

# Potential landslide-prone areas in The Kelara subwatershed using the analytical hierarchy process method

*by Syamsul A Lias*

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**Submission date:** 03-Oct-2022 04:27AM (UTC+0700)

**Submission ID:** 1914521703

**File name:** min\_2021\_IOP\_Conf.\_Ser.\_Earth\_Environ.\_Sci.\_807\_022080\_1.pdf (1.34M)

**Word count:** 4393

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# Potential landslide-prone areas in The Kelara sub-watershed using the analytical hierarchy process method

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**Abstract.** Landslides are one of the geomorphological processes active in changing the shape of the earth's surface. Landslides have an impact on life and the environment. This research will map the potential landslide-prone areas in The Kelara Sub-watershed using the Analytical Hierarchy Process (AHP) method. The method used in this research is the Analytical Hierarchy Process (AHP) method and the spatial analysis method. The potential for landslide-prone areas in The Kelara Sub-watershed has three potentials or levels of landslide vulnerability, namely low (2939.28 ha) (32.72%), medium (3082.78 ha) (34.32%), and high (2961.55 ha) (32.96%). Parameters that influence landslides in the Kelara Sub-watershed are slope parameters with a weight of 0.30 or a score of 30%.

## 1. Introduction

Landslide is one of the geomorphological processes that are active in changing the shape of the earth's surface. This process moves the mass of soil and rock downward following the slope. Several factors influence the occurrence of landslides, namely rainfall, slopes, soil types, geology, and land cover [1].

Landslides have an impact on life and the environment. The effect on life can be in the form of casualties, damage to public infrastructure, damage to facilities and infrastructure, and obstructing community activities. Meanwhile, the impact on the environment can be in the form of damage to land, loss of land cover vegetation, disturbance of the ecosystem's balance, land becoming critical so that underground water reserves are depleted, and reduced land productivity [2].

The potential for landslides depends on the characteristics of an area [3]. Areas with mountainous features and high rainfall have the potential to cause landslides [4]. The Kelara Watershed has approximately 39112 ha covering two districts, namely Gowa Regency (Bontolempangan, Bungaya, Tompobulu, and Biringbulu Districts) and Jeneponto Regency (Rumbia, Kelara, Turatea, and Binamu Districts). The upstream of the Kelara Watershed is located in Gowa Regency, while the Kelara Watershed downstream is located in Jeneponto Regency. In the downstream area, the average annual rainfall is 1056 mm/year; in the middle area, the average rainfall is 1822 mm/year, while in the upstream region, the average rainfall is 2952 mm/year [5].

Based on these characteristics, the Kelara Watershed is included one of the (macro) criteria for determining landslide-prone areas. This determination is based on the Minister of Public Works Regulation No. 22/PRT/M/2007, namely the average high level of rainfall (above 2500 mm per year). Apart from increased rainfall, one of the causes of landslides is slopes. The results of field observations show that landslides are visible on slopes of 25% (steep) to >40% (very steep), both on natural slopes



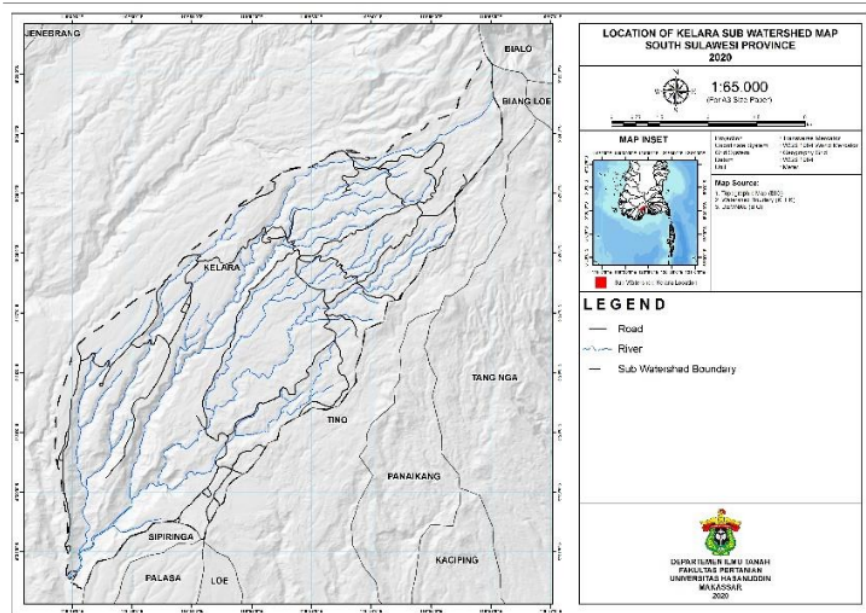
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or on artificial slopes (human work) [6]. The occurrence of landslides evidences this on Saturday, June 13, 2020, in Rumbia District, Jeneponto Regency. Therefore, it is crucial to map the potential for landslide-prone areas in the Kelara Sub-watershed to minimize the occurrence of landslides in the future.

