Landslide Potential Analysis using Geographic Information System and Analytical Hierarchy Process (AHP) (Case Study: Taktakan District, Serang City)

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ABSTRACT

This research aims to analyze the landslide potential in Taktakan Sub-district, Serang City, which is prone to landslides due to geographical and hydrometeorological factors. The analysis was conducted using Geographic Information System (GIS) method with QGIS software and Weighted Linear Combination (WLC) approach combined with Analytical Hierarchy Process (AHP). Factors causing landslides, such as slope, rainfall, geology, and land use, were analyzed based on the weights obtained from respondents' questionnaires. The results showed that rainfall has the greatest influence (42%), followed by slope (37%), geology (11%), and land use (10%). The highest landslide potential is found in Taktakan sub-district, with the dominant vulnerability level in the medium class (50.73%), while the high and very high risk areas are 20.65% and 3.66%, respectively. This study concludes that high rainfall and steep slopes are the main factors that increase the risk of landslides in the area.

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1. INTRODUCTION

Indonesia is one of the countries vulnerable to hydrometeorological disasters, especially landslides that often occur in areas with steep topography and high rainfall (Susanti et al., 2017). Taktakan Sub-district, Serang City, is one of the areas that has a high potential for landslides due to its geological conditions and land use which is dominated by dry land (Majid, 2021). With these characteristics, this area needs special attention in analyzing potential disasters and effective mitigation strategies.

Landslides can be caused by several factors, such as high rainfall, steep slopes, unstable soil types, and land use changes due to human activities (Yasien et al., 2021). Several studies show that the incidence of landslides in Indonesia is increasing in line with global climate change and uncontrolled land use change (Pungkasari, 2020). Therefore, a technology-based approach is needed to identify landslide-prone areas and determine appropriate mitigation measures.

In recent years, the use of Geographic Information Systems (GIS) has become an effective tool in mapping landslide potential (Bernhardsen, 2002). GIS enables more accurate spatial analysis by considering various factors that trigger landslides, such as rainfall, slope, soil type, and land use (Pasektiono, 2016). In addition, the Analytical Hierarchy Process (AHP) method is used to weight these factors to produce a more representative landslide risk map (Ramadhan et al., 2017).

Previous studies have shown that a combination of GIS and AHP can be used to determine disaster risk zones more effectively than conventional approaches (Prasindya et al., 2020). AHP enables multi-criteria-based decision making by systematically comparing the weights of factors that contribute to landslides (Purnam, 2009). The application of this method has been conducted in several landslide-prone areas in Indonesia and showed quite accurate results in predicting the potential for landslides (Sobirin et al., 2017). Considering the geographical condition of Taktakan Sub-district and the increasing incidence of landslides in the area, this study aims to model landslide potential using GIS and AHP methods. This study will integrate various geospatial parameters to produce a landslide prone zone map that can be used as a basis in spatial planning and disaster mitigation strategies (Rafabi, 2024).

This research is expected to contribute to the development of a more effective landslide mitigation strategy, both for the government and the local community. The results of this research can serve as a reference for policy makers in developing preventive measures to reduce the risk of landslides in Taktakan Sub-district and other areas with similar characteristics. With a data-based approach and spatial analysis, this research can provide more accurate and applicable information in future disaster mitigation efforts (Alif et al., 2020). In addition, this research also supports the implementation of more sustainable policies in environmental management and land use in disaster-prone areas (Amin et al., 2023). Thus, the results of this research are expected to be a reference for various parties in developing a GIS and AHP-based landslide monitoring and early warning system to improve community preparedness in the face of disasters (Wicaksono et al., 2020).

2. METHODS

This research is quantitative descriptive research. Quantitative descriptive research method is a study that aims to provide or describe a situation or phenomenon that occurs today using scientific procedures to answer problems actually and in the form of quantitative studies, namely classification, assessment, setting standards, and the relationship between the position of one element and another.

2.1 Identification of Problems

One of the most significant landslide problems occurred on November 17, 2022 on the Serang to Anyer alternative road, precisely in the Taktakan-Gunung Sari area. Heavy rain that fell throughout the night caused at least 15 landslides, with the most severe impact in Cilowong. As a result of this incident, the alternative road, which is the main route connecting the regions, cannot be used. In addition, landslides also have the potential to cause huge economic losses, such as damage to public facilities, disruption of the transportation sector, and loss of productive land that affects the agricultural sector and residential areas.

