of the slope is one of the effects of the significant variable on landslides. The dominant slope occurs at mountainous or hilly areas that have steep areas. Sub-Sub Watershed Mamasa has a site that is dominated by hilly regions.

![Figure 6. Graph of the ratio frequency value in each Slope class.](image)

The fr value of the slope (Figure 6) shows that the slope > 45% has a value of 1, which indicates a high probability of landslides. Next on slopes 0-8%, slopes 8-15%, slopes 15-25% and slopes 25-45% has a frequency ratio value < 1 indicating the probability value of the occurrence low landslide. However, the slope still has potential The occurrence of landslides depends on the constituent material and its response to other factors such as slope direction, land cover, and lithology [9].

3.6. Rainfall
Climate is the average weather conditions over a long period with a wide area. Climatic elements that affect the occurrence of soil landslide is rainfall. High rainfall in an area can cause landslides, of course, with other factors that are mutually related.

![Figure 7. Graph of the ratio frequency value in each rainfall.](image)
The rainfall that has the highest Fr value is 2330mm/year, 1428 mm/yr > 1.37. At 760 and 1944, rainfall was 0.52 and 0.15 and the smallest value in rainfall, 3116, namely 0.00 < 1, indicate a low chance of landslides (Figure 7). These results suggest that the frequency of rainfall. The high altitude does not always cause landslides in an area. Nasiah and Invanni (2014) stated that rainfall affects on landslides if supported by steep slopes and poor rock properties compact [10].

3.7. Fault distance
Fault distance is one of the factors used to determine to know about landslides. Fault distance is an area where some faults or faults have the potential to cause landslides. According to Buchori and Joko (2016), most regions in Indonesia have fault areas or faults that can be active at any time movement and can cause landslides [3]. The distance of the river can be seen in Figure 8.

![Figure 8. Graph of the ratio frequency value in each Slope Slope class.](image)

Based on the graph above (Figure 8), the fault distance is from 0 – 500 m, 500 – 1000 m, 1000 – 1500 m has a frequency ratio value <1, which means the probability occurrence of landslides is low. While at a distance of 1500 – 2000 m and a distance of > 2000 m, it has a frequency ratio value > one which indicates probability landslide occurrence. It can be caused by other factors such as rocks and slopes. The fault or fault affects the rock's stability so that it can affect the landslide incident.

3.8. River distance
River distance is one-factor causing landslides, the results of distance analysis rivers from the National DEM data. Fadilah (2019) stated that the possibility of landslides is higher if it is close to the river because areas close to rivers usually have high humidity, so that the soil conditions become less strong [9]. There are several classes for distance which can be seen in Figure 9.

![Figure 9. Graph of the ratio frequency value in each river distances.](image)
River distance shows the value of the ratio at a distance of 0 – 100 m has a value of frequency ratio < 1, which indicates the probability of landslides low. At a distance of 100 – 200 m and a distance of 200 – 300 m, a distance > 300 m has a frequency ratio value > 1, indicating the probability of soil occurrence high landslide. Moreover, the closer the slope to the river, the more significant it. The chance for landslides to occur is due to the level of water saturation on the slope directly affecting the slope's stability [11].

The fr values of all factors have been calculated and used to make the index landslide susceptibility is obtained from all raster maps of the causative factors landslides with the ratio frequency value. Then the erosion susceptibility value This index (LSI) is classified based on natural breaks into five different classes, as shown in Table 1.

### Table 1. Landslide Vulnerability Value using the Frequency Ratio Method.

| Class       | Class Landslide Vulnerability | Reclassify Index value | Pixel     | % Pixel |
|-------------|-------------------------------|------------------------|-----------|---------|
| 1           | Very low                      | 6.7                    | 589.628   | 12.33   |
| 2           | Low                           | 7.49                   | 1,146.450 | 23.97   |
| 3           | Medium                        | 8.42                   | 1,312.561 | 27.44   |
| 4           | High                          | 9.53                   | 1,135.870 | 23.74   |
| 5           | Very High                     | 11.25                  | 599.111   | 12.52   |

The landslide susceptibility class includes the vulnerability class is very low, low, medium, high, and very high class, presented in the form of a landslide susceptibility map shown in Figure 10.