This research will map the potential landslide-prone areas in the Kelara Sub-watershed using the Analytical Hierarchy Process (AHP) method. This method simplifies a complex or complex problem that is not structured into parts (parameters) and arranges it into a hierarchy using several parameters: rainfall, slope, soil type, geology, and land cover. The selection of these parameters is based on the factors that influence the occurrence of landslides.

**2. Methods**

This research was conducted in the Kelara Sub-watershed, South Sulawesi Province. This research took place from October to November 2020. The location of Kelara Sub-watershed is in Gowa Regency and Jeneponto Regency. Area of Kelara Sub-watershed Map (figure 1).



**Figure 1.** Location of Kelara sub-watershed map.

The tools used in this study were clinometers, Global Positioning System (GPS), cameras, writing instruments, Expert Choice 11 software, and ArcGIS. The materials used in this study are monthly rainfall data for 2010-2019, Digital Elevation Model National (DEMNAS) data with 8 m resolution, Topographic Map (RBI) in the form of vector data scale 1: 50000, Land Cover in 1:150000 or data form scale 1: 100000 and Watershed Boundar (DAS) in the form of vector data, Geology in the form of vector data scale 1: 250000, Land System in 1:230000 form of vector data scale 1: 250000.

This research's analysis method is the Analytical Hierarchy Process (AHP) method and the spatial analysis method or Geographic Information System (GIS). The Analytical Hierarchy Process (AHP) method is a decision-making method to determine the weighted value of the parameters based on experts' judgment, competent and experienced figures to provide weights for various parameters to produce a score [1].

Determination of landslide-prone areas can be done after each parameter has obtained weight and score. The landslide-prone areas' determination is carried out using spatial analysis or Geographical Information Systems (GIS). The use of GIS in disaster risk management consists of creating databases, overlapping, and determining landslide hazard classes.

This research stage is in the form of primary and secondary data collection. Then proceed with making basic maps for data analysis. This stage is carried out by studying literature related to the research topic, finding and collecting secondary data, collecting the necessary tools and materials, creating a questionnaire, and determining respondents. Primary data includes rechecking slopes in the field and collecting landslide points in the field. The interview data for AHP weighting were then obtained from interviews by distributing questionnaires to several practitioners and lecturers who were experienced in the field of landslides and knew the field conditions, especially in the research location. Secondary data includes spatial data obtained from several agencies, consisting of Topographic Map (RBI) in the form of vector data scale 1: 50000 received from the Geospatial Information Agency (BIG), 2019 Land Cover in the form of vector data scale 1: 100000 and Watershed Boundary (DAS) in the form of vector data from the Ministry of Environment and Forestry (KLHK), Sulawesi Regional Geology in the form of vector data scale 1: 250000 from Center for Geological Research and Development (P3G), Land System in the form of vector data scale 1: 250000 from the Regional Physical Planning Program for Transmigration (RePPPProT) in 1987, monthly rainfall data from satellite image analysis downloaded from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) 2010-2019, and Digital Elevation Model the 8 m resolution (DEMNAS) downloaded from the Geospatial Information Agency (BIG).

### 2.1. Basemap creation

**2.1.1. Rainfall map creation.** Rainfall maps were obtained from the process interpolate through ArcGIS software using satellite image analysis data. The satellite image is data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), which was downloaded previously. Then it is processed and analyzed to produce rainfall points on each pixel of the satellite image in the form of vector data. Each point contains rainfall data from 2010 to 2019; this data is then further processed by the interpolation method CoKriging and then cut according to the research location using the Clip to produce a rainfall map. CoKriging is one way of reducing the variance of estimating a variable or estimating several variables simultaneously [7].

