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Analysis of the landslides vulnerability level using frequency ratio method in Tangka Watershed

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Abstract. In Indonesia, the number of landslide disasters case increase each year, especially in watershed. The main factor of landslide is a gravity in slope. Another factor like the high intensity of rainfall, the wrong use of sloping land and geology structure. Focusing the many cases of landslide, this project is aim to Analysis of the Landslides Vulnerability Level Using Frequency Ratio Method in Tangka Watershed. This research was started from July-September 2019. We used Tangka Watershed Map, Imagery of Landsat 7, DEM National Imagery resolution 8-meter, geology map scale 1: 50.000, rainfall intensity from BMKG 10 years ago and imagery time series from Google Earth Pro to analyze the landslide factor, like slope, river distance, fracture distance, lithology, land cover, curvature, and aspect. Frequency Ratio Method used to analyze and get the landslide vulnerability level. There are 191 polygons in landslide inventory among 2004-2014. The frequency ratio in land cover is 5.99. It means there are higher potency of landslide in land cover area than another area.

7

1. Introduction

7 Indonesia is one of the countries with a high level of disaster vulnerability. Based on data from the National Disaster Management Agency (BNPB) in the last ten years, from 2010-2019, there were 6,548 floods with 1,984 fatalities, 4,337 landslides with 1,789 casualties, tidal waves of 188 incidents that took 64 fatalities, tomado there were 5,437 incidents with 310 fatalities, 753 drought with 2 fatalities, forest and land fires with 894 incidents with 35 fatalities, 159 earthquakes took 214 fatalities, earthquakes and tsunamis there were 2 incidents with 3,475 fatalities, tsunami there were 9 incidents with 968 fatalities and 106 volcanic incidents with 432 fatalities.

Looking at the data above, one of the disasters that often occurs with a high fatality rate is landslides. Landslides are a product of an equilibrium disturbance process that causes the movement of soil and rock masses from a higher place to a lower place [1]. According to Faizana et al (2015), this balance disorder occurs because the stability of the slope can be controlled by morphological conditions (especially slope), ro 12 soil conditions and hydrological or water conditions on the slope [2].

There are several factors that influence the occurrence of landslides. These include slope, distance from river, distance from fracture, lithology, soil type, land cover and precipitation [3]. In addition, landslides are also affected by the condition of land cover. The absence of vegetation to bind the waterproof layer, triggering landslides in areas that have steep slopes [4]. One of the efforts to prevent landslides that can be done is mapping. Landslide mapping can use the frequency ratio method. Where



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the ratio frequency can connect the location of the incident with the factors that influence the occurrence of landslides [5].

The greater the ratio of the relationship between the location of the landslide event and the factors that influence it, the greater the landslide hazard [6]. Conversely, if the smaller the ratio of the relationship between the location of the landslide event and the factors that influence it, the smaller the risk of landslides. In South Sulawesi, during the last ten years 2010-2019 there were 69 landslide incidents with 26 people died (National Disaster Management Agency, 2020). The landslides that occurred were almost evenly distributed in various watersheds (DAS). According to Rahayu et al (2009) in various upstream watersheds during the early, mid to late rainy season has the potential for landslides [7].

The Tangka watershed is one of the watershed areas in South Sulawesi which has an area of ± 47,504.86 ha. The Tangka watershed includes three districts which are Bone, Gowa and Sinjai Districts. The upstream part of the Tangka watershed is at the top of the Bulu 'Bawakareng Mountains, while the downstream part is in the East Sinjai Coast area. In 2014 there was a landslide disaster in the Tangka watershed area. This incident was the biggest disaster ever in Pattalassang Hamlet, Gowa which destroyed tens of hectares of rice fields and community farms. Landslides caused damage to two main bridges, a turbine from the Micro Hydro Power Plant (PLTMH) and one village-owned transport car but there were no fatalities [8]. Besides, landslides have also occurred in the upper Tangka watershed in the Bulu 'Bawakaraeng Mountains. According to data from Kurniawan et al (2011), The landslide incident that occurred on March 24, 2004 caused 32 fatalities, 3 km of roads that were buried under the ground, 12 houses and 430 ha of land was buried [9].

