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Research Paper

Mapping Landslide Susceptibility Areas Using GIS Analysis in Cilawu Sub-district, Garut, West Java

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Abstract

A landslide is the movement of soil mass down a slope. Landslides can be influenced by some factors including rainfall, soil type, land slope, land cover, and human activities. Cilawu Sub-district, Garut, West Java is one of the most frequently experienced landslide areas which cause severe losses. This mapping aims to provide information about the landslide-susceptibility areas in Cilawu Sub-district, Garut, West Java by using a Geographic Information System (GIS). This study used Digital Elevation Model (DEM) image, Landsat image, rainfall, geology, and soil types data which were then mapped using ArcGIS software. The analysis process used the overlay method, scoring method, and weighting method. The final result was a landslide map with 4 susceptibility levels covering low susceptibility, medium susceptibility, high susceptibility, and very high susceptibility. Based on this analysis, Cilawu District was dominated by the following classes: high susceptibility with an area of 5470.07 Ha, medium susceptibility with an area of 1627.78 Ha, very high susceptibility with an area of 515.96 Ha, and low susceptibility with an area of 366.16 Ha.

Keywords

Cilawu Sub-district, Geographic Information System, Landslide Susceptibility, Mapping, Overlay Analysis

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1. INTRODUCTION

Landslides are the movement of soil mass in the form of soil, rock, or a mixture from the top down a slope (Rahman, 2018). Based on Arsyad view's on Purba (2014), landslides occur due to the movement of a certain volume of soil in a slightly impermeable layer of saturated water. This layer may contain high levels of clay or rock in which the saturated water condition can become a slide-like clay shale. Landslides are a type of "mass wasting," which indicates any soil and rock movement down a slope under the direct influence of gravity (Prakasam et al., 2020).

Landslides can be influenced by some factors such as geological conditions, topography, climate, hydrography, and weather changes (Bokko, 2019; Silalahi et al., 2019; Chang et al., 2023). Rock types and geological structures/linearities are responsible for slope instability as the slope movement can be influenced by weathering conditions (Banuzaki and Ayu, 2021). As climate change occurs it can rising the global temperatures and increase the level of risk associated with floods, landslides, droughts, crop failures, biodiversity loss, sea level rise and deterioration of human health (Gariano and Guzzetti, 2016; Herdani et al., 2020). Rainfall characteristics are depend on meteorological and topographical factors, which can cause significant temporal and geographic variations during rainfall periods (Dhungana et al., 2023). There are two types of triggering factors that affect slope instability: driving forces and resisting forces (Mandal et al., 2018). Ministry of Energy and Mineral Resources states that in principle, landslides occur when the driving force on the slope is greater than the resisting force (Irsyad, 2017). Generally, the resisting force is influenced by rock strength and soil density, while the driving force is influenced by the slope angle, water, load, and rock soil density.

The hill or mountain topography, the dense population in the hilly or mountainous areas, and the poor use of land and space can trigger pressure on existing ecosystems (Effendi, 2016). High rainfall in steep slope areas and the absence of hard and deep-rooted plants also trigger a landslide (Isnaini, 2019). Sustainable development in mountainous areas must refer to the implementation of development schemes by considering the instability of the field to minimize the geo-environmental hazards (Anbalagan, 2014). Identification of landslide-prone areas are important to reduce the serious effects of landslides and develop appropriate planning and decision-making tools (Sharma and Mahajan, 2018; Chen et al., 2018). To avoid and minimize losses, the identification of the landslide-prone areas can be done by mapping the area to provide an overview of the susceptibility level of the area (Wang et al., 2015; Chen et al., 2018; Patil and Panhalkar, 2023). Landslide susceptibility is the spatial distribution of the probability of a landslide occurring in an area based on local geographic environmental factors (Chen et al., 2018). Creating a landslide susceptibility map of a particular area proves to be very useful in landslide hazard management because it can describe the level of vulnerability of an area to landslides with the assumption that future landslides will occur under the same conditions as in the past (Mersha and Meten, 2020). Landslide susceptibility maps provide information on landslide hazard areas, primarily by identifying areas that have experienced landslides and areas with similar or identical physical characteristics to landslide-affected areas (Xiong et al., 2017).

