Landslide Analysis in Brau-Batu, East Java, Indonesia Based on Geoelectrical Resistivity Data

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Abstract

The Brau landslide area is about 40Ha. The Brau landslide area is administratively located in the hamlet of Brau, Gunungsari village, Bumiaji sub-district, Batu city, East Java. Hamlet of Brau is famous as a tourism area and because of dairy farm in Batu city. Topographically, this area is located in a hilly area with a range of topographical heights between 1067m to 1202m or has a topographical elevation difference of 135m. With such topography, it is not surprising that this area has a potential vulnerability to landslide geological disasters.

As a precaution against further landslides, residents are planned to relocate to other safer places. However, considering that the Brau area is a source of economic livelihood for local residents, residents want to stay there. To convince and ensure the vulnerability of this area, a study related to landslide variables is needed. One thing that can be done is to apply technology that can provide subsurface information on this disaster risk area. Therefore, in this study, geophysical research was carried out using the geoelectrical resistivity method to obtain information on the subsurface conditions of the landslide field in this area. The research was conducted to obtain information on the stability of the subsurface landslide field. From 60 VES data arranged in 12 cross sections, information is obtained that 6 cross sections or 50% cross sections are in stable condition. The location with the stable condition of the landslide field is then recommended as a location for the construction of a relocation site in the landslide area of Brau.

Keywords: Brau, geoelectrical resistivity, landslide, stability.

Introduction

On tuesday, February 2, 2021, at around 20:00 Western Indonesia time, a landslide occurred in RT 02 / RW 10, Brau hamlet, Gunungsari village, Bumiaji sub-district, Batu city which was occupied by about 16 families or around 54 people. In this landslide incident, 12 families or about 37 people occupied family tents in the refugee camps, while the others chose to flee to their relatives' houses. As it is known, that this Brau hamlet is one of the dairy farm-producing hamlets in the Batu city area, even this hamlet is known as the dairy farm tourism hamlet. Therefore, in addition to evacuating residents, cattle were also evacuated. In this landslide incident, 42 cows and 13 goats were evacuated to communal cages. Although there were no fatalities, the landslide at this location has caused the collapse of the talut and slab, the breaking of the PDAM pipe, the closure of the drainage channel, the collapse of the walls of residents' houses and the increasing number of cracks that appear perpendicular to the direction of the slope of the Brau hamlet area.[8,9]

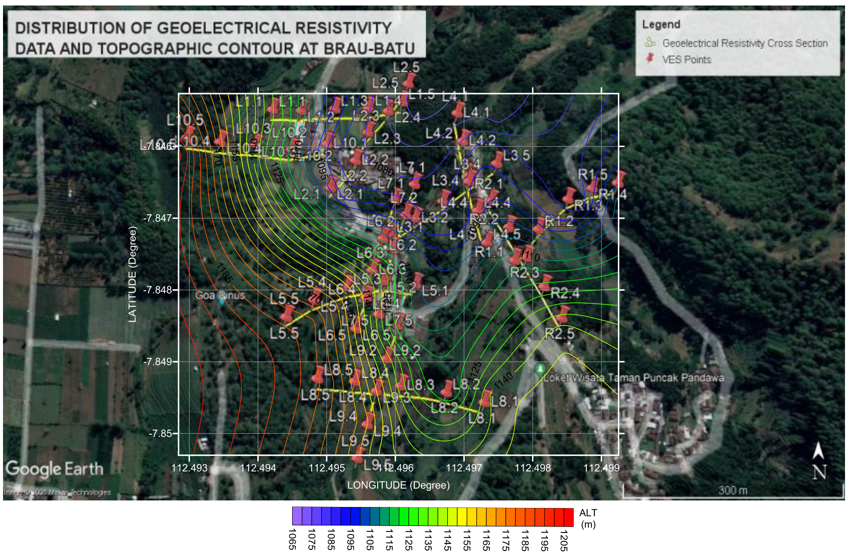


Figure 1: Distribution of geoelectrical resistivity data and topographic contour at Brau-Batu on Google earth map.

Figure 2: The landscape of Brau hamlet, Gunungsari village, Bumiaji sub-district, Batu city.

Figure 3: Cracks in the wall in the hamlet of Brau, Gunungsari village, Bumiaji sub-district, Batu city.

The landslide area of Brau hamlet has an area of about 40 hectares with a very varied topography of hills and valleys (figure 1). Based on figure 1, it shows that the hamlet of Brau has a distribution of topographical heights in the range of 1067m to 1202m with a difference in the topographical height of 135m.