Based on the data above, the Tangka watershed has the potential for landslides that can cause various losses. Therefore, it is necessary to conduct research that can see the level of landslide vulnerability by using the frequency ratio in the Tangka watershed area. With the aim of describing the factors that cause landslides and classifying landslide prone areas in the Tangka watershed (DAS) based on the Frequency Ratio method. This research is expected to be a source of information for the surrounding community and government as well as several parties related to landslide vulnerability in the Tangka watershed, so that it is hoped that efforts to prevent landslides and the application of soil and water conservation in the Tangka watershed area.

2. Material and methods

2.1. Research location

This research was conducted during July 2019 – June 2020. The research location will be conducted in the Tangka watershed, which is administratively located in Bone, Gowa and Sinjai Districts, South Sulawesi.

2.2. Tools and materials

The tools used in this study were a laptop with a geographic information system software application ArcMap 10.4 and SPSS (Statistical Product and Service Solution), a camera, and writing instruments. The materials used in this study were the boundary map of the Tangka watershed, 2003 Landsat 7 imagery, 2014 National DEM, Geological Map 1: 50,000, BMKG Rainfall Data for the period 2004 - 2014, time series imagery from Google Earth Pro spanning 2004 -2014 for landslide inventory.

2.3. Data collection technique

2.3.1. *Landslide inventory.* Landslide inventories are obtained through field surveys and interpretation of remote sensing images based on spectral characteristics, shape and contrast [10]. This study uses landslide data from 2004 to 2014 from aerial photographs of Google Earth Pro and field surveys based on data that has been identified in the last 10 years using Google Earth Pro. The study area is limited to the upper part of the Tangka watershed, with the number of landslides identified as 1,191 polygons. Landslide data from the survey and high-resolution digitization from Google Earth Pro to ArcGIS 10.1, then digitizes the time series imaging data with the interpreted landslide image and these files are saved

as a GIS-compatible format as (.kml). Then, the data is converted again into a file and a raster format of 10 x 10 meters.

2.3.2. Factors causing landslides. To create a landslide vulnerability map, determining the factors causing landslides are related to the availability of data. Therefore, the causal factors were selected based on general knowledge found in previous studies and the availability of data at the research location [10]. The causal factors that became the variables in this study included (1) slope, (2) distance from drainage/water channel/river, (3) distance from fractures, (4) lithology, (5) land cover, (6) rainfall, (7) curvature, and (8) slope direction/aspect. Determination of the factors causing landslides does not have rules so that only previous understanding and research are used based on data that has been identified in the last 10 years using Google Earth Pro.

The causative factors were then categorized based on the data found. The slope factor, the distance from the fracture and the distance from the drainage/water channel/river were obtained from the 2014 DEM image. The distance factor from the drainage/water channel/river was calculated by buffering flow line analysis. Lithology is obtained from geological maps of 1: 50,000 obtained from the Institute for Geological Research. Data related to land use factors were obtained from interpretation of Landsat imagery. The rainfall factor is obtained by making a Thiessen polygon map. Rainfall data for the last 10 years were obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) Region IV Makassar. Curvature data or curvature of the earth's surface is obtained from DEM images.

2.4. Data analysis

The data analysis used quantitative methods, i.e. using the frequency ratio method. The frequency ratio for each causative factor is calculated by dividing the landslide event rate by the area ratio. If the ratio is greater than 1.0, the relationship between landslide events and the causative factors is higher and if the ratio is less than 1.0 then the relationship between landslide events and the causative factors is low (Pradhnan and Lee (2006) in Soma and Kubota (2017) [10]. The ratio value in each class shows the relationship level of the frequency ratio value calculated by the formula [10] :

$$Fr = \frac{P_{xL} (nm) / \sum P_{nXL}}{Pixel (nm) / \sum P_{nx}}$$

Description:

P_{xL} : Number of pixels with landslides in class n of the parameter (nm)

$Pixel$: Number of pixels in class n from the parameter m (nm)

$\sum P_{nXL}$: Total pixels of the parameter m

$\sum P_{nx}$: The entire pixel of the area

After calculating the FR value of each landslide-causing factor zone, each map is overlapped to produce the **Landslide Hazard Index (LHI)** value as the formula [3].

$$LHI = FR1 + FR2 + FR3 + \dots + FRn$$

Description:

$Fr1$, $Fr2$, and Frn = raster frequency ratio maps for the factors causing landslides

2.5. Data validation

The results of the landslide hazard analysis then validated using existing landslide data. The LHI value obtained is divided into five zones, which are low hazard, very low hazard, the intermediate, high hazard and very high hazard level zone based on Natural Breaks, which is a data grouping method designed to determine the index value setting into different classes. Each LHI class is calculated as a percentage of the number of landslides and its cumulative percentage such as a rate change curve made with the LHI value as the x-axis and the cumulative percentage of landslide events as the y-axis. The Area Under Curve (AUC) value is calculated from the rate change curve which indicates the predictive accuracy value of the frequency ratio model [10].