Landslide susceptibility has been evaluated at many sites around the world since the early 1980s with different mapping units, combinations of variables and different methods (Rossi and Reichenbach, 2016). Some previous studies have focused on mapping landslides (Purba, 2014; Effendi, 2016). Several researchers have used GIS-based landslide vulnerability mapping methods along with statistical models (Nohani et al., 2019; Chowdhury and Hafsa, 2022; Malka, 2022). A few researchers focused on used several variables to determine landslide-prone areas including slope, land use, soil erodibility, and rainfall with weights of 40, 30, 20, and 10, respectively. Another study used variables of rainfall, soil type, land slope, altitude, and land cover which were then analyzed using the Fuzzy Logic method to determine the susceptibility level of the landslide.

This present study uses different variables and areas. In terms of parameters, this study refers to Center for Soil and Agroclimate Research (2004) including rainfall, geological formation (source rock), land slope, land cover, and soil type. This study was carried out in a landslide-prone area of Cilawu Sub-district, Garut District, West Java.

Cilawu Sub-district has an altitude of 700-1200 meters above sea level (Central Agency on Statistics Garut District, 2020). Some parts of its area are the eastern slope of Mount Cikuray dominated by steep slopes (>40%) (Central Agency on Statistics Garut District, 2018). Besides, the Forecast Map of the Land Movement Area in March 2020, Garut District (Center for Volcanology and Geological Hazard Mitigation, 2020) shows that Cilawu Sub-district is included in the Medium – High soil movement areas. Cilawu Sub-district is one of the sub-districts experiencing the most frequent landslides in the Garut District (Regional Disaster Management Agency Garut, 2021). Based on Statistics Indonesia, this area experienced at least 35 landslides during 2018-2020 (Central Agency on Statistics Garut District, 2020). Referring to the data of the Garut Disaster Mitigation Agency, 12 landslides occurred in this sub-district in 2021. The frequent landslides in this sub-district are very disturbing due to the severe losses such as damaging houses and roads. To minimize the impact of the landslide, this present study is concerned with mapping the landslide susceptibility level and providing information about landslide hazards in Cilawu Sub-district, Garut, West Java by using the Geographic Information System (GIS). The mapping used the ArcGIS software with the overlay method as the main tool for analysis. The mapping of landslide-prone areas in the Cilawu Sub-district is expected to minimize losses and take preventive actions for areas with a high susceptibility level.

2. EXPERIMENTAL SECTION

2.1 Materials

This study used secondary data processed in 2022. The data consisting of Digital Elevation Model (DEM) image data to obtain land slope maps (Herrera-Coy et al., 2023). The process were done using SRTM global digital elevation data at a nominal resolution of 30 m. 1"SRTM DEM it is currently the most widely used worldwide because of its tolerable vertical and horizontal quality and accuracy (Milevski, 2014). DEM with 10-30m resolution estimate elevation and derived topographical properties unbiasedly and display topographical information with similar quality (Chaplot et al., 2000). Land cover data was obtained from world imagery of ArcGIS 10.7.1. Rainfall data of Garut District, soil types, geological distribution, and the administration data of Cilawu Sub-district (Figure 1) was also used. Due to limitations in the form of secondary data availability, the scaling of several maps is not the same. Soil type data was taken from soil types map of Garut Regency with a scale of 1: 50,000 and rock type data was obtained from the Geological Map of Garut-Pameungpeuk Sheet, scale 1: 250,000.