2.2 Literature Studies

Literature study in this research was conducted to obtain in-depth understanding of factors causing landslides as well as appropriate analysis methods. References used included scientific journals, books, previous disaster risk assessment documents, as well as archived maps of Serang City and government regulations related to disaster mitigation. The study helped in determining the main parameters that contribute to landslides, such as rainfall, slope, geology and land use. In addition, the analysis methods such as Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC) used in this study are also based on theories and previous studies. By conducting a literature study, this research can ensure that the methods applied are in accordance with scientific standards and provide valid results for landslide vulnerability mapping.

2.3 Data Gathering

Data collection in this research was conducted through two main sources, namely primary data and secondary data. Primary data was obtained through interviews with competent resource persons, such as employees of the Regional Disaster Management Agency (BPBD) of Serang City and employees of Cilowong Village, to determine the weight of parameters causing landslides using the Analytical Hierarchy Process (AHP) method. Meanwhile, secondary data was collected from various government agencies, including Bappeda, ESDM, and BMKG, which provided information in the form of digital maps, such as geological maps, slope maps, rainfall maps, and land cover maps. These data were then used in the analysis process using Geographic Information System (GIS) to produce an accurate and data-driven landslide vulnerability map.

2.4 Data Analysis

Data collection in this research was conducted through two main sources, namely primary data and secondary data. Primary data was obtained through interviews with competent resource persons, such as employees of the Regional Disaster Management Agency (BPBD) of Serang City and employees of Cilowong Village, to determine the weight of parameters causing landslides using the Analytical Hierarchy Process (AHP) method. Meanwhile, secondary data was collected from various government agencies, including Bappeda, ESDM, and BMKG, which provided information in the form of digital maps, such as geological maps, slope maps, rainfall maps, and land cover maps. These data were then used in the analysis process using Geographic Information System (GIS) to produce an accurate and data-driven landslide vulnerability map.

Table 1. Classification of Each Parameter

Parameters	Class	Vulnerability Level	Scors
Rainfall (mm/yr)	3500 – 4000	Very High	4
	3000 – 3500	Tall	3
	2500 – 3000	Low	2
	2000 – 2500	Very Low	1
Slope (%)	> 45	Very High	5
	25 – 45	Tall	4
	15 – 25	Medium	3
	8 – 15	Low	2
	< 8	Very Low	1
Geology	Volcanic rock hills	Very High	4
	Sedimentary rock hills	Tall	3
	Calcareous hills	Low	2
	Alluvial plains	Very Low	1
Land Use	Rice fields/settlements/Tegalan	Very High	4
	Shrubs/bushes	Tall	3
	Plantation	Low	2
	Forest	Very Low	1

In Process Hierarchy Analysis (AHP), the calculation of the Consistency Index (CI) and Consistency Ratio (CR) is an important step to ensure that the assessments provided by decision-makers are consistent and reliable. AHP involves paired comparisons between criteria or alternatives, which relies on individual subjective assessments. Due to its subjective nature, there is a possibility of inconsistencies in assessment.

$$\lambda\ maks = \frac{\sum Consistency\ Vector}{n} \quad (1)$$

$$CI = (\lambda maks - n) / (n - 1) \quad (2)$$

Information:
CI = Consistency Index.
λ maks = Average value of the entire criterion
n = Number of criteria parameters

From the formula above, to determine the Consistency Vector (VK) by dividing the results of the Weighted Sum Vector (VJT) by the eigenvalue of the pairwise comparison matrix, then to determine the Weighted Sum Vector (VJT) by multiplying the pairwise comparison matrix by the eigenvalue of the pairwise comparison matrix. The Consistency Index (CI) measures the level of inconsistency in the pairwise comparison matrix. The higher the CI value, the more inconsistent the judgment. However, CI alone is not enough to determine whether the inconsistency is acceptable. Therefore, the Consistency Ratio (CR) was introduced. CR is the ratio between the CI and the Randomized Consistency Index (RI), which is the average CI value of random matrices with the same scale.

$$CR = CI / RI \quad (3)$$

Information:
CR = *Consistency Ratio*
CI = *Consistency Index*
RI = *Random Index*

The RI value is the random index value issued by Oarkridge Laboratory. The random index value can be obtained from the table below.

