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Landslide and Evacuation Zone in Cugenang Area Cianjur Regency, West Java Province

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ABSTRACT

Ground motion is the process of moving masses of soil or rock in the upright, horizontal and oblique directions from the original or original state, the Cianjur region has experienced many earthquakes at some time so it is necessary to study the fault zone in this area and see the geological aspects of this area. This research is located in Cugenang and surrounding areas, Cianjur Regency, West Java Province. This research aims to be able to determine the ground motion vulnerability zone according to the parameters that affect the research area, and to determine the place of evacuation zone based on the results of the ground motion vulnerability zone map in the research area. The method used is overlapping based on the classification of the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG) with five parameters, namely: rainfall, land use, slope, soil type, and geology. From the results of making ground motion vulnerability zones, three types of ground motion vulnerability zones were obtained in the research area, namely: very high ground motion zone ± 72.72%, high ground motion zone ± 24.74%, and moderate ground motion zone ± 4.54%. The study area has an evacuation zone located in the east and southwest of the study area. This research can be a reference to be used as a mitigation measure for Landslide disasters in the research area.

Keywords: Cianjur, Landslide, Directorate of Volcanology and Geological Hazard Mitigation (DVMBG), Geographic Information System (GIS).

I. INTRODUCTION

Geographically, Indonesia is located at the junction of three major tectonic plates: the Eurasian, Indo-Australian, and Pacific plates, as well as the smaller Philippine microplate. The interaction between these plates creates subduction zones in several regions, such as western Sumatra, southern Java to Nusa

Tenggara, northern Maluku, and northern Papua, making Indonesia prone to earthquakes and volcanic activity caused by the release of energy in the Earth's crust due to plate movements or magma activity. For example, the Cianjur earthquake on November 21, 2022, claimed 268 lives. In addition to earthquakes, ground movements such as landslides also pose geological threats resulting from endogenous and exogenous processes. Therefore, geological studies, the application of Geographic Information Systems (GIS), and methods from the Directorate of Volcanology and Geological Hazard Mitigation are needed to analyze and reduce geological disaster risks in Indonesia..

II. METHODS AND MATERIAL

The methods employed include weighting and classification based on the classification system of the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG), modified according to the study area. Geographic Information System (GIS) was utilized for data processing, serving as a tool for analysis, processing, and creating overlays from the obtained parameters. The data were redigitized and integrated to produce a classification and level of landslide susceptibility. The parameters used refer to DVMBG, consisting of rainfall, geology, soil type, land use, and slope gradient.

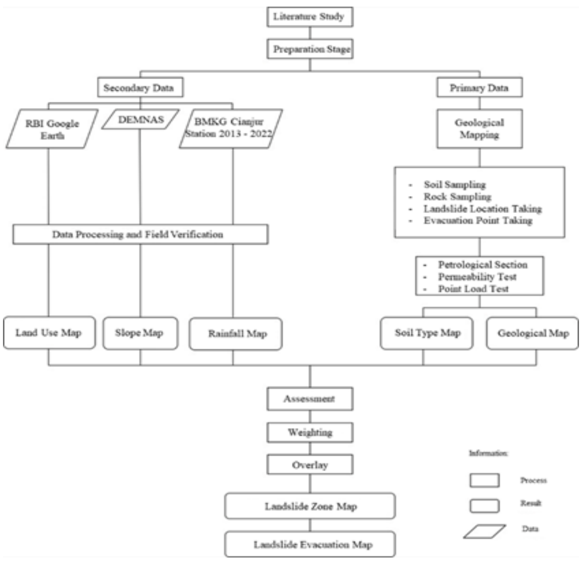

FIGURE 1: RESEARCH DIAGRAM

The DVMBG classification based weighting and grading method employes parameters with assigned weight values.

TABLE I: LANDSLIDE CLASS WEIGHT (DVMBG TAUFIK ET AL, 2016)

No	Parameters	Weight Value
1	Rainfall	30%
2	Geology	20%
3	Soil Type	20%
4	Land Cover	15%
5	Slope	15%

The score was calculated using the following formula:

$$\text{Score} = (30\% \times A) + (20\% \times B) + (20\% \times C) + (15\% \times D) + (15\% \times E)$$

Description:

A: Rainfall

B: Geology

C: Soil Type

D: Land Cover

E: Slope

III.RESULTS AND DISCUSSION

The research was conducted using the classification from the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG), with adjustments to the study area by replacing the soil type parameter with soil permeability ranking and the geological parameter with rock strength testing. The landslide susceptibility zoning map was developed by processing data using a Geographic Information System (GIS) based on ArcGIS software. The analysis stages began with the creation of a rainfall map, slope gradient map, land-use map, soil type map, and geological map, which were then overlaid to produce a landslide susceptibility zoning map and a landslide evacuation zone map.