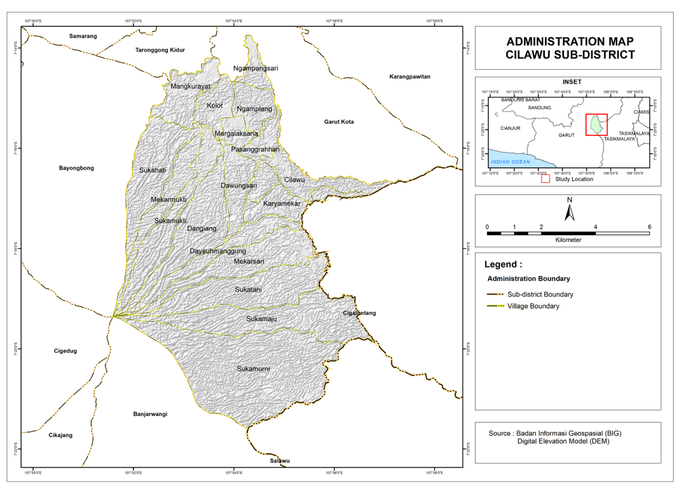

Figure 1. Administration Map of Cilawu Sub-district

2.2 Methods

Data were processed using ArcGIS 10.7.1 software. DEM image data were processed using slope tools in ArcGIS software to obtain land slope maps. Land cover digitization was carried out using high-resolution satellite imagery from the ArcGIS basemap to obtain a land cover map. The geological map of Garut Pameungpeuk was digitalized (Alzwar et al., 1992) and proceeded with geo-referenced. Rainfall map was developed from annual rainfall data recorded 10 years from 2006 to 2016 in four rainfall stations, there are Pamegatan station, Kepakan station, Tarogong station, Leuwi Goong station. The data were processed using Inverse Distance Weighting (IDW) tools to obtain a rainfall map. The soil type data from the Center for Agricultural Land Resources (BBSDLP) were clipped with Cilawu Sub-district administration data in ArcGIS software to produce a soil type map. This map has same scale as administrative map (1 : 25,000) from BIG and then used as reference data for determining the location of the study and as a reference for mapping analysis of the susceptibility levels in Cilawu Sub-district. To create a landslide susceptibility map, this study will analyze it based on the susceptibility class in the village administration unit.

The analysis was carried out after all map data were ready in digital form. Each type of map was classified based on a score and given weight. Then, the scores were grouped and analyzed using the overlay method. The classification of scores and weights referred to the 2004 Center for Soil and Agroclimate Research (Puslittanak) estimation model with the parameters of the land slope, soil type, land cover, rainfall, and geological formations (source rock) (Rahmad et al., 2018; Yassar et al., 2020). The 2004 Center for Soil and Agroclimate Research model uses the following Equation (1).

$$\text{Total Score} = 0.3FCH + 0.2FBD + 0.2FKL + 0.2FPL + 0.1FJT \quad (1)$$

Notes:
FCH = Rainfall factor
FBD = Type of rock factor
FKL = Land slope factor
FPL = Land cover factor
FJT = Type of land factor
0,3;0,2;0,1 = Weight value

Overlays were performed on land slope maps, land cover maps, rainfall maps, soil type maps, and geological maps by using ArcGIS software. The map was overlaid on the administrative map of the Cilawu Sub-district so that each village gets a susceptibility score. The higher the score, the higher the potential for landslides. Therefore, there are four classification areas for the potential level of landslides covering low, medium, high, and very high by calculating the score interval using the following Equation (2).

$$\text{Score Interval} = \frac{\text{Highest score - Lowest score}}{\text{Number of classification class}} \quad (2)$$

The field verification process was carried out by looking at the location of the landslide points that occurred in 2021. The actual landslide data were obtained from the Central Agency on Statistics Garut District (2021) and the findings in the field with a total of seven landslide points. The map of the actual landslide location is presented below (Figure 2).