3. Result and discussion

3.1. Actual landslide inventory

Based on the results of 2004-2014 landslide inventory using Google Earth Pro aerial photography, it shows the number of landslides identified was 1,191 polygons in three districts which are Gowa, Bone and Sinjai. The landslide data that has been identified are then processed in raster form, then divided into two, training data (80%) of 76,123 pixels and validation data (20%) of 53,184 pixels. The map of landslide events for 2004-2014 in the Tangka watershed can be seen in Figure 1.

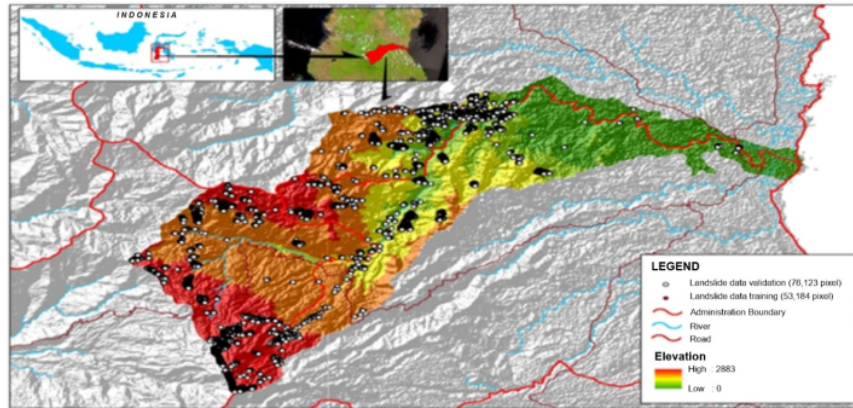


Figure 1. Landslide hazard map.

3.2. Factors causing landslides

The frequency ratio is used to determine the level of landslide vulnerability based on the factors that cause landslides. The factors used in analyzing the level of landslide vulnerability using the frequency ratio method include:

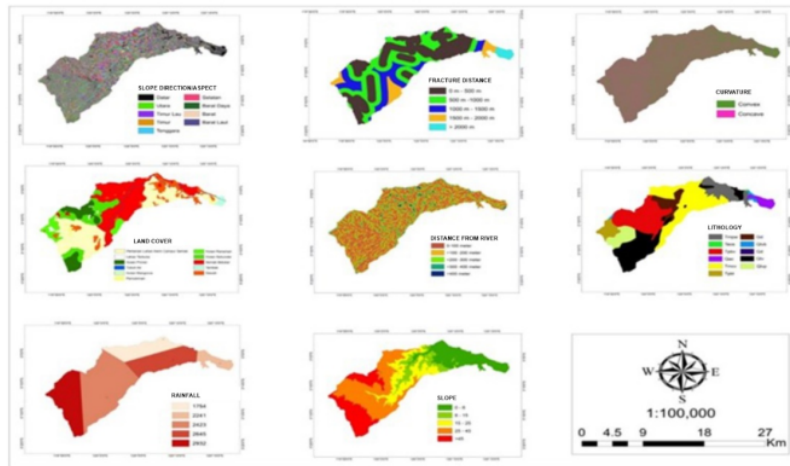


Figure 2. Map of the factors causing landslides.

3.2.1. Lithology. The factors causing landslides are in the form of lithology in the Tangka watershed which consists of 10 types of rock, those are Tmpw (Walanae Formation), Teos (Salo Kalupang

Formation), Tpbv (Baturape Volcano Rocks), Qac (Alluvium Deposits), Tmcv (Camba Volcano Rocks), Tpb1 (Lava Member), Qlvb (Breccia Rock), Qlv (Parasitic Volcano Rock). The value of the frequency ratio in the Tangka watershed lithology class is presented in Figure 3.