Thus, Brau hamlet from the aspect of topographical expanse has the potential for landslides to occur, considering the condition of the slope is quite steep. Based on land use, the landscape of Brau hamlet and its surroundings is widely used for productive crops such as rice, vegetables, grass and various types of horticultural crops. There is not much vegetation with deep roots as can be seen in figure 2.

Until now, Brau hamlet is still in a dynamic condition because residents are still active in locations that still have the potential for further landslides. The situation in Brau hamlet that still needs to be watched out for is the increasing number of signs of ground movement in the form of cracks in the soil, fence walls and houses of residents, as well as the increasing frequency of landslide EWS sounds installed at several locations as can be seen in figure 3.

Based on the results of coordination and discussion with the Regional Disaster Management Agency (BPBD) of Batu City, the solution to this landslide problem is to relocate. However, various reasons are:

1. The local hamlet is fertile land with adequate water supply for agriculture,
2. The local hamlet is highly suitable for dairy farm and one of the milk producers in Batu city.
3. The local hamlet is well-known as an icon of dairy farms producing milk.

The local people still want to stay in the local location. The Regional Disaster Management Agency (BPBD) of Batu City requested assistance from the Brawijaya University to collect data and study the urgency of the relocation solution or not. One of the data as the basis for the study for this solution is to apply technology to determine landslide variables at local locations. One of the technologies that can be applied is to take measurements using non-destructive equipment, namely geoelectrical resistivity at a local location. With this geoelectrical resistivity technology, it will be possible to estimate the depth and slope of the slip plane at the local location. If the slope of the landslide as a result of the application of this non-destructive technology is stable, then the solution is land use management in the local hamlet. However, if the slope of the landslide field is unstable, then the best solution is total relocation or at least relocation of housing, but other activities such as livestock, agriculture, tourism etc. will be still allowed with infrastructure support based on geological disaster mitigation and security procedures.

The general objectives of this research are:
1. Obtaining landslide parameters based on geophysical methods as slope stability variables.
2. Conducting slope stability analysis at local locations.
3. Having zoning level of vulnerability based on the results of slope stability analysis.
4. Providing recommendations for technical handling as a disaster mitigation effort.

Material and Methods

Acquisition of data in the form of position data, slope and stability parameters is by using geophysics geoelectrical resistivity. Measurement of resistivity in general is by injecting current into the ground through 2 current electrodes (C1 and C2, figure 4) and measuring the potential difference response it causes at 2 potential electrodes (P1 and P2). From the current value data (I) and potential difference (V), the apparent resistivity value can be calculated (ρ_a) as equation 1: [4,14,20]

$$\rho_a = k\frac{V}{I} \quad (1)$$

where k is a geometric factor that depends on the arrangement of the 4 electrodes previously mentioned.[19]

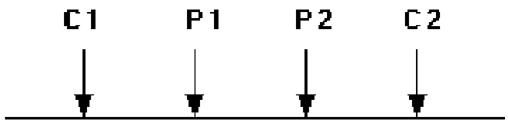


Figure 4: Simple arrangement of 4 electrodes for measuring subsurface resistivity

The calculated resistivity value is not the actual subsurface resistivity value, but it is a apparent value which is the resistivity of the earth which is considered homogeneous and gives the same resistance value for the same electrode arrangement. The relationship between apparent resistivity and resistivity is actually very complex[20], so to determine the actual value of the subsurface resistivity, it is necessary to calculate forward and inversion using computer assistance.

The arrangement of the electrodes in the Wenner-Schlumberger configuration is shown in figure 5. The space between the electrodes is “a”, the total stretch is AB and the measurement point is “c”. The apparent resistivity value of the Wenner-Schlumberger configuration can be seen in equation 2:

$$\rho_a = \frac{\pi(AB/2)^2}{a}\frac{\Delta V}{I}(\Omega m) \quad (2)$$

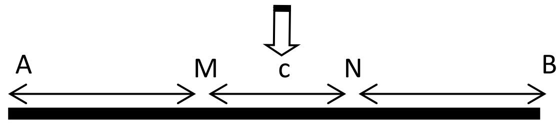


Figure 5: Wenner-schlumberger configuration arrangement (modified Schlumberger).

