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The Role of Geoelectrics in Landslide Mitigation Strategies in Malang City

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ABSTRACT

The city of Malang faces a significant risk of landslides due to rapid population growth and increasingly dense residential development. To address this pressing issue, it is highly important to implement effective and integrated mitigation strategies. One reliable method that can be used in landslide disaster mitigation is the geoelectric resistivity method. The methodology employed in this research is a literature review, conducted by systematically collecting and analyzing data from various relevant sources. This paper comprehensively discusses the vital role of geoelectric methods in landslide mitigation strategies specifically in the city of Malang. The fundamental working principles of the geoelectric resistivity method are clearly explained, including the detailed analysis of geoelectric resistivity data. Additionally, this article also discusses practical landslide mitigation strategies and how using geoelectric methods can help identify potential landslide risks. In this study, geoelectric data collection was carried out at several locations in the city of Malang, and the results were directly used to plan effective disaster mitigation actions.

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1. INTRODUCTION

Malang City ranks 17th in population among the 94 registered cities in Indonesia [1]. The population in Malang City continues to grow, rising from 843,810 to 846,126 people between 2020 and 2022, based on demographic data from the Malang City Central Bureau of Statistics [2]. This significant population increase and the limited available land cause land prices in the city center to rise. The economic and social situation in Malang City makes low-income residents choose to settle in suburban areas, especially in regions close to riverbanks.

The geological structure in Malang City is very diverse, with a wide highland in the south, a fertile northern part, a highland in the east, and a very vast highland in the west [3]. Malang City also has four different soil types, namely blackish-gray alluvial, brown mediterranean, a reddish-brown latosol and greyish-brown association, and a brown and grey humus andosol association. This difference in geological structure provides a variety of environmental conditions in this city. Besides having a diverse geological structure, Malang City also faces challenges caused by population growth and increasingly dense settlements in riverbank areas.

This situation leads to a decrease in the availability of riverbank areas as conservation zones and open spaces, as well as an increase in environmental degradation and disaster risks, especially landslides [4]. Data from the Malang City BPBD Operations Control Center (Pusdalops) in 2017 showed that there were 74 landslide events during that year, causing significant losses in terms of both casualties and material damage. Therefore, understanding the geological structure and environmental conditions of Malang City is very important to overcome this challenge. Landslides can be defined as the displacement of slope-forming materials, whether original rocks or fill materials, that move downwards and outwards from the slope.

One factor that strongly influences the occurrence of landslides is the slip surface, which is the plane that becomes the base for soil mass movement. Therefore, the analysis of the slip surface and soil structure needs to be done as an initial step in landslide disaster mitigation. Identifying the characteristics of the subsurface slip surface using the geoelectric resistivity method has proven to be very effective in mapping landslide-prone zones with high precision at specific depths [5]. The slip surface itself is a watertight and slippery surface, generally consisting of clay layers [6].

To reduce the risk of landslide disasters, the community must take preparedness actions by understanding and implementing various available systems and measures. These preparedness actions include identifying available resources, early warning systems, rescue actions, community socialization, coordination with related agencies, and so on. The importance of this disaster education effort is supported by field evaluations proving that structured mitigation socialization can significantly improve students' cognitive values and understanding regarding emergency preparedness in the school environment [7]. Therefore, it is important to identify areas that are potentially exposed to landslide hazards as a disaster mitigation effort [8].

To understand the geological structure that includes different soil types, we can use the geoelectric method to obtain information about the rock resistivity characteristics in the area. The geoelectric method can also be used to identify subsurface structures that might be related to landslide risks or other geotechnical problems. By obtaining information about rock resistivity, we can find out the zones that have low stability and have the potential to cause soil movement. This can help in determining mitigation steps and protection against natural disaster risks.

In determining fast and precise geophysics-based mitigation steps, computational efficiency is highly needed, similar to the use of a Python-based numerical algorithm to speed up the calculation of disaster decay time [9]. The reliability of automated phase picking is also important to detect hazard parameters proactively and in real-time [10]. The geoelectric resistivity method is one of the geophysical techniques that can be applied to determine the soil layer structure and detect the slip surface by studying the characteristics of electrical flow in the earth. This technique involves measuring potential, current, and electromagnetic fields that occur naturally or are caused by sending electrical currents into the earth.