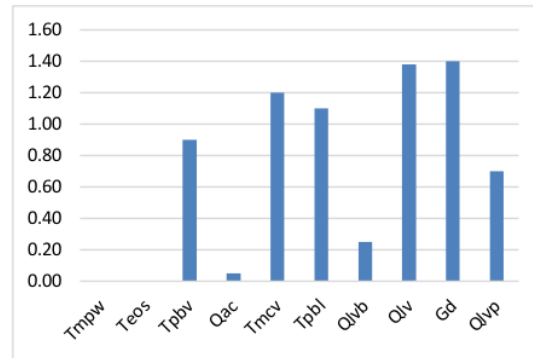


Figure 3. Graph of frequency ratio value in lithology class.

Based on the picture above, it can be seen that areas that have lithology classes Tmcv, Qlv and Gd have a frequency ratio value above 1. This indicates a high level of landslide vulnerability. This is because these rock types are generally composed of tuff and volcanics. Basically, this type of rock has also experienced cracks or expansions so that it is easy to move [11]. Whereas in the lithology class Tmpw, Teos, Tpbv, Qac, Qlvb and Qlvp have a frequency ratio value below 1, which means that the level of landslide vulnerability is low.

3.2.2. *Slope.* One of the most influential causes of landslides is the slope of the slope. There are several classes of slopes, from flat to steep slopes. The ratio frequency of each slope class can be seen in Figure 4.

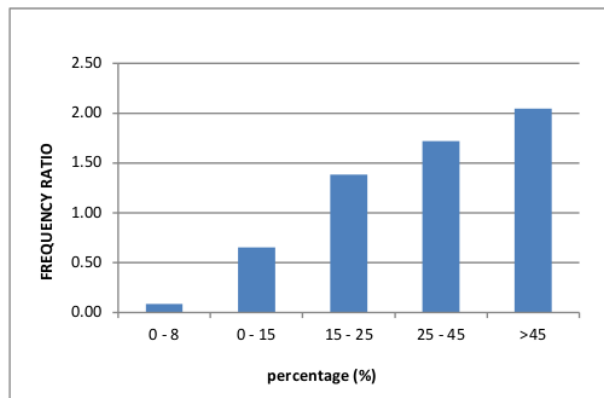


Figure 4. Graph of frequency ratio value on land slope.

It can be seen in Figure 6, areas that have slope classes above 15-45 have a frequency ratio of more than 1. This shows that in this class the level of landslide vulnerability is high. Meanwhile, the slopes 0-8 have a frequency ratio below 1 which indicates a low level of landslide hazard. As is known, the slope of the land is one of the factors that triggers landslides. The higher the slope level, the greater the potential for landslides to occur. Likewise, the more steep the land, the human activities and natural

processes will cause the slope to become unstable [12]. This happens because the top of the slope has porous soil or easily passes water. So that rainwater will easily enter the ground. Apart from that, the gravitational force also has the effect of pushing the material towards the area. Meanwhile, according to Sobirin et al (2017) The steeper the slope, the greater the potential for landslides in an area to occur, and conversely, the smaller the slope, the smaller the potential for landslides to occur in that area [13].

3.2.3. *Land cover.* The landslide hazard factor map of land cover was used the 2003 Landsat 7 image which was then digitized with a comparison of the 2003 land cover map to produce a cover map that was divided into several classes. The land cover classes include open land, primary forest, water bodies, mangrove forests, settlements, ponds, plantation forests, secondary forests, shrubs, dry land farming mixed with shrubs and rice fields. The frequency ratios for this land cover class can be seen in Figure 5.

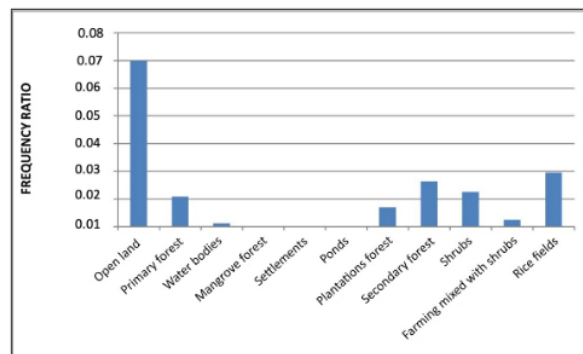


Figure 5. Graph of frequency ratio value in land cover class.