Figure 10. Landslide Hazard Level Map.

The extent of the landslide susceptibility level in the medium hazard class has the most expansive area of about 27.44% (13,125.03 ha), a light class with an area of approximately 23.77% (11,464.00 ha), high with an area of about 23.74% (11,358.20 ha), very high with an area of about 12.52% (5,990.85
ha), and Very light vulnerability class has an area of approximately 12.33% (5,896.02 ha) of the total area of the Mamasa sub-basin is 47834.09 ha. The Landslides data was processed in geographic information system software. Moreover, it was validated with SPSS software (Statistical Product And Service Solutions) and analyzed using ROC (receiver operating characteristic) to see the model's level of success and determine the level of model prediction for events Avalanche. Validation 1 and validation 2 have an AUC success rate with values of 0.754 and 0.752, respectively. It means both are in a pretty good class with a value range of 0.7 – 0.8 according to the classification of landslide validation results. Rasyid et.al, 2016 in Soma & Kubota, 2018 stated the range of landslide validation values 0.7 – 0.8 is in a pretty good class.

4. Conclusion
Based on the landslide susceptibility map that has been analyzed with using factors that cause landslides and frequency ratios, in Sub-Sub-Waterlands Mamasa has five classes of landslide susceptibility, namely Very low with an area of about 12.33% (5,896.02 ha) of low vulnerability class with an area of 23.77% (11,464.00 ha). Moreover, medium vulnerability class with an area of 27.44% (13,125.03 ha), high vulnerability class has an area of 23.74% (11,358.20 ha), and Very high vulnerability class has an area of about 12.52% (5,990.85 ha). Factors causing landslides used in this study include others, slope, land cover, aspect of slope direction, distance from the river, rare from faults, rainfall, curvature (curvature of the earth), and lithology. The most influential factor based on the frequency ratio was a primary forest with a frequency ratio value of 2.03.

References

[1] Nandi 2007 Landslide (Bandung: Education Indonesia University)
[2] Faridah N S and Ahmad M 2011 Use-Based Watershed Management Land Using Fuzzy Multi-Attribute Decision Making Method Prosiding Seminar Nasional Perteta (Makassar: Faculty of Agriculture, Hasanuddin University)
[3] Buchori I and Susilo J 2016 Spatial Model for Area Identification Landslide Prone Tataloka 14 282–94
[4] Rudiyanto 2010 Analysis of Potential Landslide Hazards Using the System Geographical Information (Sig) in Selo District, Boyolali (Muhammadiyah Surakarta University)
[5] Nusantara Y P and Setianto A 2015 Landslide Hazard Mapping with Frequency Ratio Method in Piyungan and Pleret Districts, Bantul Regency, Special Region of Yogyakarta Proceedings of the 8th National Earth Seminar (Academia-Industry Linkage, Graha Sabha Pramana) pp 513–522
[6] Soma A S, Kubota T and Aditian A 2019 Comparative Study of Land Use Change and Landslide Susceptibility Using Frequency Ratio, Certainty Factor, and Logistic Regression in Upper Area of Ujung-Loe Watersheds South Sulawesi Indonesia Int. J. Eros. Control Eng. 11 103–115
[7] Rahimanizah T, Apriyanto B and Astutik S 2016 Landslide Potential In the Karst Area of Mount Sadeng Puger Due to Activities Mining (Jember University)
[8] Vijith H and Madhu G 2008 Estimating potential landslide sites of an upland sub-watershed in Western Ghat’s of Kerala (India) through frequency ratio and GIS Environ. Geol. 55 1397–405
[9] Fadilah N 2019 Analysis of Landslide Vulnerability Using Frequency Ratio Method in the Bialo River Basin [In Bahasa Indonesia] (Hasanuddin University)
[10] Nasiah and Invanni I 2014 Identification of Landslide Prone Areas as an Effort Disaster Management in Sinjai Regency J. Sainsmat 3
[11] Hidayah A, Paharuddin and Massinai M A 2017 Disaster Hazard Analysis Avalanche Using the Ahp (Analytical Hierarchy Process) Method in the District North Toraja J. Geocelerbes 1