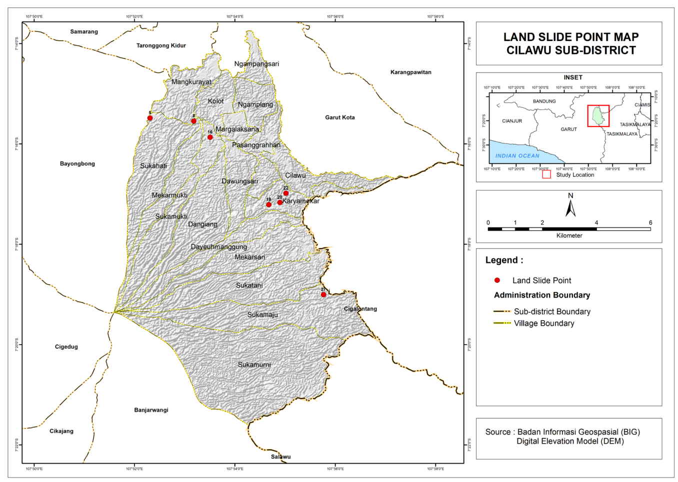

Figure 2. Location of 2021 Landslide Point

3. RESULTS AND DISCUSSION

3.1 Analysis of Factors Influencing Landslides in Cilawu Sub-district

3.1.1 Rainfall

Annual rainfall data per station from Garut Public Work Agency showed that the average rainfall in Cilawu Sub-district was dominated by high-intensity rainfall of 2500-3000 mm covering an area of 7791.63 Ha or almost all of its territory. Meanwhile, rainfall of more than 3000 mm/year covering an area of 197.59 ha was only in Sukamurni Village. Rainfall is one of the parameters with the highest weight in the 2004 Center for Soil and Agroclimate Research method. Rainfall provides significant impacts on landslides as rainwater can saturate the soil so that the soil loses its binding capacity (Batumalai et al., 2023). Rainfall parameters covering the size, intensity, and distribution determine the probability of landslides and the predicted location of the landslides. The distribution of the average annual rainfall for 10 years (2006-2016) in the Cilawu Sub-district can be seen in Figure 3.

3.1.2 Type of Rock

Geologically, Cilawu Sub-district has volcanic rock structures due to its location between Mount Cikuray and Mount

Table 1. Classification of Scores and Weights

Variabel	Parameter	Weight	Score
	Very wet (>3000)		5
	Wet (2501-3000)		4
Rainfall (mm)	Medium (2001-2500)	30%	3
	Dry (1501-2000)		2
	Very dry (<1500)		1
	Volcanic rock		3
Type of Rock	Sedimentary rock	20%	2
	Fluvial rock		1
	>45		5
	30-45		4
Slope	15-30	20%	3
	8-15		2
	<8		1
	Field, rice field		5
	Shrub		4
Land Cover	Forest and plantation	20%	3
	City/settlement		2
	Pond, reservoir, water bodies		1
	Regosol		5
	Andosol, Podsolik		4
Type of Soil	Brown Latosol	10%	3
	Yellowish-brown Latosol Association		2
	Alluvial		1