Based on the picture above, it can be seen that the one with the highest landslide hazard level is the open land cover class. This is supported by the frequency ratio value that reaches 6. Whereas in the class of primary forest, secondary forest, shrubs and rice fields also still have a high level of vulnerability because it has a frequency ratio value above 1. Open land is the most influencing factor for vulnerability. landslides due to the role of vegetation in the case of landslides are very complex. Vegetation is one of the soil binders so that landslides are not easy. Meanwhile, according to Nandi (2007) If there are trees on the surface of the soil, landslides can be prevented because the water will be directly absorbed by the plants and their growth roots will also bind the soil [14]. Another case in the class of land cover of water bodies, mangrove forests, settlements, ponds, plantations and dry land mixed with shrubs agriculture has a low landslide hazard level with a frequency ratio value below 1. The higher the frequency ratio value in the land cover class, the landslides are also vulnerable to occur in that class.

3.2.4. *Curvature of the earth.* The factors of curvature of the earth in the Tangka watershed were obtained from the national DEM which produced two curvature classes, those are convex and concave. The frequency ratio values on the curve are presented in Figure 6.

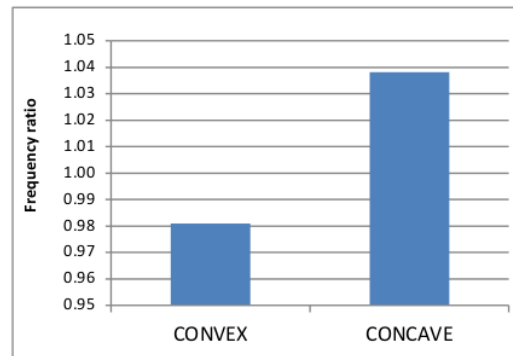


Figure 6. Graph of frequency ratio value in curvature class.

Based on the picture above, it can be seen that those with high landslide vulnerability are in the concave curvature class with a frequency ratio above 1. While the convex class has a frequency ratio value below 1, which means that the level of landslide vulnerability is low.

3.2.5. Distance from river. The factors of distance from rivers or proximity to determine the effect of landslides with rivers are obtained from the National DEM. The factors causing landslides in the form of distance from the river in the Tangka watershed are classified based on the distance, start from 0 - 100, 100 - 200, 200 - 300, 300 - 400 and > 400 meters. The value of the frequency ratio can be seen in Figure 7 below.

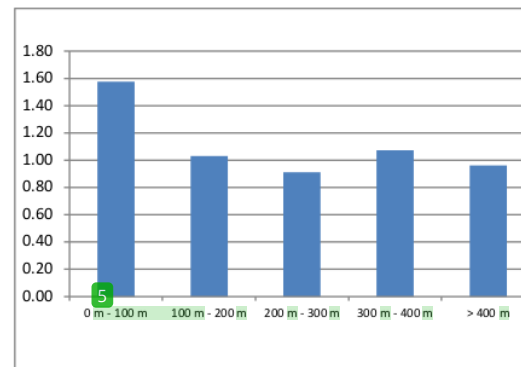


Figure 7. Graph of frequency ratio value in distance class from river.

From the picture above, it can be seen that areas with a distance of 0 - 100, 100-200 and 300 - 400 meters have a frequency ratio value above 1, which means that the area has the potential for landslides. This happens when the area has moist soil, unstable rocks, as well as rainfall, soil types and rock types. Whereas at a distance of 200 - 300 and above 400 meters, the frequency ratio value is below 1, so the effect on landslide vulnerability is low.

3.2.6. Fracture distance. This factor is almost the same as the distance from the river, which is to determine the effect of the proximity of landslides to the fracture. The factors causing landslides in the form of distance from the fracture in the Tangka watershed were obtained from the National DEM which was then classified based on the distance start from 0 - 500, 500 - 1000, 1000 - 1500, 1500 - 2000 and > 2000 meters. The value of the frequency ratio at the fracture distance can be seen in Figure 8.

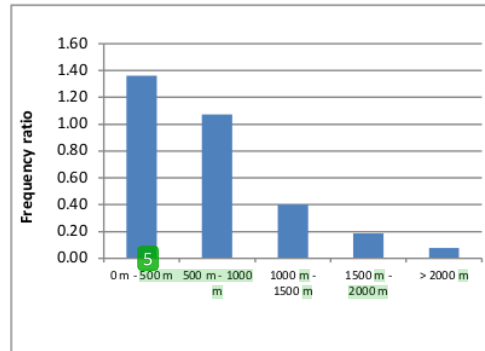


Figure 8. Graph of Frequency Ratio Value in the Fracture Distance class.