Table 2 Index Random Value

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

If the CR is less than or equal to 0.1 (10%), the assessment is considered consistent and acceptable. If the CR exceeds 0.1, the judgment needs to be revised to improve consistency. Thus, the calculation of CI and CR helps to ensure that the AHP results are reliable and reflect the preferences of decision makers in a logical and consistent manner. After that, the four parameters were overlaid to obtain the landslide potential. From the overlay results, the total score is then calculated using the equation. Decision making using WLC is shown in the following equation (Hong at al., 2007).

$$K = \sum_{i=1}^{n} (Wi \times Xi) \quad (4)$$

Information:
K = Vulnerability Value
Wi = Weight for the i-th parameter
Xi = Value of the class of the ith parameter

The determination of the level of vulnerability is carried out by dividing the vulnerability values equally by the number of class intervals so that the equation is as follows: (Purnama, 2009)

$$i = \frac{T}{n} \tag{5}$$

Information:

i = Class Interval

T = Difference between Maximum Value and Minimum Value

n = Number of Vulnerability Classes

3. RESULTS AND DISCUSSION

This research is located in Serang City, which is the result of the expansion of Serang Regency based on Law Number 32 of 2007, has an area of approximately 26,674 hectares with a low to moderate topography, with an altitude below 500 meters above sea level. The city has a tropical climate with an average temperature of 27.07°C, an air humidity of around 84%, and annual rainfall ranging from 1,500-2,000 mm, with peak rainfall in January and December. The geography is dominated by lowlands and some hilly areas, such as in Kecamatan Taktakan, which has slopes varying from flat to very steep. Soils in the region consist of volcanic, sedimentary, and alluvium rocks, with land use including rice fields, plantations, forests, and settlements. Factors such as slope, high rainfall, and rock type make some areas, especially in Taktakan sub-district, more prone to landslides.

3.1 Landslide Vulnerability Parameter Factors

1. Slope Parameters

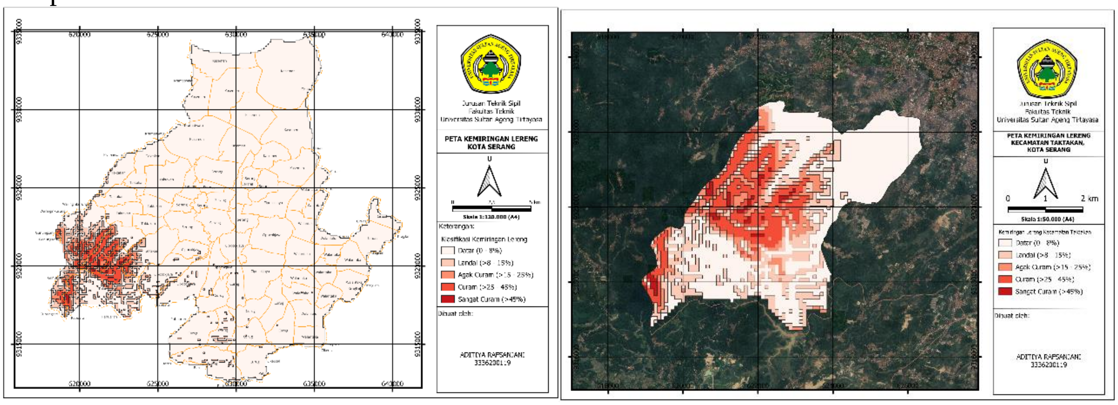

Figure 1. Map of the Slope of Serang City and Taktakan District

Figure 1 shows that the slope in Serang City varies with the majority of areas having slopes below 8% (91.54%), which are classified as flat, while areas with slopes >45% (very steep) are only 0.19%. Taktakan sub-district has a greater variation in slope, with some areas having a very steep slope of 1.81%, making it more prone to landslides. Steeper slopes increase the risk of landslides by accelerating surface water flow and reducing soil stability.