A. Rainfall parameters

The rainfall parameter weight 30% was obtained from BMKG Meteorology Station of Cianjur for the period of 2013–2022 (12 months per year). The results indicate a rainfall range of 2,444–4,500 mm/year, which can be categorized as a very high rainfall level, as outlined in the table

TABLE II: CIANJUR METEOROLOGI STATION RAINFALL DATA RESULTS 2013-2022 (BMKG)

Tahun	Bulan												Total Tahunan (mm)
	Januari	Februari	Maret	April	Mei	Juni	Juli	Agustus	September	Oktober	November	Desember	
2013	851	338	405	344	494	123	275	131	70.1	198.6	259	501.6	3990.3
2014	1134	623.8	266.7	403.8	219.9	199.1	344.1	249.8	33.6	94.2	548.3	445.7	4563
2015	284.2	345.4	335.7	196.3	148	14.8	0	0	18.8	50.1	457.7	409	2260
2016	272.5	581.7	553.2	461.2	231.2	201.7	252.6	82.6	365.9	386.7	309.6	142.5	3841.4
2017	261	688.5	283.7	400.8	225.9	130.8	89.1	49.3	33.7	367.4	420.8	320.7	3271.7
2018	333.1	671.5	432	290.8	108	156.4	9	20.5	161.7	130.4	382.1	195.7	2891.2
2019	408.3	427.9	210.8	463	167.4	61.9	35.4	18.8	5.8	180.2	143.8	320.9	2444.2
2020	421.3	537.1	511.8	328.2	383.6	88.3	63.1	38	68.4	276.6	165.7	319.9	3202
2021	384	687.1	187.4	358.2	115.3	257.6	66.3	165.7	187.6	311	343.8	446	3510
2022	110.2	304	239.3	455.6	218.3	348.3	143.4	246.6	242.7	489.3	283.2	428.7	3509.6
Total Bulanan (mm)	4459.6	5205	3425.6	3701.9	2311.6	1581.9	1278	1002.3	1188.3	2484.5	3314	3530.7	**Rata - Rata per Tahun** 3348.34

The rainfall data from 2013 to 2022 shows an average of 3,348.34 mm/year, which, based on the DVMBG classification, falls into the very wet category with the highest value of 5.

TABLE III: RAINFALL CLASS PARAMETERS (DVMBG TAUFIK ET AL, 2016)

No	Parameters (mm/year)	Value
1	<1500	1
2	1501 – 2000	2
3	2001 – 2500	3
4	2501 - 3000	4
5	>3000	5

TABLE IV: RAINFALL PARAMETER DATA RESULTS AT RESEARCH LOCATIONS

No	Parameter (mm/year)	Value
1	3348.43	5

Based on the classification from Directorate of Volcanology and Geological Hazard Mitigation (DVMBG), the entire study area has an annual rainfall of 3,348.34 mm/year (BMKG data from the last 10 years). Thus, it can be concluded that the area has a very high rainfall vulnerability level with a weight of 5 and rainfall vulnerability of >3,000 mm/year.

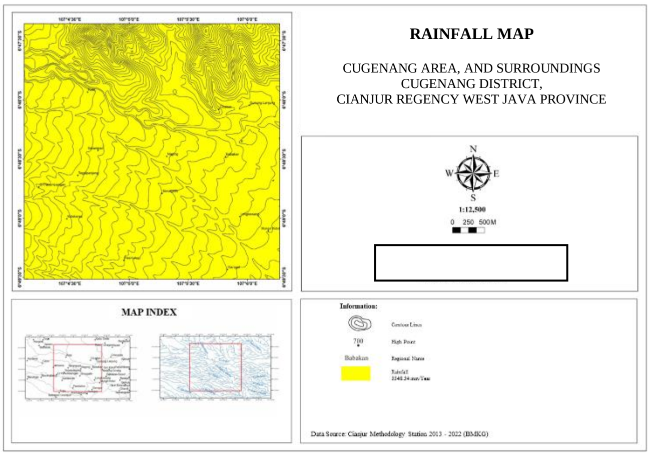

FIGURE 2: RAINFALL MAP IN RESEARCH AREA

B. Land use parameters

Land use parameters have a weight of 15%, derived from the Indonesian topographic map and Google Earth, as well as manual digitization with field verification in the study area. The identified land use types include settlements, rice fields, shrubs, plantations, and forests. The land use value is directly proportional to the potential for ground movement, meaning that the lower the land use value, the lower the susceptibility to landslides, and vice versa.

TABLE V: LAND USE CLASS PARAMETERS (DVMBG ET AL, 2016)

No	Parameters	Value
1	Dense forest/vegetation and water bodies	1
2	Gardens and mixed shrubs	2
3	Plantations and irrigated rice fields	3
4	Industrial and residential areas	4

TABLE VI: LAND USE PARAMETERS OF THE RESEARCH AREA (DVMBG TAUFIK ET AL, 2016)

No	Parameters	Value
1	Built-up area	4
2	Rice field	3
3	Garden	2
4	Scrubland	2
5	Forest	1

FIGURE 3: SATELITE IMAGE OF RESEARCH AREA SOURCE: GOOGLE EARTH (2023)