From the picture above, it can be seen that the closer the landslide is to the fracture, the higher the landslide hazard. This happens at a distance of 0 - 1000 meters with a frequency ratio above 1, which means that the level of landslide vulnerability is high. Nandi (2007) said the long dry season will result in large amounts of water evaporation on the soil surface [14]. This results in the appearance of pores or soil cavities, causing cracks to occur, and cracks the surface soil. When it rains, water will infiltrate the cracked soil so that the soil will quickly expand again and landslides occur. Whereas at a distance of 1000 to more than 2000 meters, it has a low level of landslide hazard with a frequency ratio of less than 1.

3.2.7. Rainfall. Rainfall is one of the factors that influence the level of landslide hazard. Rainfall data for this study were taken in the last 10 years 2004 - 2014 which produced average rainfall data per each station. The Tangka watershed consists of five stations including Biring Ere, BPP. Kahu, Lamati Riattang, BB. Malino and Manipi. The effect of rainfall on the frequency ratio can be seen in Figure 9.

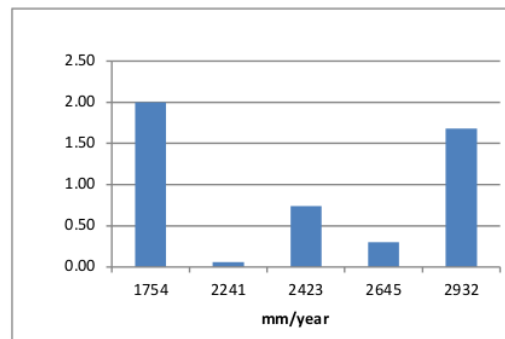


Figure 9. Graph of frequency ratio value in rainfall class.

Based on the picture above at the BPP station. Kahu with rainfall 1754 and BB. Malino with rainfall of 2932 has a frequency ratio value above 1, which means that the level of landslide vulnerability is high. Heavy rain at the beginning of the season can cause landslides because through the soil that breaks the water so that it easily enters and accumulates the bottom of the slope, causing lateral movement. High rainfall intensity usually often occurs at the beginning of the rainy season, so that the water content in the soil becomes saturated in a short time according to Nandi (2007) [14]. Whereas at Biringere station

with 2241 rainfall, Lamati Riattang with 2645 rainfall and Manipi with 2423 rainfall had a frequency ratio value below 1 which means that the level of landslide vulnerability is low. It can be seen that the level of rainfall in a place does not affect the risk of landslides. However, it is a driving factor for other causes of landslides.

3.2.8. *Slope direction/aspect.* The factors of slope direction/Aspect were obtained from the National DEM, then processed to produce several classes of slope directions /Aspect those are flat, north, northeast, east, southeast, south, southwest, west and northwest. The effect of the class of the slope direction/aspect on the value of the frequency ratio can be seen in Figure 10.

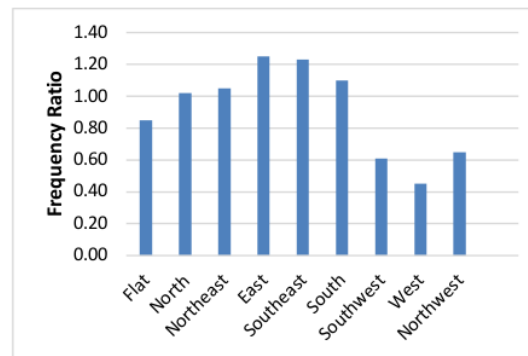


Figure 10. Graph of Frequency Ratio Value in Slope Direction/Aspect class.

On picture above, it can be seen that the north, northeast, east, southeast and south classes have a frequency ratio value above 1 indicating a high level of landslide vulnerability. This is because the slopes are often exposed to sunlight and produce rain, the heat from the sun combined with high rainfall will make the land easily weathered and cause erosion [15]. Whereas in the flat class, southwest, west and northwest have a frequency ratio value below 1 indicating a low level of landslide vulnerability.

3.3. *Landslide validation using the frequency ratio method*

Validation is used to predict the success rate of the accuracy value of this study. The analysis used in this validation is the Receiver Operating Characteristic (ROC) which obtain an accuracy value based on the Area Under Curva (AUC). In this analysis, there are two validation results. The first validation was done to see the success rate of the frequency ratio value. Meanwhile, the second validation was done to determine the prediction level of landslides. The results of the validation with the ROC analysis are presented in Figure 11 and the AUC accuracy value is in Table 1.