The configuration of the electrode arrangement of the Wenner-Schlumberger is a modified vertical electrical sounding (VES). The data obtained from data acquisition activities are in the form of data on electric current (I), potential difference (V), resistance (R) and the distance between the electrodes (a and MN). These data cannot be analyzed or interpreted before the calculation is carried out to get the resistivity value. Therefore, it is necessary to process data using res2dinv or curve matching (IPI2WIN, PROGRES) where the algorithm is based on the quasi-Newton method whose calculation is the approximate value of the partial derivative of apparent resistivity data or curve matching[12,13].

The calculated resistivity value is not the actual subsurface resistivity value, but it is a pseudo value which is the resistivity of the earth which is considered homogeneous and gives the same resistivity value for the same electrode arrangement at all depths within the measuring range of the equipment. In the next stage, analysis and zoning and technical implementation recommendations are carried out.

Data acquisition was carried out in the hamlet of Brau at a total of 60 geoelectrical resistivity measuring points that form 12 cross sections. The measuring points and the cross-sectional trajectory can be seen in figure 1.

Geophysical method is a way to determine the conditions and structures below the earth's surface through measurements above the surface. Thus, this method is safe, non-destructive, inexpensive and effective. Only by measuring above the earth's surface, all the parameters needed to determine the level of stability or vulnerability to landslides can be known. Furthermore, this is used as material for zoning the level of stability or vulnerability and compiling technical recommendations for its implementation.

The calculation of the stability of the slip plane to get the value of landslide stability is carried out using the USLE method (Universal Soil Loss Equation). This calculation provides a general estimate of the stability limit between the slip plane and the thickness of the layer that accumulates above it.[5-7,10,11,15,18,21] The results of the calculations are carried out for the stability limit $F \geq 1.2$ (assumption of stability values for normal loading) and also $F \geq 1.5$ (assumption of stability values for heavy loading). The calculation is based on equation 3 where: β is the angle of inclination of the slope in degrees, α is the angle of inclination of the slip plane in degrees and F is the value of the landslide stability factor.

$$F = \frac{c}{\gamma H Cos^2(\alpha).Tg(\alpha)} + \frac{\gamma'.Tg(\varphi)}{\gamma.Tg(\alpha)} \quad (3)$$

Calculations are made based on the following conditions[7]:

F assumption for infinite slope with seepage
calculation of maximum weight with condition:

cohesion (c) (kN/m^2)	18.75
Angle of friction (φ) (derajat)	13
Bulk unit weight (g)(kN/m^3)	19.6
Effective unit weight (g')(kN/m^3)	9.79
Stability factor (F)	1.2 and 1.5

Results and Discussion

The data obtained in data acquisition activities are in the form of data on electric current (I), potential difference (V), resistance (R) and the distance between the electrodes (a and MN). These data cannot be analyzed or interpreted before calculating the resistivity value. Therefore, it is necessary to process data using res2dinv or curve matching (IPI2WIN, PROGRES) where the algorithm is based on the quasi-Newton method whose calculation is the approximate value of the partial derivative of apparent resistivity data or curve matching[3,13].

The calculated resistivity value is not the actual subsurface resistivity value, but it is a pseudo value which is the resistivity of the earth which is considered homogeneous and gives the same resistance value for the same electrode arrangement. The relationship between apparent resistivity and resistivity is actually very complex[12] so to determine the actual value of the subsurface resistivity. An inversion calculation using a computer assistant is required.

Analysis and interpretation to obtain lithology and aquifers are based on the terminology of the conversion of geoelectrical resistivity values to lithological or aquifer classes along with local geology and their effective porosity.

Based on the physiographic map[2] and the geological sheet of Kediri[16] and the geological map of the Malang sheet[17], it is shown that the research location consists of volcanic rocks of Anjasmoro (Qpat) which consists of volcanic breccia, lava, tuff and hacks. Besides that, there are also volcanic rocks of Anjasmoro muda (Qpva) which consist of volcanic breccias, lava, tuff and hacks with a younger age.

As a reference in data processing and interpretation, lithology classes are made based on the relationship between the resistivity values obtained from field data acquisition and local geology with the terminology of lithology classes as shown in the table 1.[1,20]

To find out the relationship between the litology distributions of vertical electrical sounding (VES) points with each other, a cross section is made between one point to another. The cross section is made in by making cross sections which connects one VES point with another in 1 cross section. For example, the calculations in this study, taken for the cross section of L5, can be seen in figure 6 and table 2.