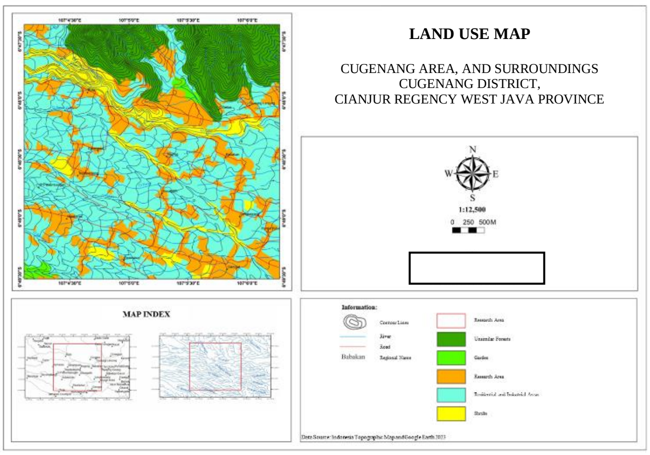

FIGURE 4: LAND USE MAP IN THE RESEARCH ARE

FIGURE 5: DISSIMILAR FOREST LAND USE (LEFT) AND SHRUBLAND (RIGHT) AT THE RESEARCH LOCATION

FIGURE 6: LAND USE OF GARDENS (LEFT), RESIDENTIAL (CENTER), AND RICE FIELDS (RIGHT) IN THE RESEARCH AREA.

C. Slope parameters

Slope Parameter with a weight of 15%, Processed from Indonesia's Topographic Map (RBI) Data. Based on the classification by the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG), five slope parameter categories were derived: flat, gentle, moderately steep, steep, and very steep (Table). The analysis results indicate that the higher the slope gradient value (%), the steeper the terrain, thereby increasing the potential for landslides. Conversely, lower slope values indicate gentler terrain, resulting in a reduced likelihood of landslides.

TABLE VII: SLOPE CLASS PARAMETERS (DVMBG TAUFIK ET AL, 2016)

No	Slope Class	Slope Gradient	Score
1	Flat	<8 %	1
2	Gentle slope	8 – 15 %	2
3	Moderately steep	15 – 25 %	3
4	Steep	25 – 45 %	4
5	Very steep	>45 %	5

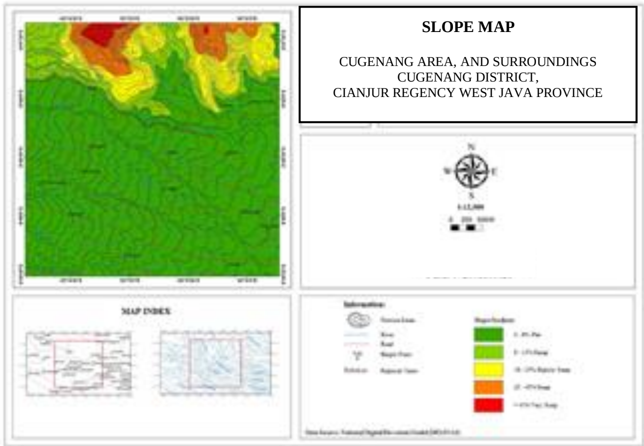

FIGURE 7: SLOPE GRADIENT MAP IN THE RESEARCH AREA.

D. Soil type parameters

The soil type parameter, weighted at 20%, was determined through permeability testing using the constant head permeability method. The permeability test was conducted to assess the degree of water saturation in the soil. A higher permeability rate indicates greater water saturation, which consequently worsens the soil's ability to prevent landslides. Conversely, a lower permeability rate corresponds to reduced water saturation, improving the soil's effectiveness in preventing landslides.

Out of 29 sample points, 21 were classified as having very rapid permeability, while 8 were classified as rapid. The study area's soil types were divided into two categories: rapid, with values ranging from 12.7 to 25.4 cm/hour, and very rapid, with values exceeding 25.4 cm/hour. These data were visualized in a soil type map, with classifications based on DVMBG (Taufik et al., 2016) and the Department of Soil Science, FP-USU (2003).

TABLE VIII: SOIL TYPE CLASS PARAMETERS (DVMBG TAUFIK ET AL, 2016)

No	Parameters	Value
1	Not sensitive	1
2	Smewhat sensitive	2
3	Less sensitive	3
4	Sensitive	4
5	Very sensitive	5

TABLE IX: SOIL TYPE CLASS PARAMETERS (DEPARTMENT OF SOIL SCIENCE, FP-USU 2003)

No	Parameters
1	Very slow (<0,5 cm/hour)
2	Slow (0,5 – 6,3 cm/hour)
3	Medium (6,3 – 12,7 cm/hour)
4	Fast (12,7 – 25,4 cm/hour)
5	Very fast (>25,4 cm/hour)