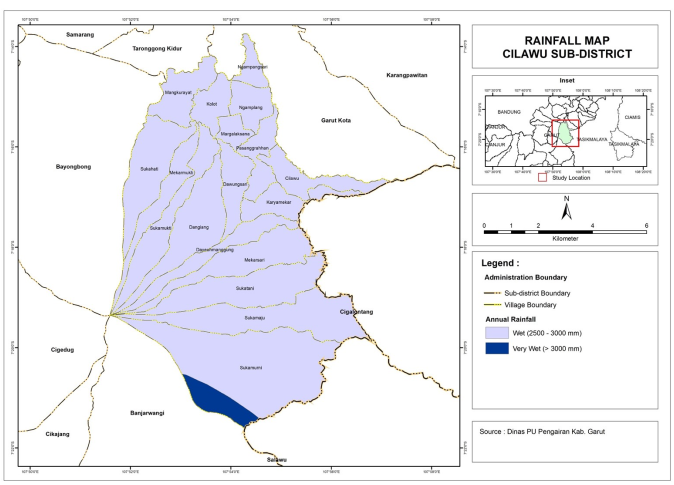

Figure 3. Annual Rainfall Map of Cilawu Sub-district

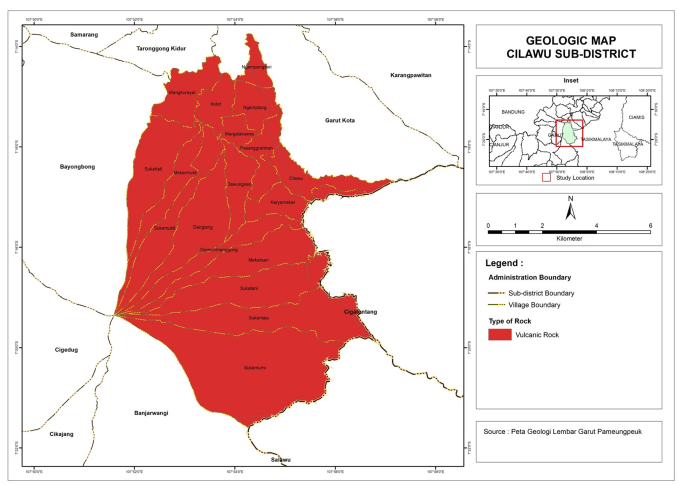

Figure 4. Geological Map in Cilawu Sub-district

Satria. Some types of volcanic rocks can be found in Cilawu Sub-district for example, Qyc (Young Volcanic Rock of Mount Cikuray) covering an area of 7375.8 Ha, Qkp (Kracak-Puncakgede Volcanic Rock) covering an area of 588.73 Ha, and Qtv (Old Volcanic Unbreakable Rock) covering an area of 27.57 Ha. The more detailed information on the type of rocks in this sub-district can be seen in Figure 4.

3.1.3 Type of Soil

Cilawu Sub-district has some types of soil such as Andosol, Brown Latosol, and Alluvial soil. Based on the Center for Soil and Agroclimate Research classification by the erosion sensitivity, the type of soil in the study location can be classified into Sensitive to Erosion/Slow Permeability (Podsolic, and Andosol), Slightly Sensitive to Erosion/Quick Permeability (Latosol), and Insensitive to Erosion/Very Fast

Permeability (Alluvial and clay). Andosol soil type dominates the Cilawu area with a total area of 7969.95 Ha. Brown Latosol soil can be found in Sukamurni Village with an area of 4.31 Ha. The detail distribution of the type of soil can be seen in the following Figure 5.

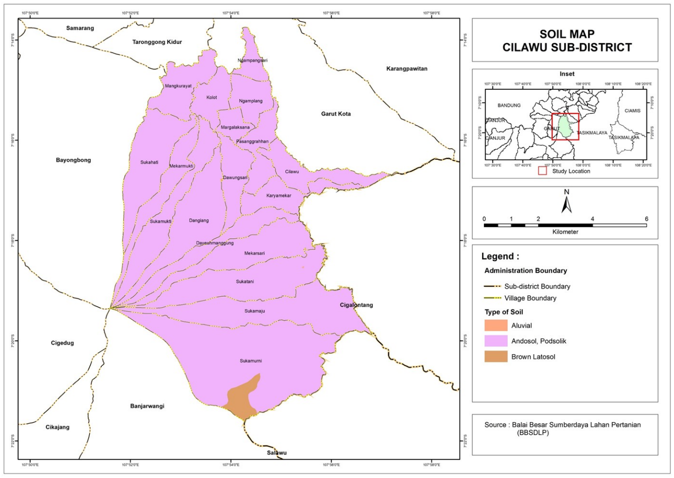

Figure 5. Type of Soil Map in Cilawu Sub-district

3.1.4 Slope

The results of DEM (Digital Elevation Model) data processing showed that the research location had varied slopes from flat (<8%) to steep (>45%). The most dominating slopes in Cilawu Sub-district were 15-30% in which each class has an area of 1053.04 Ha for <8% slopes, 1313.84 Ha for 8-15% slopes, 2937.82 Ha for 15-30% slopes, 1496.52 Ha for 30-45% slopes, and 1168.61 Ha for >45% slopes. Sukamurni village has the widest area of >45% slope, namely 320.6 hectares. The distribution of the slopes can be seen in the following map (Figure 6).