2. Rainfall Parameters

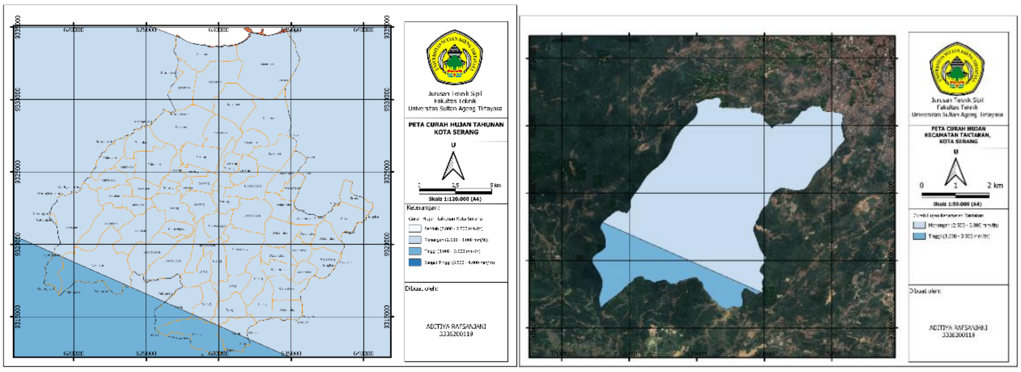

Figure 2. Rainfall Map of Serang City and Taktakan District

Figure 2 shows that rainfall in Serang City is generally at the medium level (2,500-3,000 mm/year) covering 93.07% of the area, while areas with high rainfall (3,000-3,500 mm/year) are around 6.93%, especially in the southern part such as Taktakan Sub-district. High rainfall can trigger landslides by increasing the water content in the soil, which causes a decrease in cohesion and soil stability, especially in areas with steep slopes.

3. Geological Parameters

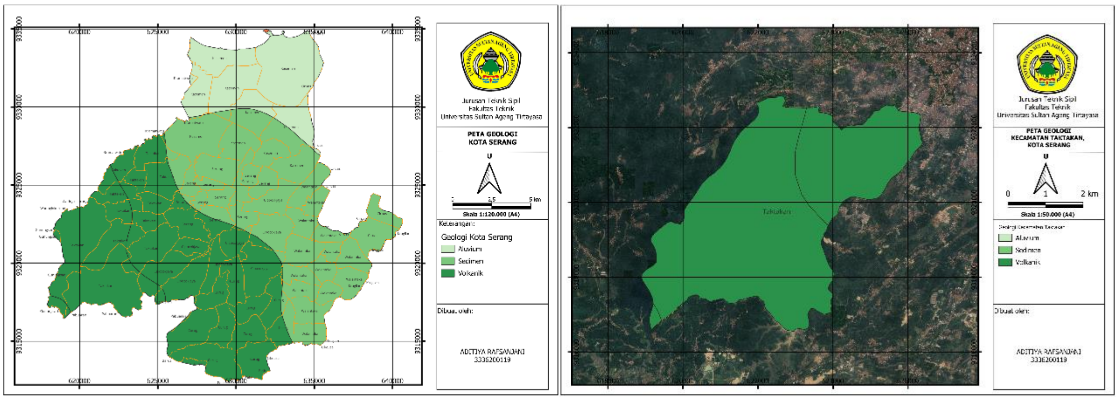

Figure 3. Geological Map of Serang City and Taktakan District

Figure 3 shows that the geological structure of Serang City consists of volcanic rocks (47.58%), sedimentary rocks (37.71%), and alluvium (14.71%). Volcanic and sedimentary rocks are more prone to landslides because they are less sturdy and easily weathered, especially when exposed to prolonged rain. Taktakan sub-district has a dominance of volcanic and sedimentary rocks, making it more at risk of landslides than areas with more stable alluvium rocks.