TABLE X: SOIL TYPE PARAMETERS IN THE RESEARCH AREA

No	Parameters	Value
1	Sensitive	4
2	Very Sensitive	5

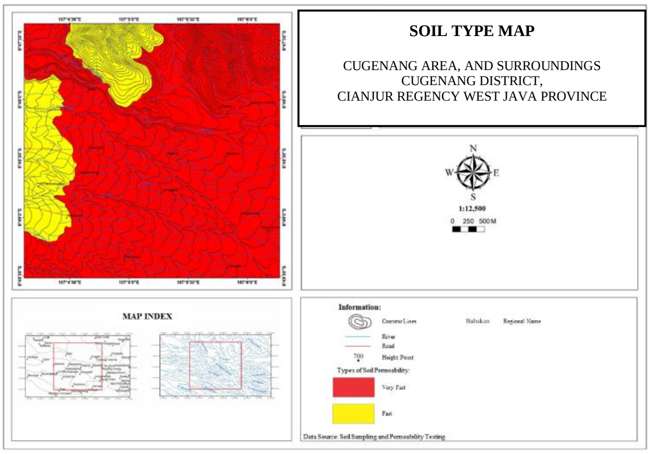

FIGURE 8: SOIL TYPE MAP IN RESEARCH AREA.

E. Geological parameters

Geological parameters have a weight of 20%. From these parameters, information is obtained regarding lithological compactness, lithology in the study area, and rock resistance level. Rocks with high hardness, good compactness, and massive structure (such as igneous rocks) will have a low landslide susceptibility level, in contrast to rocks with low hardness, which will have a high landslide susceptibility level.

The geological parameters refer to the Directorate of Volcanology and Geological Hazard Mitigation (DVMBG) classification, divided into two units: andesite unit and volcanic breccia unit. Subsequently, a point load test was conducted, resulting in a geological map.

TABLE XI: GEOLOGICAL CLASS PARAMETERS (DVMBG TAUFIK ET AL, 2016)

No	Parameters	Value
1	Alluvial material	1
2	Volcanix material 1	2
3	Sedimentary material 1	3
4	Sedimentary material 2 volcanic 2	4

TABLE XII: LITHOLOGY UNIT DATA IN THE RESEARCH AREA BASED ON (DVMBG TAUFIK ET AL, 2016)

No	Unit	Value
1	Andesite	2
2	Volcanic Breccia	4

TABLE XIII: RESULTS OF POINT LOAD TEST IN RESEARCH AREA

No	Unit	Parameters	Is (Point Load Strength Index)	Value
1	Andesite	Volcanic material 1	10,23 Kn/cm²	2
2	Volcanic Breccia	Sedimentary material 2 volcanic 2	3,1 Kn/cm²	4

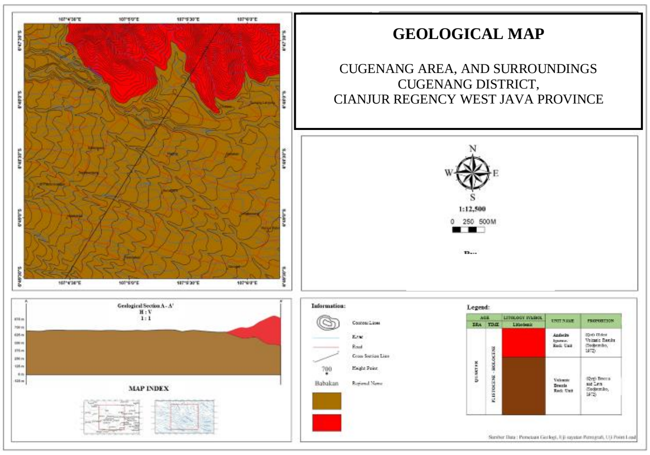

FIGURE 9: GEOLOGICAL MAP OF THE RESEARCH AREA.

Based on geological interpretation and mapping, a fault distance map was obtained. The study area was divided into five classes: very close (approximately 100 meters from the fault, marked in red), close (approximately 200 meters, marked in orange), moderate (approximately 300 meters, marked in yellow), far (approximately 400 meters, marked in dark green), and very far (500–4000 meters, marked in light green).

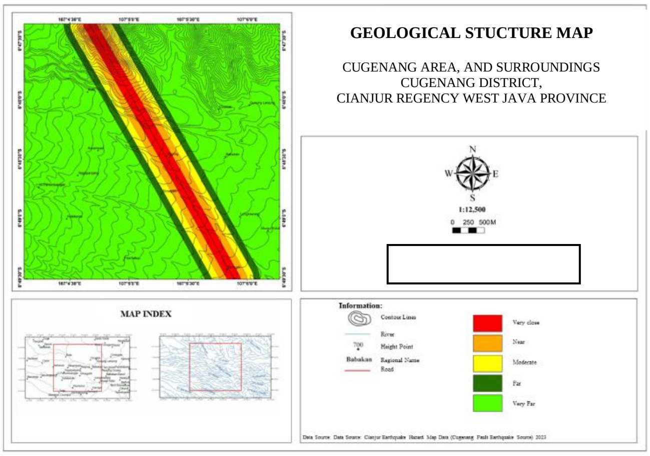

FIGURE 10: DISTANCE MAP OF FAULTS OR FRACTURES IN THE RESEARCH AREA

Data processing involves maps, values, and weights for each parameter, resulting in a landslide susceptibility map of the study area using ArcGIS software. The overlay process with the Union tool was applied to integrate all parameters while simultaneously calculating the existing attribute data, thereby determining landslide vulnerability zones. From the creation of a landslide movement zone map to obtain a score for the landslide susceptibility level, the following calculations were performed:

Highhest Value (Xt):

Xt = (5 X 30%) + (5 X 20%) + (4 X 20%) + (5 X 15%) + (4 X 15%) = 4.65

Lowest Value (Xr):

Xr = (1 X 30%) + (1 X 20%) + (1 X 20%) + (1 X 15%) + (1 X 15%) = 1

Average (Ki):

K = Number of classes

$$Ki = \frac{Xt - Xr}{K} = \frac{4,65 - 1}{5} = 0.73$$

The level of landslide susceptibility based on calculations is divided into five categories: very high susceptibility zone, high susceptibility zone, moderate susceptibility zone, low susceptibility zone, and very low susceptibility zone. By integrating the parameters used, the landslide zonation map generated using ArcGIS software is divided into three landslide zones: very high, high, and moderate.

TABLE XIV: PETROGRAPHIC ANALYSIS OF BATUJAJAR SUB-BASIN

No	Vulnersbility Level	Score	Color Description
1	Very low	1 – 1,73	
2	Low	1,74 – 2,47	
3	Medium	2,48 – 3,21	
4	High	3,22 – 3,95	
5	Very high	3,96 – 4,69	

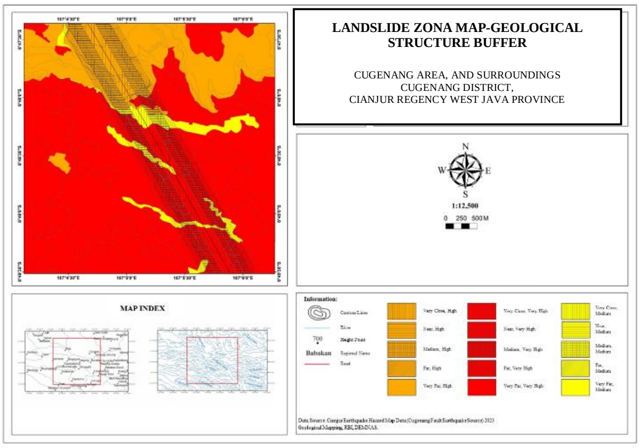

FIGURE 11: LANDSLIDE ZONE MAP IN THE RESEARCH AREA..

Data processing using parameters such as rainfall, slope gradient, land use, geology, and soil type produced a landslide potential zoning map divided into landslide susceptibility classes: a very high susceptibility zone covering 72.72%, a high susceptibility zone at 22.74%, and a moderate susceptibility zone at 4.54%.

The high-vulnerability zone covers approximately 72.72% of the study area, determined through five parameters: rainfall (30%), with the average annual rainfall from 2013 to 2022 reaching 3348.34 mm/year, placing it in Class 5 (based on DVMBG classification). Geologically (20%), the area is dominated by volcanic breccia (weight = 4) and andesite (weight = 2). The soil type (20%) has a permeability >25.4 cm/hour, assigned a weight of 5. Land use (15%) is divided into five categories following DVMBG classification: settlement (score = 5), rice fields (score = 3), plantations settlement (score = 5), rice fields (score = 3), plantations (score = 2), shrubs (score = 2), and forest (score = 1). The slope gradient (15%) in the study area includes very steep (>45%, Class 5), steep (25–45%, Class 4), moderately steep (15–25%, Class 3), gentle (Class 2), and flat (<8%, Class 1) areas. The research area, classified as having a very high landslide susceptibility level, contains several landslide points according to the Varnes (1978) classification. The landslides are of the translational slide type, which occur along a flat slip plane with soil material movement characterized by rotation.

FIGURE 12: LANDSLIDE POINT LOCATION IN VERY HIGH LANDSLIDE ZONE AREA.

The high landslide susceptibility zone in the study area covers approximately 22.74% of the region, assessed based on five key parameters. Rainfall (30%), with an average annual precipitation of 3,348.34 mm/year (2013–2022), falls into Class 5 according to DVMBG classification. Geologically (20%), the area is dominated by andesite (weight: 2) and volcanic breccia (weight: 4). Soil type (20%) exhibits high permeability, dominated by very rapid and rapid infiltration rates, corresponding to DVMBG permeability values of >25.4 cm/h (weight: 5) and 12.7–25.4 cm/h. Land use (15%) includes settlements (score: 5), rice fields (3), shrublands (2), and forests (1) per DVMBG classification. Slope gradient (15%) ranges from very steep (>45%, Class 5), steep (25–45%, Class 4), moderately steep (15–25%, Class 3), gentle (Class 2), to flat (<8%, Class 1). The high-susceptibility zone features several landslide points, predominantly translational slides (Varnes 1978).

FIGURE 13: LANDSLIDE POINT LOCATION IN VERY HIGH LANDSLIDE ZONES.