**2.1.2. Slope map creation.** Map slope obtained from the manufacturing process Slope through ArcGIS software using data DEMNAS. The first step taken was the DEMNAS data projected. Then fill in the empty raster data using Fill. Then cut the DEMNAS data according to the research location using the Clip. After that, identify the slopes of each raster in DEMNAS using the slope. Then the slope map results are obtained, then rechecking in the field is carried out to match the map with conditions in the field.

**2.1.2.1. Soil map creation.** The soil map was obtained from the Land System in vector data (Shapefile) with a scale of 1: 250000 from the Regional Physical Planning Program for Transmigration (RePPPProT) in 1987. This map is then cut with the research location using the Clip to produce a soil type map.

**2.1.2.2. Geology map creation.** The rock formation map was obtained from the Sulawesi Regional Geology sourced from the Center for Geological Research and Development (P3G) in vector data with a scale of 1: 250000. This map is then cut with the research location using the Clip to produce a map of the rock formation.

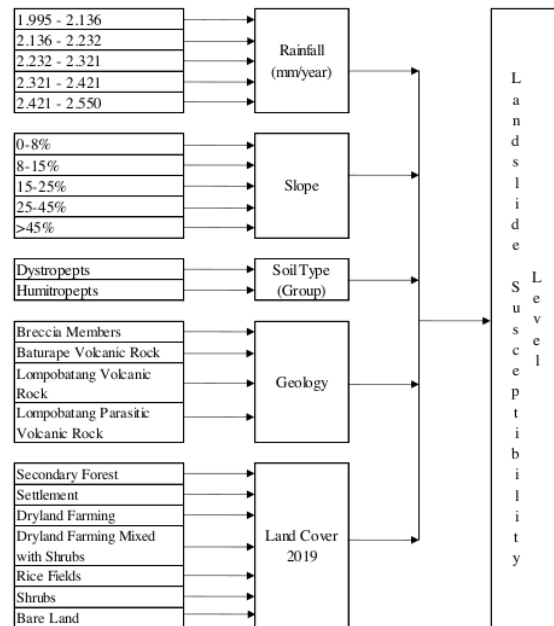
2.1.2.3. **Land cover map creation.** The land cover is obtained from the Land Cover 2019 in vector data with a scale of 1: 100000 from the Ministry of Environment and Forestry (KLHK). This map is then cut with the research location using the Clip to produce a land cover map.

2.1.3. **Weighting with Analytical Hierarchy Process (AHP).** Weighting with the Analytical Hierarchy Process (AHP) is a method that uses data from interviews with several practitioners and lecturers who are experienced in the field of landslides. The most important thing in making a landslide-prone map using AHP is determining each parameter and sub-parameters weight.

Each parameter weight and subparameter is determined with the help of Expert Choice 11 software (EC). Expert Choice (EC) is software that can be used to assist decision-makers in determining a decision from several predetermined parameters to produce weight and score. Determining the weight of each parameter can be done in several steps, namely:

- 1) Creating a project: determining objectives and criteria,
- 2) Hierarchical arrangement (input and parameter setting),
- 3) Determine the weight of each criterion/parameter,
- 4) Determination of alternatives based on assessment criteria,
- 5) Synthesis testing and data analysis presentation of alternative determination.

The hierarchical arrangement in this study (figure 2).



**Figure 2.** The Hierarchical analysis in this study.

2.1.4. **Spatial analysis.** The spatial analysis was carried out by overlapping the digital maps after obtaining each parameter's weight against landslide hazard through the AHP method. Spatial analysis was carried out to produce zoning of locations with the potential for landslide hazards. After that, make a classification regarding the type of landslide hazard based on the level of threat. The digital maps are overlaid by entering each weight. The weights are rainfall map, slope map, soil map, geology map, and land cover map.

2.1.5. *Validation.* Validation is carried out to match the results of making a potential map of landslide-prone areas with landslide points in the field. This is done as a process of proving that the map produced is appropriate or not. A review must be carried out back to the data analysis stage if it is not suitable.