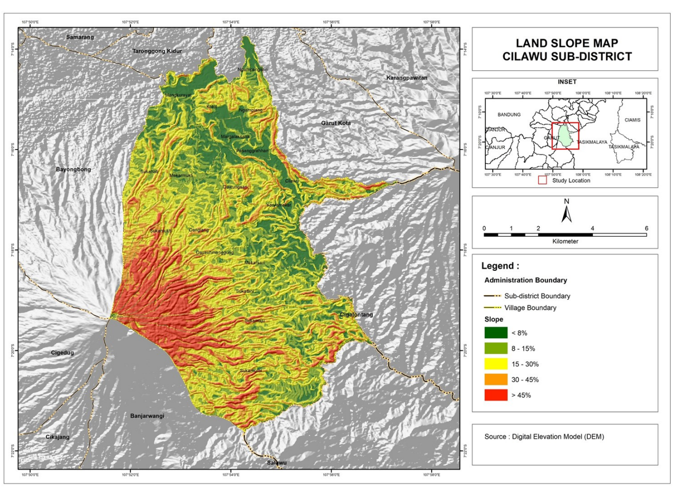

Figure 6. Slope Map of Cilawu Sub-district

3.1.5 Land Cover

Land cover in Cilawu Sub-district consisted of dry fields, rice fields, shrubs, forests, plantations, settlements, and rivers/bodies of water. The most dominant land cover was forest and plantations covering an area of 3912.44 hectares, followed by rice fields and fields with an area of 2777.64 hectares, and rivers and city/settlement with an area of 993.28 hectares. Land cover is associated with human economic activities and each type provides certain characteristics. The land cover distribution in Cilawu Sub-district can be seen in Figure 7.

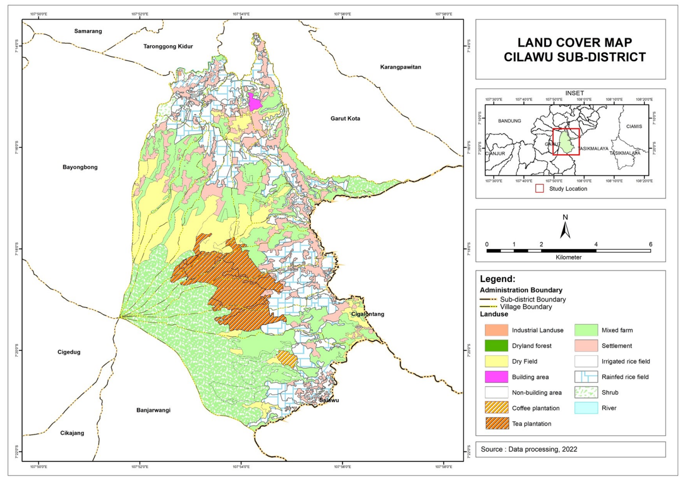

Figure 7. Land Cover Map of Cilawu Sub-district

3.1.6 Analysis of Landslide Susceptibility

Analysis of landslide susceptibility used an estimation method based on the Center for Soil and Agroclimate Research (2004) classification research. The parameters were rainfall, rock type, land slope, land cover, and soil type weighted 30%, 20%, 20%, 20%, and 10% of each. The results of the analysis of the five parameters obtained four landslide susceptibility levels covering low, medium, high, and very high. Based on the determination of the score using this method, the study obtained the highest score of 4.4 and the lowest score of 2.3. These two values were then used to determine the interval and the result was 0.525. The classification of susceptibility levels based on the score intervals can be seen in Table 2.

Table 2. Score Intervals of Landslide Susceptibility Levels in Cilawu Sub-district

Score Intervals	Susceptibility Levels
2.3 – 2.83	Low
2.84 – 3.35	Medium
3.36 – 3.88	High
3.89 – 4.4	Very high

3.1.7 Distribution of Landslide Susceptibility Levels

Based on the total score of the landslide susceptibility levels obtained through the overlay intersect process using the ArcGIS Version 10.7.1 application, Cilawu Sub-district has 4 landslide susceptibility levels (Figure 8-9):

a. Low Susceptibility Level

Low susceptibility level has a small possibility for landslides. This level has rainfall of 2500-3000 mm, slopes <8-15%, and dominant land use of water bodies, settlements, and industrial buildings. This level covers a total area of 366.16 Ha. Three villages have the widest low susceptibility level, namely Mangkurayat (51.92 Ha), Mekarsari (42.69 Ha), and Cilawu (38.65 Ha).

b. Medium Susceptibility Level

Medium susceptibility level has a medium possibility of landslides. This level has rainfall of 2500-3000 mm, slopes of 0-30%, and dominant land use of water bodies, settlements, industrial buildings, and agriculture. This susceptibility level has a total area of 1627.78 Ha. Three villages have the widest medium susceptibility area, namely, Sukamurni (151.43 Ha), Sukahati (127.05 Ha), and Mekarsari (122.04 Ha).