4. Land Use Parameters

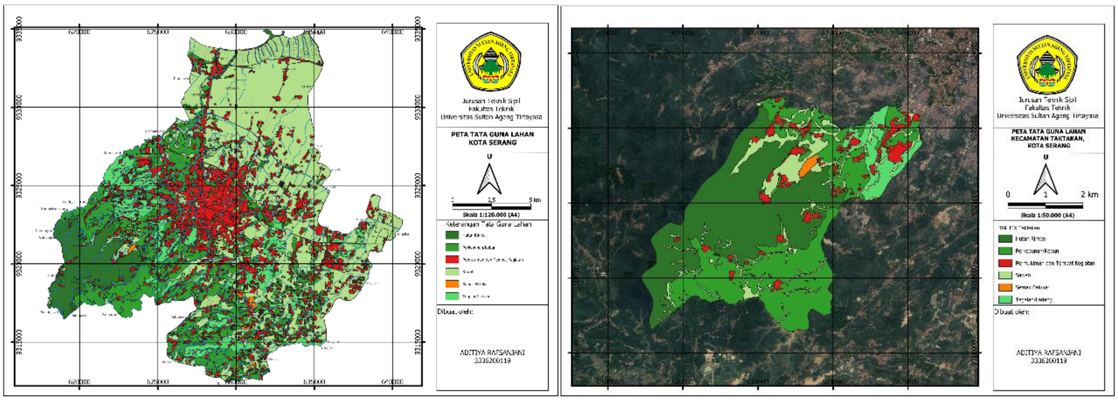

Figure 4. Land Use Map of Serang City and Taktakan District

Figure 4 shows that land use in Serang City is dominated by rice fields (39.79%), plantations (24.92%), and settlements (18.64%). Taktakan sub-district has dominant forest land (41.10%), followed by plantations (35.92%) and rice fields (10.67%). More vegetation-covered land such as forests can help reduce the risk of landslides, while areas with agricultural and residential activities have the potential to increase erosion and soil instability, especially if deforestation or inappropriate land management occurs.

3.2 Results of Analysis of the *Analytical Hierarchy Process* (AHP) Method

1. Normalized Calculation of Weight of Each Parameter and Eigenvector Matrix

Table 3. Result of Scoring Data Value

Parameters	Rainfall	Slope	Geology	Land Use
Rainfall	1,00	1,00	3,87	5,00
Slope	1,00	1,00	2,83	4,00
Geology	0,26	0,35	1,00	0,87
Land Use	0,20	0,25	1,15	1,00
Sum	2,46	2,60	8,86	10,87

Table 3 shows the scoring data for each parameter obtained from the interviews and has been converted into a pairwise matrix. This comparison matrix is filled with numerical values that represent the relative importance of an element to other elements. This means that the number may be lower or higher than other factors. To get the priority weight (w) of each parameter, the normalized principal eigenvector must be calculated. The value of each parameter will be divided by the sum of all parameter values, then the value of each parameter row will be averaged into the Eigenvector value.

$$\begin{bmatrix} {}^{1}/_{2,46} & {}^{1}/_{2,60} & {}^{3,87}/_{8,86} & {}^{5}/_{10,87} \\ {}^{1}/_{2,46} & {}^{1}/_{2,60} & {}^{2,83}/_{8,86} & {}^{4}/_{10,87} \\ {}^{0,26}/_{2,46} & {}^{0,35}/_{2,60} & {}^{1}/_{8,86} & {}^{0,87}/_{10,87} \\ {}^{0,20}/_{2,46} & {}^{0,25}/_{2,60} & {}^{1,15}/_{8,86} & {}^{1}/_{10,87} \end{bmatrix} = \begin{pmatrix} 0,41 & 0,38 & 0,44 & 0,46 \\ 0,41 & 0,38 & 0,32 & 0,37 \\ 0,11 & 0,14 & 0,11 & 0,08 \\ 0,08 & 0,10 & 0,13 & 0,09 \end{pmatrix}$$

Eigenvector Row 1 or Rainfall $= \frac{\sum \text{Row element}}{\text{Number of columns}} = \frac{0{,}41+0{,}38+0{,}44+0{,}46}{4} = 0{,}42$

Eigenvector Row 2 or Slope $= \frac{\sum \text{Row element}}{\text{Number of columns}} = \frac{0{,}41+0{,}38+0{,}32+0{,}37}{4} = 0{,}37$

Eigenvector Row 3 or Geology $= \frac{\sum \text{Row element}}{\text{Number of columns}} = \frac{0{,}11+0{,}14+0{,}11+0{,}08}{4} = 0{,}11$

Eigenvector Row 4 or Land Use $= \frac{\sum \text{Row element}}{\text{Number of columns}} = \frac{0{,}08+0{,}10+0{,}13+0{,}09}{4} = 0{,}10$