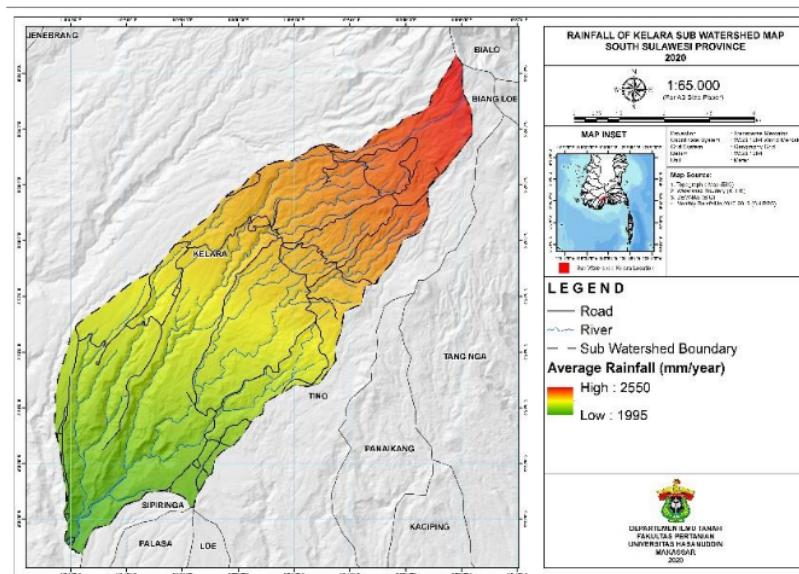
**3. Results**

**3.1. Landslides parameters**

Several parameters as landslides factors are;

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3.1.1. *Rainfall.* Based on satellite imagery analysis downloaded from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), the results show that the rainfall in the Kelara Sub-watershed ranges from 1995-2550 mm/year. Rainfall of Kelara Sub-watershed Map (figure 3).



**Figure 3.** Rainfall of Kelara Sub-watershed map.

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3.1.2. *Slope.* Based on the analysis of DEMNAS 8 m data and rechecking in the figure 5, the results show that the slopes in the Kelara Sub-watershed consist of five slope classes, namely 0-8% (flat), 8-15% (gentle), 15-25% (slightly steep), 25-45% (steep), and >45% (very steep). The slope of Kelara Sub-watershed map (figure 4).

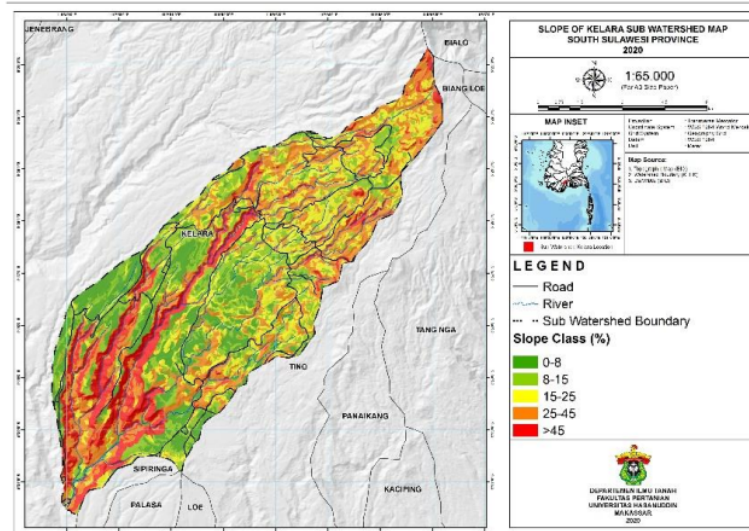


Figure 4. The slope of Kelara Sub-watershed map.

3.1.3. Soil. Based on the Land System in the form of vector data with a scale of 1: 250000 from the Regional Physical Planning Program for Transmigration (RePPProT) [8], it was found that the soil types in the Kelara Sub-watershed consist of two types of soil, namely Dystropepts and Humitropepts. The soil of Kelara Sub-watershed Map (figure 5).

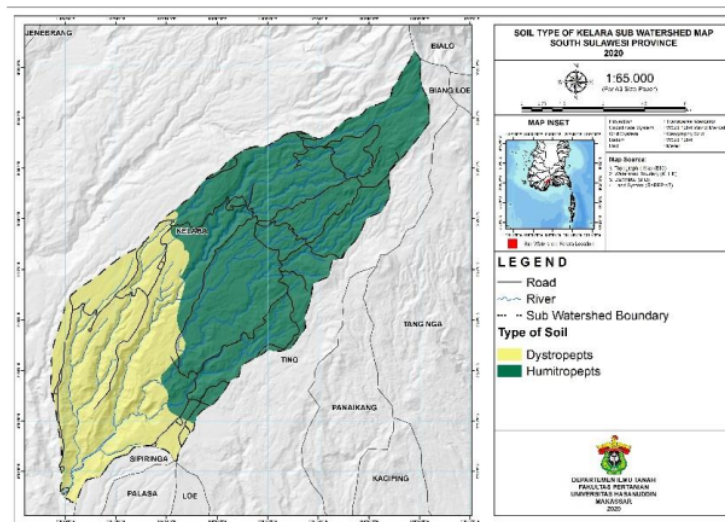


Figure 5. The soil of Kelara Sub-watershed map.