c. High Susceptibility Level

High susceptibility level has a high probability of landslides. This level has rainfall of 2500->3000 mm, slopes of 0-45%, and dominant land use of forests, plantations, fields and agriculture. This high susceptibility level covers a total area of 5470.07 Ha. Three villages have the widest high susceptibility level, namely Sukamurni (1395.36 Ha), Sukamaju (638.95 Ha), and Sukatani (565.17 Ha).

d. Very High Susceptibility Level

Very high susceptibility level has a very high probability of landslides. This level has rainfall of 2500->3000 mm, slopes of 0->45%, and dominant land of forests, plantations, fields and agriculture. This level covers a total area of 515.96 Ha. Three villages have the widest very high susceptibility level, namely Sukamurni (110.37 Ha), Sukahati (75.76 Ha), and Sukamukti (73.75 Ha).

The use of GIS in mapping landslide susceptibility areas could determine the low, medium, high, and very high susceptibility areas. The area was obtained from the results of calculating the geometry of each susceptibility level. The results of the calculations are presented in Table 3.

Table 3. Size of Areas based on the Lanslide Susceptibility Levels in Cilawu Sub-district

Susceptibility Levels	Size (Ha)
Low	366.16
Medium	1627.78
High	5470.07
Very high	515.96

Based on the results of the maps and graphs above, all villages in Cilawu Sub-district are dominated by medium

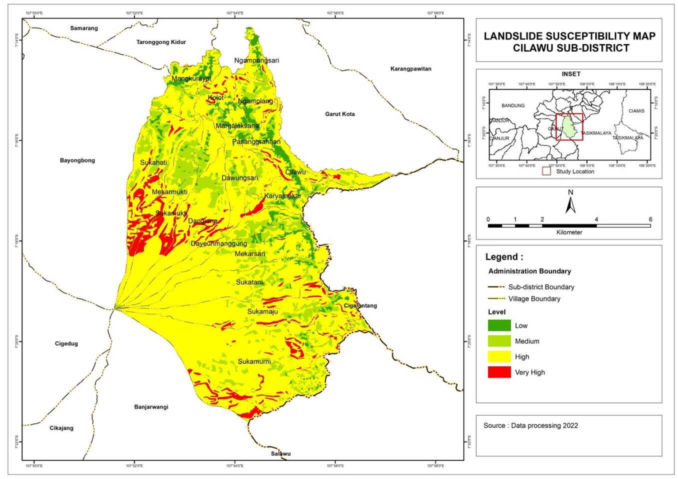

Figure 8. Landslide Susceptibility Map of Cilawu Sub-district

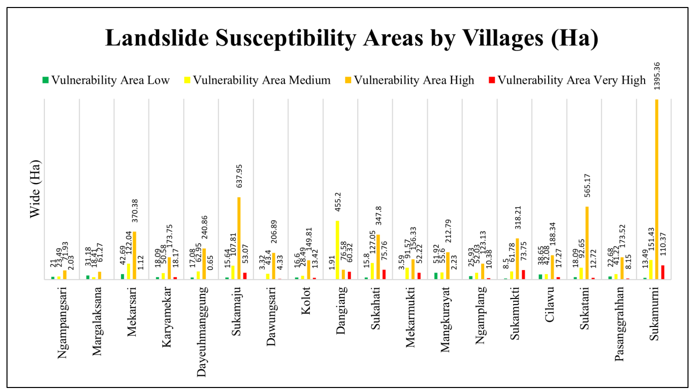

Figure 9. Comparison Graph of Landslide Susceptibility Areas by Villages (Ha)

and high levels of susceptibility. Based on the landslide definition by the Ministry of Energy and Mineral Resources (2015), landslides occur because rainfall which acts as a driving force tends to be high, while the soil as a retaining force is dominated by land cover in the form of forests, plantations, fields, and rice fields so that the density is lower. It was also mentioned in previous research that the potential for occurrence on slopes depends on rock and soil conditions, geological structure, rainfall, and land use (Purba, 2014). Areas with forest land cover tend to have lower susceptibility due to the availability of strong roots that can withstand soil movement (Hairiah et al., 2020). Meanwhile, areas with land cover in the form of fields, rice fields, and plantations tend to be vulnerable to soil movement due to the weak root system to hold the soil (Jebur et al., 2014). Even, the existence of irrigation canals can increase the chance of soil erosion. The dominance of Andosol soil types also affects the landslide susceptibility in this sub-district because this type of soil is sensitive to erosion. Rainwater that seeps into the ground as well as water from rice fields and irrigation canals results in a decrease in slope stability (Hidayat and Munir, 2019). Irrigation canal damage can be caused by several factors such as the presence of sediment, garbage, or the age of the canal (Dhana et al., 2019). Such damage can increase the chance of a landslide occurring.