Based on table 3, it can be seen that about 50% (6 cross sectons) of the total number of cross sections (12 cross sections) indicate a relatively stable slope (F), namely: R1, R2, L2, L3, L6 and L8. On the other hand, 50% (6 cross sections) of the total number of cross sections (12 cross sectiona) showing relative instability are: L1, L4, L5, L7, L9 and L10.

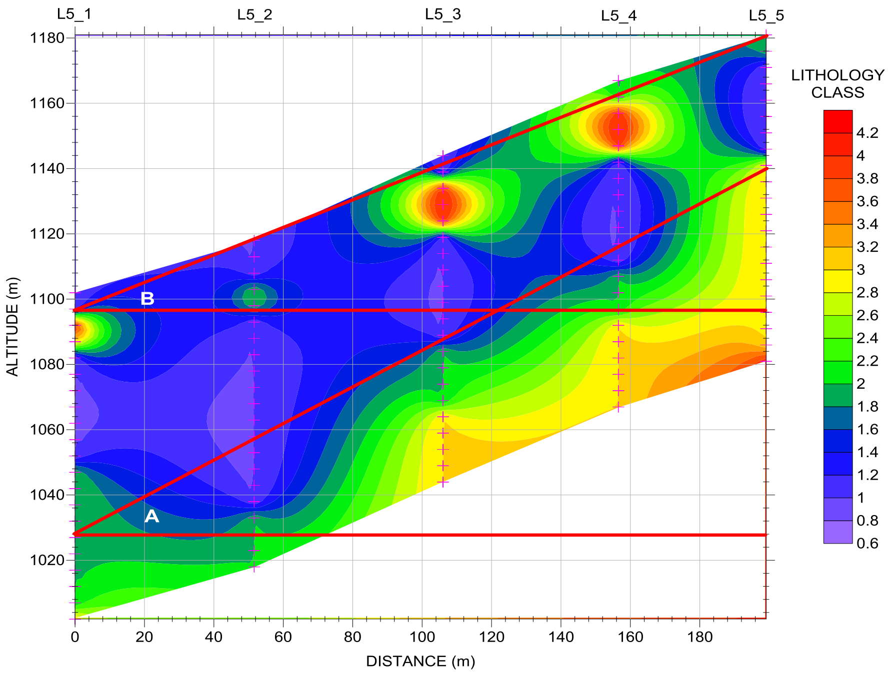


Figure 6: Slope condition of L5 line based on geoelectrical resistivity data.

Table 1
Terminology of the conversion of resistivity geo-electrical resistivity values to litology classes.

S.N.	RESISTIVITY (Ω.m)	LITOLOGY CLASS		LITOLOGY
1	0-100	I		Clay and Aluvium
2	100-1000	II		Aluvium and lava
3	1000-3000	III		Breksi and tuff
4	>3000	IV		Breksi and andesit

Table 2
Calculation of slope stability (F) based on geoelectrical resistivity data for L5 line.

Slope stability calculation (F):				
CONDITION	**LINE**	**α (deg.)**	**H (m)**	**F**
F Fakta	L5	29.36	54	0.25
F>=1.2		29.36	2.65	1.2
F>=1.5		29.36	2.04	1.5

Table 3
Summary of slope stability calculation (F).