The area of moderate landslide susceptibility in the study region covers approximately ±4.54% of the total area, with five key parameters contributing to this classification. Rainfall (30%) plays a significant role, with an average annual precipitation of 3,348.34 mm/year from 2013 to 2022, placing it in class 5 according to DVMBG (Directorate of Volcanology and Geological Hazard Mitigation) classification. Geological conditions (20%) are dominated by andesite and volcanic breccia units, classified as volcanic sedimentary materials (Group 2) with a weight of 4. Soil type (20%) was categorized based on permeability, where fast permeability dominated the moderate landslide susceptibility zone, exhibiting values of 12.7–25.4 cm/hour and a weight of 5 (DVMBG classification). Land use (15%) was divided into four categories: settlements (score 5), rice fields (score 3), shrubs (score 2), and forests (score 1). The slope aspect (15%) was classified into five categories: very steep (>45%, class 5), steep (25–45%, class 4), moderately steep (15–25%, class 3), gentle (8–15%, class 2), and flat (<8%, class 1). These factors collectively contribute to the moderate landslide susceptibility observed in the area.

F. Relationship between landslide distribution and land use

Based on the land use parameters, residential areas show the highest distribution of landslides with 9 landslide points, followed by forests with 6 points, rice fields with 4 points, and shrubs with 2 points. This indicates that residential areas have very high vulnerability to landslides.

TABLE XV: RELATIONSHIP BETWEEN LANDSLIDE DISTRIBUTION AND LAND USE

No	Land Use	Ground Motion Point
1	Dissimilar forests	6
2	Gardens	0
3	Settlements	9
4	Rice Fields	4

5	Bushes	2

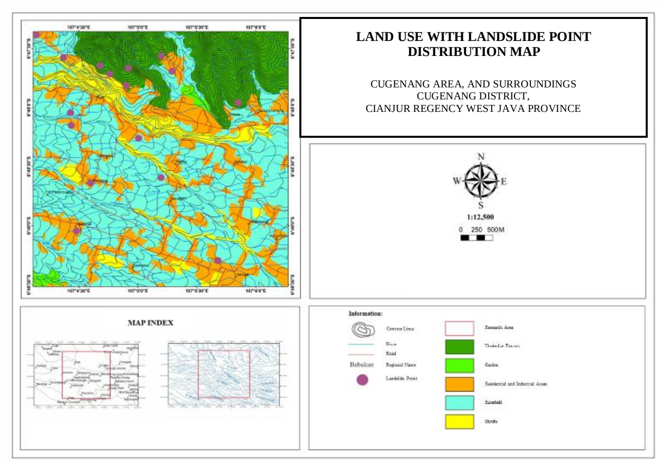

FIGURE 14: LAND USE WITH LANDSLIDE POINT DISTRIBUTION MAP.

G. Relationship between distribution of landslide and slope

Based on the slope gradient parameter, flat slopes have 7 landslide points, gentle slopes have 4 landslide points, moderately steep slopes have 4 landslide points, and steep slopes have 4 landslide points. Thus, areas with a slope gradient of <8%, classified as flat, have the highest distribution of landslide occurrences. Meanwhile, areas with a slope gradient of >45%, classified as very steep, have no distribution of landslide occurrences.

TABLE XVI: RELATIONSHIP BETWEEN DISTRIBUTION OD LANDSLIDE AND SLOPE

No	Slope	Ground motion point
1	< 8%Flat	7
2	8 – 15% Sloping	4
3	15 – 25% Rather steep	4
4	25 – 45%Steep	4
5	>45% Very Steep	0

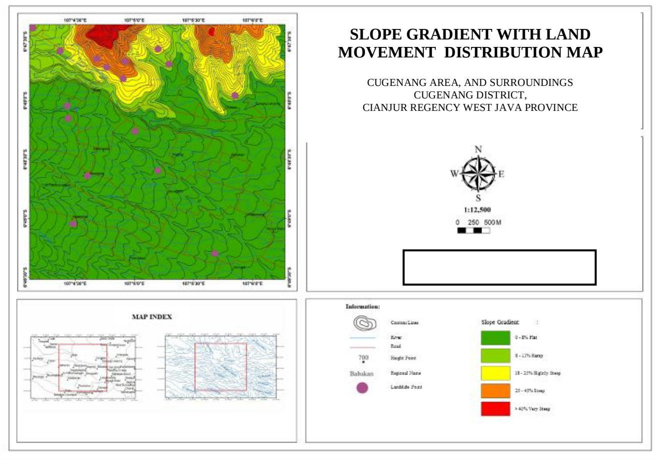

FIGURE 15: SLOPE GRADIENT WITH LANDSLIDE DISTRIBUTION MAP

H. Relationship between the distribution of ground movements and soil type

In the soil type parameter, the distribution of landslide occurrences consists of 7 landslide points in highly permeable soil and 9 landslide points in extremely permeable soil. The distribution of landslide points in highly sensitive soil types with extremely high permeability shows a greater number of landslide occurrences.