Slope was chosen as one of the key factors for mapping landslide susceptibility because it is related to shear pressure inside the soil (Hong et al., 2019). With a dominant slope of 15-30%, this sub-district is vulnerable to soil movement because the land flow velocity is high and able to move soil material to a lower area due to gravity resulting in a more significant opportunity for soil movement to experience landslides (Sudaryatno et al., 2019). Based on the distribution of susceptibility levels on the landslide susceptibility map and the previous graph of the area of susceptibility per village, the widest very high and high susceptibility areas are in Sukamurni Village with an area of 110.37 Ha and 1395.36 Ha, respectively. This is influenced by the area and land cover which is dominated by fields/rice fields and plantations so the land becomes more vulnerable to erosion with the high rainfall. The medium susceptibility area is Dangiang Village and the widest low susceptibility area is Mangkurayat Village because the slopes are relatively flat. Previous research stated that landslides would increase along with the increase in the slope of an area (Effendi, 2016; Sun et al., 2023); that's why villages with field cover in areas near Mount Cikuray, such as Sukahati, Sukamukti, and Mekarsari tend to have areas with high susceptibility levels because the slope is high. The relationship between the landslide susceptibility levels and the landslide can be seen from the validation results of the landslide in Figure 10.

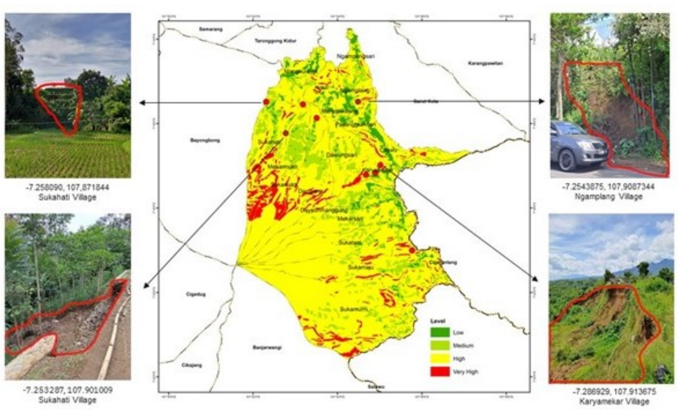

Figure 10. Validation of Landslide Points in Cilawu Sub-district

The validation process compares landslide susceptibility level and the history of landslide disasters on 2021 from the Regional Disaster Management Agency. Based on the results of the validation, four landslide points could still be seen until May 2022. The first landslide point is in Sukahati Village with a medium susceptibility level. The second landslide point is in Sukahati Village which is included in the high susceptibility level. The third landslide is in Ngamplang Village with a very high susceptibility level. The last, the biggest landslide is in Karyamekar Village with a high susceptibility level. Based on the validation results, landslides often occur in medium, high, and very high susceptibility level areas.

4. CONCLUSIONS

The use of Geographic Information Systems (GIS) in mapping the landslide susceptibility in Cilawu Sub-district generates four susceptibility levels: low, medium, high, and very high. Based on validation result, in Cilawu Sub-district landslides often occur in high and very high vulnerability level areas. The levels of landslide vulnerability are higher in area with high rainfall because it has a higher driver, high slope percentage that cause more significant opportunity for soil movement and dry field or rice field land cover that has weak root system to hold the soil. Based on this analysis, Cilawu Sub-district was dominated by the following classes: high vulnerability with an area of 5470.07 Ha, medium vulnerability with an area of 1627.78 Ha, very high vulnerability with an area of 515.96 Ha, and low vulnerability with an area of 366.16 Ha. High susceptibility dominates areas with high rainfall, slopes between 30->45%, and land cover of field/rice filed. The location has steep-very steep on the slopes of Mount Cikuray and in areas covered by field/rice fields.

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