2. Calculating Weighted Sum Vectors and Consistency Vectors

To determine the Weighted Number Vector (VJT) by multiplying the initial paired comparison matrix by the eigenvalue of the paired comparison matrix and then adding it to each column. The following is the calculation:

$$\begin{bmatrix} 1\times0{,}42 & 1\times0{,}37 & 3{,}87\times0{,}11 & 5\times0{,}10 \\ 1\times0{,}42 & 1\times0{,}37 & 2{,}83\times0{,}11 & 4\times0{,}10 \\ 0{,}26\times0{,}42 & 0{,}35\times0{,}37 & 1\times0{,}11 & 0{,}87\times0{,}10 \\ 0{,}20\times0{,}42 & 0{,}25\times0{,}37 & 1{,}15\times0{,}11 & 1\times0{,}10 \end{bmatrix} = \begin{bmatrix} 0{,}42 & 0{,}37 & 0{,}42 & 0{,}50 \\ 0{,}42 & 0{,}37 & 0{,}31 & 0{,}40 \\ 0{,}11 & 0{,}13 & 0{,}11 & 0{,}09 \\ 0{,}08 & 0{,}09 & 0{,}13 & 0{,}10 \end{bmatrix}$$

VTJ $= 0{,}42 + 0{,}37 + 0{,}42 + 0{,}50 = 1{,}71$

Then calculate the Consistency Vector (VK) by dividing the result of the Weighted Sum Vector (VJT) by the eigenvalue of the paired comparison matrix. Here's one of the calculations for rainfall rows:

VK $= \frac{\sum \text{VJT}}{\text{Eigenvector}} = \frac{0{,}42+0{,}37+0{,}42+0{,}50}{0{,}42} = 4{,}05$

The following are the results of the calculation of the Weighted Number Vector (VJT) and the Consistency Vector (VK), as follows:

Table 4. Results of Weighted Sum Vector (VJT) and Consistency Vector (VK) Calculations

Parameters	Rainfall	Slope	Geology	Land Use	VTJ	VK
Rainfall	0,42	0,37	0,42	0,50	1,71	4,05
Slope	0,42	0,37	0,31	0,40	1,50	4,05
Geology	0,11	0,13	0,11	0,09	0,43	4,01
Land Use	0,08	0,09	0,13	0,10	0,40	4,02

3. Calculate the Consistency Index (CI) and Consistency Ratio (CR)

Based on the Consistency Vector value that has been obtained in **Table 4**, the average value of the Consistency Vector or can be referred to as λmax is needed to obtain the Consistency Index (CI) value along with the Consistency Ratio (CR).

λmax $= \frac{\sum \text{VK}}{\text{n}} = \frac{4{,}05+4{,}05+4{,}01+4{,}02}{4} = 4{,}03$

CI $= \frac{\lambda\text{max} - \text{n}}{\text{n-1}} = \frac{4{,}03-4}{4-1} = 0{,}01$

CR $= \frac{CI}{RI} = \frac{0,01}{0,9} = 0,013 < 0,1 \rightarrow$ OK

Because the CR value <0.100 means that the respondent's preference is consistent, meaning that the weight value given between the criteria is equal. So that the results of the calculation of the weight value of the main criteria can be used and seen in the table below:

Table 5. Amount Value of AHP Calculation Results

Parameters	Amount
Rainfall	42%
Slope	37%
Geology	11%
Land Use	10%
Sum	100%

Table 5 shows the results of the Analytical Hierarchy Process (AHP) weighting processing values obtained from the sources, resulting in that the rainfall aspect has a greater influence on landslide potential with a weight of 42% than other aspects. As for the smallest parameter, it shows that land use parameter has less influence than other parameters with 10% weight,

3.3 Landslide Vulnerability Analysis

Based on the results of the analysis, an overlay was then performed on QGIS by considering the factors that cause landslides. From the overlay results, the total score was calculated using the equation and the results of the highest and lowest scores on QGIS are presented in **Figure 5**.

Vulnerability Level = (0.42 × Rainfall Score) + (0.37 × Slope Score) + (0.11 × Geological Score) + (0.10 × Land Use Score)

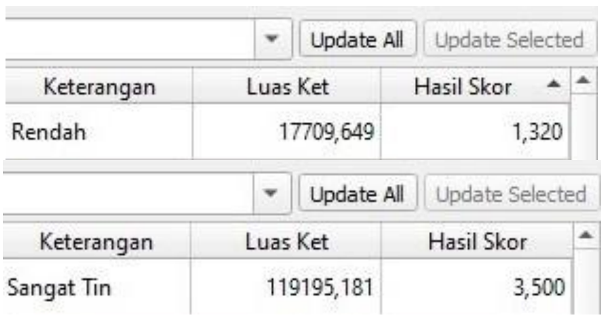

Figure 5. Results of the Highest Score and the Lowest Score at the Landslide Vulnerability Level