TABLE XVII: RELATIONSHIP BETWEEN THE DISTRIBUTION OF GROUND MOVEMENTS AND SOIL TYPE

No	Soil Type	Ground Movement Point
1	Very fast	9
2	Fast	7

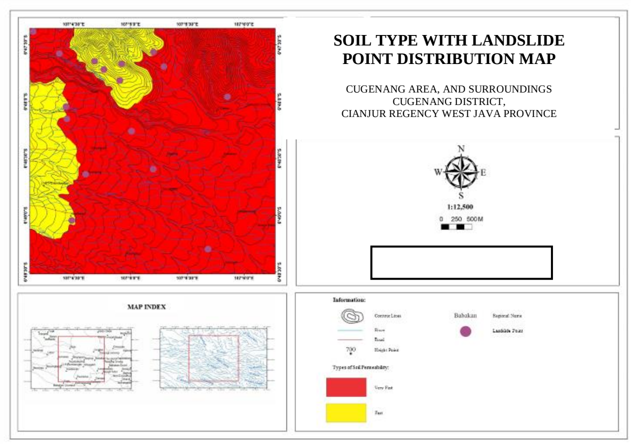

FIGURE 16: SOIL TYPE WITH LANDSLIDE POINT DISTRIBUTION MAP

I. Relationship between landslide distribution and geology

Based on geological parameters, andesite rock lithology has 7 landslide points, while volcanic breccia rock has 9 landslide points, making this lithology have a higher level of ground movement.

TABLE XVIII: RELATIONSHIP BETWEEN LANDSLIDE DISTRIBUTION AND GEOLOGY

No	Geology	Ground Movement Point
1	Volcanic breccia unit	9
2	Andesite lava flow unit	7

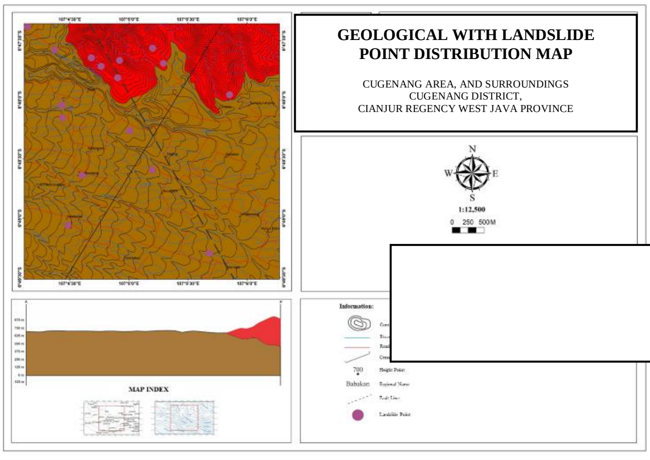

FIGURE 17: GEOLOGICAL WITH LANDSLI DISTRIBUTION MAP

J. Relationship between distance from fault or fracture to landslide zone

There are several landslide occurrence points in areas at varying distances from faults or fractures, as follows: areas very close to the fault have 1 landslide point, areas near the fault have 3 landslide points, areas at an intermediate distance from the fault have 3 landslide points, areas far from the fault have no landslide points, and areas very far from the fault have 9 landslide points.

TABLE XIX: RELATIONSHIP BETWEEB DISTANCE FROM FAULT OR FRACTURE TO LANDSLIDE ZONE

No	Distance from fault or fracture	Ground Movement Point
1	Very close	1
2	Near	3
3	Moderate	3
4	Far	0
5	Very Far	9

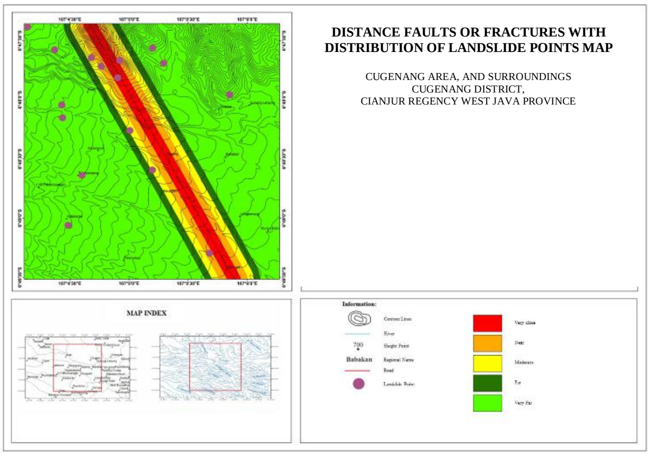

FIGURE 18: DISTANCE FAULTS OR FRACTURES WITH DISTRIBUTION OF LANDSLIDE POINTS MAP

Relationship between landslide distribution and landslide zones

In the landslide-prone zone, the occurrence of landslides is distributed across areas with varying susceptibility levels. Areas classified as having high landslide susceptibility contain 7 landslide points, while those with very high susceptibility have 9 landslide points. In contrast, regions with moderate landslide susceptibility zones show no distribution of landslide occurrences.