3.1.4. *Geology*. Based on the Sulawesi Regional Geology in the form of vector data at a scale of 1: 250000 from the Center for Geological Research and Development (P3G) [9], the results show that the rock formations in the Kelara Sub-watershed consist of four rock formations, namely breccia members, Baturape volcanic rocks, Lompobatang volcanic rocks, and Lompobatang parasitic volcanic rocks. Geology of Kelara Sub-watershed Map (figure 6).

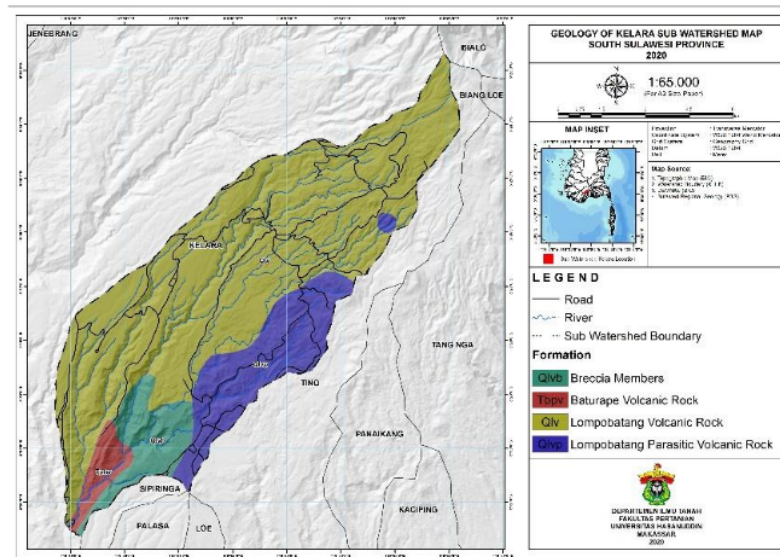


Figure 6. Geology of Kelara Sub-watershed map.

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3.1.5. *Land Cover*. Based on the Land Cover 2019 in the form of vector data (Shapefile) at a scale of 1: 100000 from the Ministry of Environment and Forestry (KLHK) [10], the results show that land cover in the Kelara Sub Watershed consists of seven land covers, namely secondary forest, settlement, dryland farming, dryland farming mixed with shrubs, rice fields, shrubs, and bare land. Land Cover of Kelara Sub-watershed Map (figure 7).

### 3.2. Interview Result

Interview data for AHP weighting were obtained from interviews by distributing questionnaires to several practitioners and lecturers experienced in landslides and knowing the field conditions, especially in the research location. The total of the interviewer is six people.

### 3.3. The weighting of parameters and sub-parameters using AHP

The results of interviews with several respondents were then processed by AHP using Expert Choice software. Parameter weights with AHP (figure 8) and sub-parameter weights and scores with AHP (table 1).

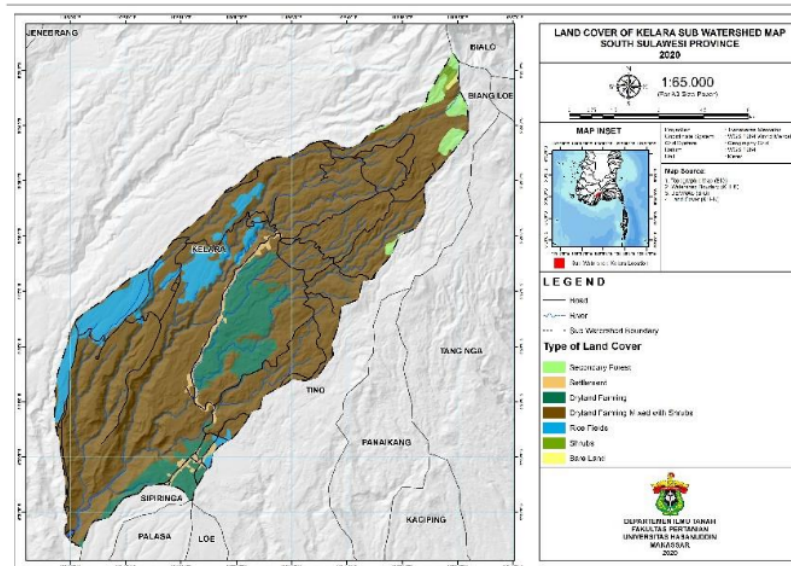


Figure 7. Land cover of Kelara Sub-watershed map.