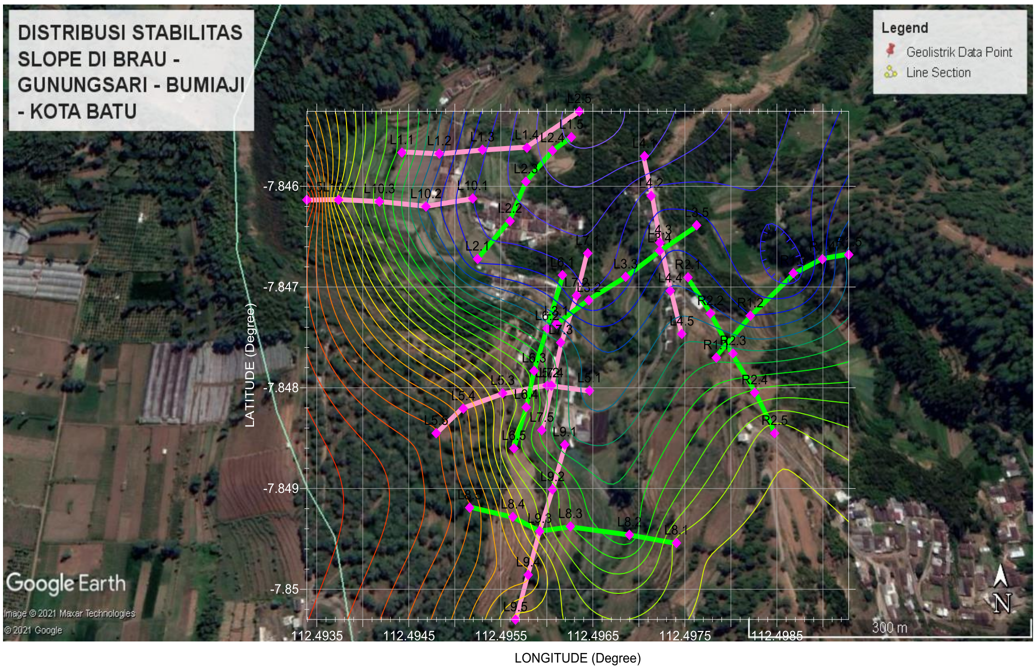
S.N.	LINE	SLOPE (α)	Havg (m)	F	STABILITY
1	R1	11.17	6.00	2.04	stable
2	R2	3.41	25.00	3.12	stable
3	L1	23.09	60.00	0.33	unstable
4	L2	11.79	12.50	1.21	stable
5	L3	2.28	36.00	4.14	stable
6	L4	18.65	58.00	0.43	unstable
7	L5	29.36	54.00	0.25	unstable
8	L6	3.43	26.00	3.06	stable
10	L8	9.42	16.00	1.35	stable
11	L9	15.48	12.00	0.92	unstable
12	L10	27.29	12.00	0.47	unstable

In addition to tabular form, namely table 3, the distribution of slope stability (F) can also be seen in figure 7 which describes the distribution of slope stability (F) in spatial or horizontal directions superimposed on the map of the Digital Elevation Model (DEM) of the research location.

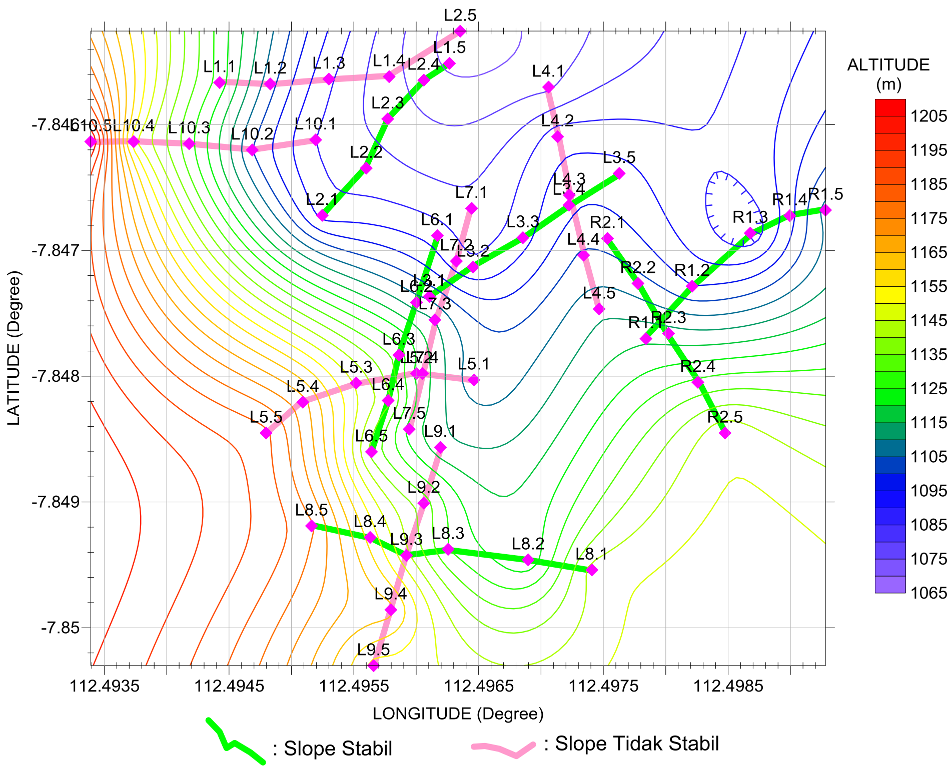
The resistivity log shows that the location of Brau hamlet, Gunungsari village, Bumiaji sub-district, Batu city has good underground water potential. Based on the resistivity geo-electrical data that has been carried out, it is recorded that there are at least 19 points out of 60 geoelectrical resistivity measuring points which show good underground water potential, namely points: R1_1, R1_5, R2_1, R2_3, L4_2, L4_3, L9_1, L9_2, L6_2, L6_3, L10_2, L10_5, L7_1, L7_5, L2_1, L8_4, L8_5, L1_1 and L1_5. This shows that the location of the hamlet of Brau, in addition to the potential for surface water which is currently suficient, also has potential for underground water which has not been utilized until now. In terms of land use, Brau hamlet is strongly supported by adequate underground water potential and this is very suitable to support agricultural activities, animal husbandry and other activities that require an adequate supply of water.