TABLE XX: RELATIONSHIP BETWEEN LANDSLIDE DISTRIBUTION AND LANDSLIDE

No	Landslide Zone	Ground Motion Point
1	Very high	9
2	High	7
3	Moderate	0

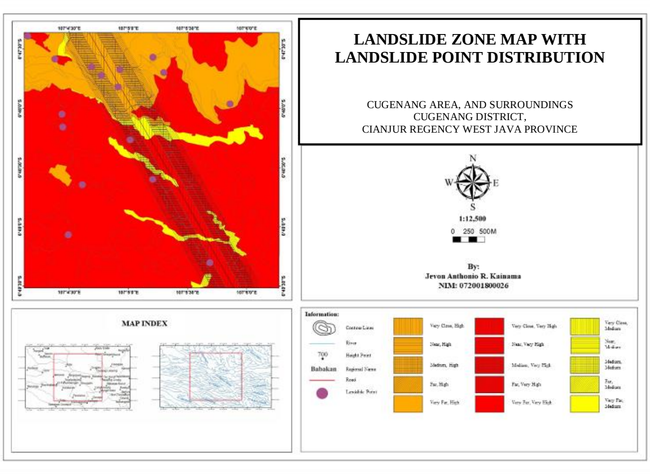

FIGURE 19: LANDSLIDE ZONE MAP WITH LANDSLIDE POINT DISTRIBUTION

L. Direction of landslide

The research area shows a distribution of landslide or mass movement points with movement directions to the east and south, generally occurring in highland areas sloping toward lowlands or lower relief. Thus, in this research area the direction of landslide or mass movement is nearly uniform, with movements predominantly oriented eastward from the study region.

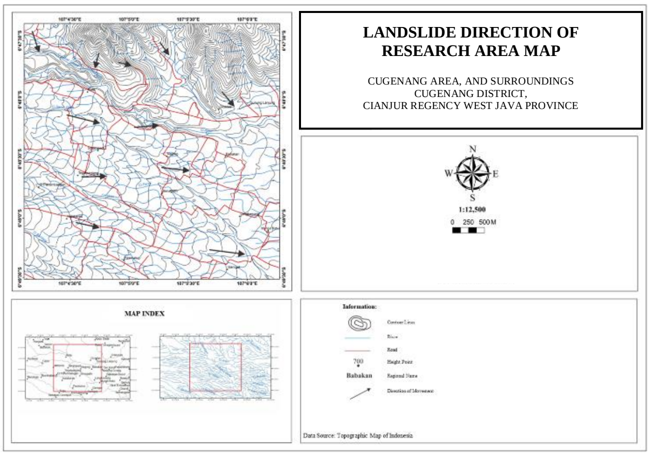

FIGURE 20: LANDSLIDE DIRECTION OF RESEARCH AREA MAP

This study identifies three vulnerability zones in the research area: a very high vulnerability zone, a high vulnerability zone, and a moderate vulnerability zone. There are two evacuation zones located in the eastern and southwestern parts of the study area that can be used as safe locations. The evacuation zones are already situated at a distance of more than 100 meters from major rivers. Additionally, these locations are at low elevations and are considered relatively safe, with access to footpaths and public roads, making them functional as evacuation zones. The evacuation zones are located in the Kolaberes, Babakan, and Cicadas areas, characterized by rice fields and settlements with access to clean water, which can serve as essential resources during evacuation.

The evacuation zones are divided into two: Evacuation zone 1 includes several assembly points, such as educational facilities and places of worship, while evacuation zone 2 has an assembly point in the form of a village hall.

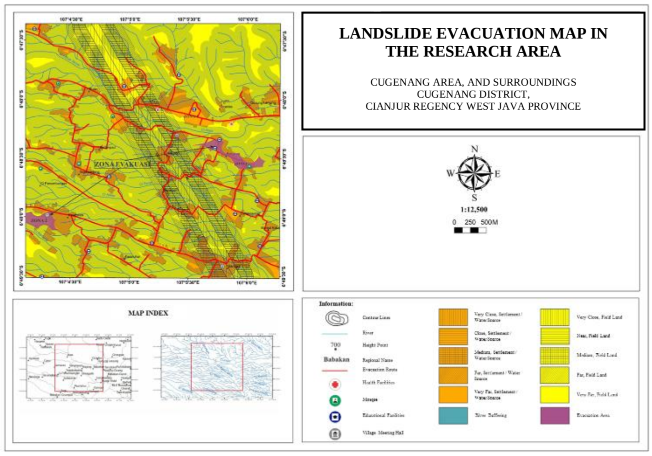

FIGURE 21: LANDSLIDE EVACUATION MAP IN THE RESEARCH AREA

IV. CONCLUSION

The study area has three levels of potential landslide occurrence, measured using several parameters: rainfall, land use, slope, soil type, and geology. The results indicate that the zone of very high landslide susceptibility covers approximately 72.72% of the study area, the high susceptibility zone covers about 24.74%, and the moderate susceptibility zone accounts for roughly 4.54%. The study area also has two evacuation zones, located in the east and southwest of the research site. These zones are classified as safe areas and can therefore serve as evacuation sites in the event of a disaster. Additionally, several gathering points are available, including health facilities, educational facilities, village halls, and mosques.

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