Figure 8. Parameter weights with AHP.

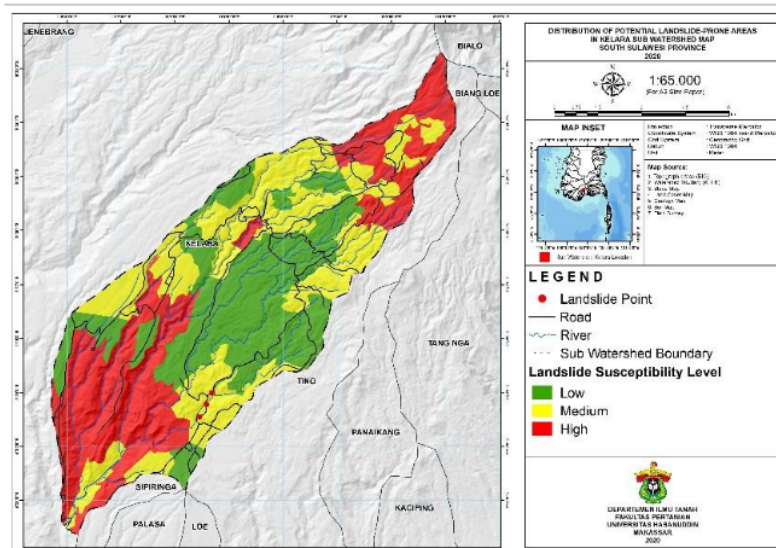
Table 1. Sub-parameter weights and scores with AHP.

No	Parameter	Sub Parameter	Weights	Scores
1	Slope (%)	0-8%	0,046	4,6
		8-15%	0,08	8
		15-25%	0,164	16,4
		25-45%	0,31	31
		>45%	0,401	40,1
<b>Inconsistency = 0,00971</b>				
2	Land Cover 2019	Secondary Forest	0,086	8,6
		Settlement	0,127	12,7
		Dryland Farming	0,142	14,2
		Dryland Farming Mixed with Shrubs	0,124	12,4
		Rice Fields	0,139	13,9
		Shrubs	0,103	10,3
	Bare Land	0,279	27,9	

<b>Inconsistency = 0,00541</b>			
3	Rainfall (mm/year)	1.995-2.136	0,069 6,9
		2.136-2.232	0,115 11,5
		2.232-2.321	0,168 16,8
		2.321-2.421	0,263 26,3
		2.421-2.550	0,385 38,5
<b>Inconsistency = 0,0082</b>			
4	Soil Type (Group)	Dystropepts	0,629 62,9
		Humitropepts	0,371 37,1
<b>Inconsistency = 0,00</b>			
5	Geology	Breccia Members	0,321 32,1
		Baturape Volcanic Rock	0,17 17
		Lompobatang Volcanic Rock	0,244 24,4
		Lompobatang Parasitic Volcanic Rock	0,265 26,5
<b>Inconsistency = 0,00278</b>			

**1** 3.4. Distribution of potential landslide-prone areas in Kelara subwatershed

The Kelara Sub-watershed has three levels of landslide vulnerability, namely **29** (2939.28 ha) (32.72%), medium (3082.78 ha) (34.32%), and high (2961.55 ha) (32.96%). Map of the distribution of landslide-prone areas in Kelara Sub-watershed (figure 9).



**28** Figure 9. Map of the distribution of landslide-prone areas in Kelara Sub-watershed.

**1** 4. Discussion

Based on the results obtained, the potential for landslide-prone areas in the Kelara Sub-watershed and landslides in the Kelara Sub-watershed is influenced by the slope parameter with the highest weight among other parameters, namely 0.30 or a score of 30% (figure 8). Field observations indicate that landslides are visible on slopes of 25% (steep) to >40% (very steep), both on natural slopes or on artificial slopes (human work) [11]. Areas with steep slope topography will have the potential for more

significant soil movement than areas with gentle slope topography. This is because the ratio between the holding and driving forces on a steep slope is relatively smaller than a gentler slope [12].