Regarding the potential for natural disasters in terms of surface topography, considering the fact that the research location is located in the hamlet of Brau, Gunungsari village, Bumiaji sub-district, Batu city, based on the National Digital Elevation Model (DEMNAS) map, it is located in an altitude range of 1067m - 1202m with the difference between the lowest and highest elevations being 135m. With varying topography, the potential for natural disasters such as flash floods and landslides is something to watch out for.

Flash floods will occur due to loose surface soil erosion which is transported by abundant rainwater. This can be exacerbated if the management of surface vegetation is not managed properly. Changes in land function from vegetation have creeping roots (such as banyan etc.) and fern roots (pine, cypress, resin etc.). Excessive rain will cause surface erosion which can cause flash floods and landslides due to loose soil on the surface. Dynamic topographic surface conditions and tendency to be steep are very vulnerable to flash floods and landslides of this type



(a)



(b)

Figure 7: Distribution of slope stability (F) in the spatial or horizontal direction at the location of Dusun Brau. (a). On a Google Earth map, (b). On the map of Digital Elevation Model (DEM)

Flash floods and landslides of the first type are due to erosion and off-surface soil are based on the data from the geo-electrical resistivity measurements as shown in figure 7. The results of this study indicate that 6 of the 12 total paths (50% of the total paths) indicate the instability of the subsurface landslide field in this research location. Tracks that have sufficient stability are: R1, R2, L2, L3, L6 and L8. The paths L1, L4, L5, L7, L9 and L10 indicate an unstable slope or landslide area. Landslides that occur due to unstable subsurface slopes will tend to have widespread adverse effects. Widespread impacts of landslides due to subsurface slope instability can occur because the landslide area is usually located under the vegetation root system. Vegetation or civil buildings on the surface will also be carried away by landslides. These landslides must be more vigilant, in addition to landslides due to surface soil erosion which can be reduced by eco-engineering through vegetation that has deep roots and creeps.

Based on the existing conditions of the research location and the results of research in the hamlet of Brau, Gunungsari village, Bumiaji sub-district, Batu city, the following are recommended:

1. Relocation: The research site should not be used as a residential area. If it is forced to be used as a residential area, it should be placed in a location with stable slope stability as can be seen in table 3 and figure 7. Even though the local location point has a safe slope stability status, it is not impossible to affect by other locations with higher topography in the vicinity.

2. Eco-Engineering: Eco-engineering needs to be done. Exploitation of nature without considering the balance of the environment will bring bad impacts. It is necessary to encourage the planting of vegetation with roots that plunge (nails) and creeps (vines) to resist landslides due to weathering of loose surface soils. In addition, it will also maintain the resilience of the potential for underground water at the research site and avoid cracks in the surface soil (cracks) during the dry season which will become a place for water to enter during the rainy season. Surface cracks will accelerate the soil layer above the slope to saturate and smooth the landslide area which can cause landslides to occur more quickly.

3. Community Education: Community needs to be given insight into the disaster potential of local locations. The target is to form a disaster-resilient community up to the RT level, even families and individuals.

4. Implementation of disaster mitigation protocols: In carrying out daily activities, the community must always involve as part of the disaster mitigation tool.

5. Installation of signs and early warning systems: Signs for potential disasters must be installed at points that are easily accessible to the public. In addition, early warning equipment must be a concern so that when there are signs of a landslide, it can be detected early so that the community has sufficient time to protect themselves from possible landslides that may occur.

Conclusion

It can be concluded that 6 of the 12 total paths (50% of the total paths) are showing the instability of the subsurface landslide field at the location of this study. The stable trajectories are: R1, R2, L2, L3, L6 and L8. The paths L1, L4, L5, L7, L9 and L10 indicate an unstable slope or landslide field. Stable path is recommended as a place for relocation.

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