Figure 5 shows the results of the values obtained, namely the highest value at the landslide vulnerability level is 3.50 and the lowest value at the landslide vulnerability level is 1.32. So from those two values, the interval value of the classification class can be calculated as follows:

Class Interval Value $= \frac{Tn-T1}{n} = \frac{3,50-1,32}{4} = 0,545$

The following are the results of the maximum and minimum score limits for landslide vulnerability levels in each class, which are as follows:

Table 6. Landslide Vulnerability Level Limit for Each Class

No.	Vulnerability Level Classes	Vulnerability Level Assessment
1.	Low	1,320 – 1,865
2.	Medium	1,865 – 2,410
3.	High	2,410 – 2,955
4.	Very High	2,955 – 3,50

Table 6 shows that based on the classification value of vulnerability class obtained, it can be converted into landslide vulnerability map, then the area of each landslide vulnerability can be calculated automatically in QGIS software. The distribution and area of each landslide vulnerability in Taktakan Sub-district, Serang City is presented below:

Table 7. The extent of landslide vulnerability in Taktakan District, Serang City

District	Potential Level	Area (Ha)	Area (%)
Taktakan	Low	595,07	24,96
	Medium	1209,47	50,73
	High	492,21	20,65
	Very High	87,28	3,66
Sum		2384,03	100,00

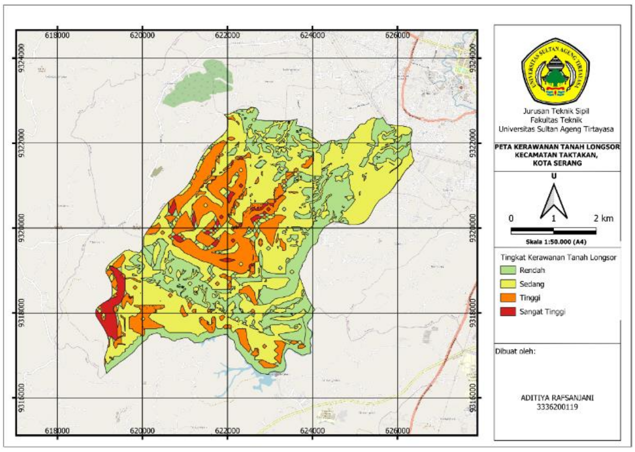

Figure 6. Landslide Vulnerability Map in Taktakan District, Serang City

Table 6 and **Figure 6** show that landslide vulnerability in Taktakan Sub-district, Serang City is dominated by moderate level with an area of 1209.47 Ha or 50.73 percent. However, Taktakan Sub-district has a high potential for landslide vulnerability which is quite large at 492.21 Ha or 20.65 percent. In addition, due to the conditions in Taktakan Sub-district there are very high slopes in several locations, then high class rainfall of 3,000-3,500 mm/year, and volcanic geology. Thus, there are several locations in Taktakan Sub-district that have a very high potential level of 87.28 Ha or 3.66%. With this condition data, mitigation efforts are needed between the community and BPBD Serang City to prevent landslides.

4. CONCLUSION

Based on the results of data analysis and discussion of research results, it can be concluded that:

a. The potential for landslides in the research area is influenced by several factors, namely slope, rainfall, geology, and land use. Steep slopes, high rainfall, unstable geological conditions, and certain types of land use such as plantations or open land can increase the risk of landslides.
b. Based on the results of the analysis, the weight of each parameter obtained is rainfall has a weight of 42% and has the largest weight because high rainfall directly affects the level of soil saturation and increases the risk of landslides. Slope slope has a weight of 37% and is the second most influential factor, especially because steep slopes increase the rate of soil movement. Geology has a weight of 11% because the type of rock and geological conditions, especially volcanic rocks and sediments, contribute to slope stability and susceptibility to landslides. Land Use has a weight of 10% because land use, such as open land or plantations, is influential but the weight is lower than rainfall and slope factors.
c. The highest landslide potential in Serang City is recorded in Taktakan Sub-district because there are areas with very steep slopes, high rainfall intensity (3,000 - 3,500 mm per year), and vulnerable volcanic geology. Taktakan sub-district has a dominant landslide vulnerability level in the medium class (50.73% of the total area). The area with high risk is 20.65%, and very high potential is 3.66% (87.28 Ha), especially in areas with very steep slopes, high rainfall, and volcanic soil types.

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