After the slope parameter, the second position 7 occupied by the rainfall parameter with a weight, namely 0.271 or a score of 27.1% (figure 8). The long dry season 7 will cause a large amount of water evaporation on the soil surface. This results in the appearance of pores or soil cavities, causing cracks and cracks to occur. When it rains, water will infiltrate the cracked area so that the soil quickly re-expands [13]. At the beginning of the rainy season, high rainfall intensity usually occurs frequently so that the water content in the soil becomes saturated in a short time. Heavy rain at the beginning of the season can cause landslides because through the cracked soil, and water will enter and accumulate at the bottom of the slope, causing lateral movement. If there are trees on the surface, landslides can be prevented because water will be absorbed by plants that bind the soil [5]. The rainfall factor is one of the triggers for landslides because excessive rainfall can cause a decrease in slope stability and cause the soil to fall, which triggers landslides [4].

The parameter that occupies the third position is the land cover parameter with weight, namely 0.178 or a score of 17.8% (figure 8). The secondary forest weights of 0.086 or a score of 8.6%, settlements weight 0.127 or a score of 12.7%, dry-land farming weights 0.142 or a score of 14.2%, dry-land farming mixed with shrubs weights 0.124 or a score of 12.4 %, rice fields weight 0.139 or a score of 13.9%, shrubs weight 0.103 or a score of 10.3% and open land weights 0.279 or a score of 27.9% (table 1). The use of grass or shrub land has good sensitivity due to low vegetation cover, but the rock outcrop is open so that it has a heavy load. In contrast, residential land use is a type of parameter of soil movement that has moderate sensitivity. This is due to the absence of effective (vegetation) management, has a relatively heavy load, and has a low level of water porosity into the soil. Another type of land use that has moderate sensitivity to soil motion is rice fields [13]. Rice fields have good management; however, the level of water porosity into the soil is very low, so that the load becomes heavier. Types of land use with low sensitivity are garden, fields, dry land [4]. Forest land use areas with a low level of erosion and are less likely to move the soil than areas prone to erosion, such as open areas with no vegetation [8]. Land-use planning is very needed for regional spatial planning for land sustainability [13,14].

Parameters that occupy the fourth position are geology parameters with weight, namely 0.142 or a score of 14.2% (figure 8). Volcanic sediment and sedimentary rocks of sand size and a mixture of gravel, sand, and clay are less intense. These rocks will easily become ground when subjected to a weathering process and are generally susceptible to landslides if there are steep slopes [5].

The parameter that occupies the last position is the parameter of soil type with a weight, namely 0.109 or a score of 10.9% (figure 8.). Dystropepts weights 0.629 or a score of 62.9%, and Humitropepts weigh 0.371 or 37.1% (table 1). Dystropepts have the characteristics of infertility and low base saturation, whereas Humitropepts have characteristics of fine organic matter or humus [14]. Soil type is a very determining factor for the potential for erosion and landslides [16] because the soil has water-permeability properties. The soil characteristic can describe the strength or weakness of the soil's binding power (cohesion) so that loose soil will easily pass water to enter the soil cross-section. This condition causes the loose soil will be triggered a landslide compared to blocky soil (massive) [6].

The results obtained in the map of the distribution of landslide-prone areas in the Kelara Sub-watershed are dominated by the potential or medium level of landslide vulnerability. The existence of three landslide points proves the potential level of landslide vulnerability in the field. Then, the parameter that dominates the potential for landslide-prone areas in the Kelara Sub-watershed and landslides in the Kelara sub-watershed is the slope parameter. Slope parameters that dominate in the field range from 8-45%. The slope is a critical factor in landslides; this is because steep slopes will increase the driving force. Areas with a slope between 0-15% will be stable against the possibility of landslides, while above 15%, the potential for landslides to occur during the rainy season and earthquakes will be even more significant. A steep slope or cliff will increase the propulsion or gliding force. The steep slopes are formed due to the filling of rivers, springs, seawater, and wind [3].

## 5. Conclusions <sup>1</sup>

The potential for landslide-prone areas in the Kelara Sub-watershed has three potentials or levels of landslide vulnerability, namely low (2939,28 ha) (3,302%), medium (3082,78 ha) (34,32%), and high (2961,55 ha) (32,96%). Parameters that influence landslides in the Kelara Sub-watershed are slope parameters with a weight of 0,30 or a score of 30%.

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