Table 1. AUC value based on roc analysis for success rate and prediction of frequency ratio to landslide events.

Method	Fr
AUC Success Rate (Validation 1)	0.820
AUC Prediction Rate (Validation 2)	0.816

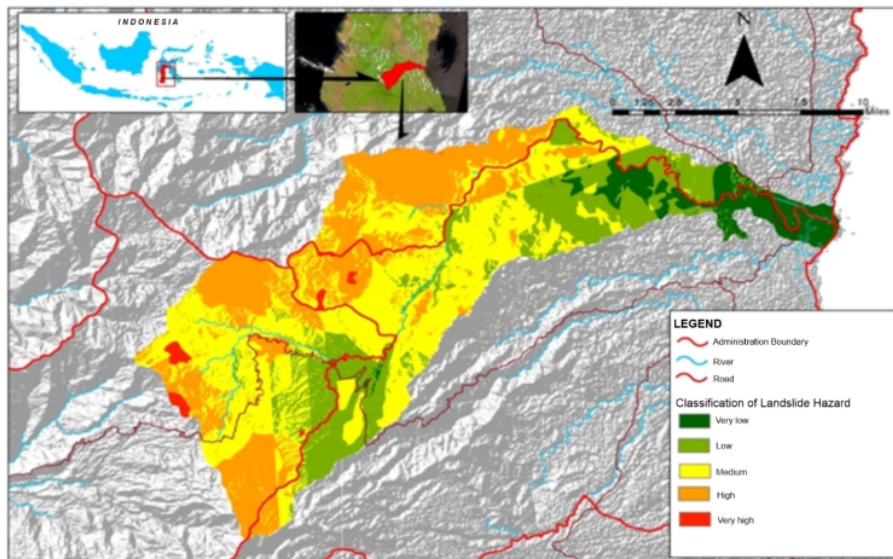


Figure 11. Landslide Hazard map in the Tangka watershed.

Based on the results of the validation in Figure 11 and the AUC value in Table 1, it shown that the first validation has a higher frequency ratio value of 0.820. Meanwhile, the second validation has a value of 0.816. This shows that both validations are vulnerable to landslides. As it is said Soma and Kobuta (2017), AUC success rate with a value above 0.8 is declared good according to the classification of landslide validation results [10].

Figure 11 shows that the landslide hazard is classified into 5 class levels which are very low, low, medium, high and very high landslide hazard. The upstream and middle areas of the Tangka watershed are locations that have very high, high and medium hazard classes. Meanwhile, the downstream area is the location of the low and very low landslide hazard class. Based on the picture above, we can see that the landslide hazard class in the very low class has an area of 4072.17 ha (8%), the low hazard class has an area of 8869.89 ha (18%), the medium hazard class has an area of 1553.32 ha (32%), the class high hazard has an area of 15405.32 ha (32%) while very high hazard class has an area of 3524.18 ha (7%) of the total area of the Tangka watershed area of 47385.34 ha.

The ratio between very low and very high hazard classes is not too different where we can see that the area of each class is only 1% different. However, in the high and medium hazard classes that dominate the distribution of landslide hazard, we can categorize the Tangka watershed as an area that has a high potential for landslides. The medium and high hazard classes are scattered in the upstream and middle areas of the Tangka watershed. In the area of Gowa, the areas that have low vulnerability class cover an area of 181.46 ha, medium 4587.88 ha, high area of 310.08 ha and very high area of 10247.36 ha. Bone Regency which has a very low hazard class with an area of 3108.10 ha, a low area of 563.92 ha, medium area of 16.08.67 ha, a high of 1031.04 ha and very high with an area of 7385.44 ha.

4. Conclusions

The results of the analysis based on the calculation of the frequency ratio can be seen in the land cover landslide hazard factor in open land which has a frequency ratio value of 5.99 so that the potential for landslides is very high compared to other factors causing landslides. After that followed by factors of slope, rainfall, river distance, lithology, fracture distance and slope direction/Aspect. Based on the

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landslide hazard map, it is classified into 5 classes those are very low, low, medium, high and very high. Areas with moderate to high landslide vulnerability areas in the Tangka watershed are found in the upstream area, while low landslide vulnerability areas are in the middle and downstream.

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