The basic principle of the geoelectric method is to send an electrical current into the ground surface through a pair of electrodes and measure the potential difference using another pair of electrodes. By measuring the potential difference and electrical current, the resistance value of the medium inside the earth being studied can be estimated. This method has the advantage of not damaging the environment, is relatively cheap, and is able to detect several meters of depth in the soil layer [11]. Another advantage of this method is its ability to map subsurface cross-sectional models in 2D and 3D, thus providing a comprehensive visualization regarding the weathered layer thickness that has the potential to become landslide material [12].

Previous research did not include landslide mitigation strategies, the principles of the geoelectric method, and the relationship between geological structures and landslides. In this paper, we combine various elements that were present in previous studies. The first objective of this writing is to find out the working principle of the geoelectric resistivity method in determining the soil layer structure and slip surface. The other objectives are to understand the benefits of this method in identifying potential landslide risks, planning effective mitigation, and understanding its potential and limitations as an alternative solution in Malang City.

2. RESEARCH METHOD

In the research regarding the geological characteristics of the area, geoelectric data collection was conducted by observing rock types at two different coordinates, namely 08°10'13.0" E 112°38'20.0" S and 08°10'14.6" E 112°38'18.2" S, with elevations of 367 and 368 meters above sea level, respectively, and recorded in Table 1 and Table 2. This observation was carried out by paying attention to the depth and rock resistivity in each of those layers. In addition, research was also conducted at a mini football field in Jatimulyo, Lowokwaru, Malang City, East Java, which has the coordinates 7°56'50.71" S 112°36'57.77" E. This mini football field has a size of 70m × 60m, but in this research, only a part of the field was used, namely five points with a distance of 10 meters between points.

Table 1. Observation data at coordinates 08°10'13.0" E 112°38'20.0" S, 368 MASL [13]

Depth (m)	Resistivity (Ωm)	Rock Type
0 – 2.57	36.96	Surface Soil
2.57 – 5.46	24.69	Tuff
5.46 – 8.19	17.90	Clay
8.19 – 29.37	92.79 – 109.17	Sand
29.37 – 63.74	15.76	Tuff
63.74 – 104.10	95.92	Sand

Table 2. Observation data at coordinates 08°10'14.6" E 112°38'18.2" S, 367 MASL [13]

Depth (m)	Resistivity (Ωm)	Rock Type
0 – 2.57	79.93	Surface Soil
2.50 – 11.44	23.94 – 46.35	Tuff
11.44 – 21.86	14.09	Clay
21.86 – 33.43	50.79	Sandy Silt
33.43 – 45.76	29.48	Tuff
45.76 – 91.92	294.97	Gravel

Table 3. Observation data at coordinates 7°56'50.46" S 112°36'56.41" E [14]

N	ρ (Rho)	h	d	Alt
1	9.698	0.9	0.9	-0.9
2	8.775	1.054	1.954	-1.9541
3	12.43	2.289	4.243	-4.2426
4	25.85	4.969	9.212	-9.2116
5	12.75	10.79	20	-20
6	21.42			

Table 4. Observation data at coordinates 7°56'50.27" S 112°36'56.60" E [14]

N	ρ (Rho)	h	d	Alt
1	10.46	0.9	0.9	-0.9
2	8.738	1.054	1.954	-1.9541
3	15.07	2.289	4.243	-4.2426
4	15.58	4.969	9.212	-9.2116
5	17.1	10.79	20	-20
6	19.84			

Table 5. Observation data at coordinates 7°56'50.05" S 112°36'56.82" E [14]

N	ρ (Rho)	h	d	Alt
1	10.52	0.9	0.9	-0.9
2	8.528	1.054	1.954	-1.9541
3	15.86	2.289	4.243	-4.2426
4	14.92	4.969	9.212	-9.2116
5	17.62	10.79	20	-20
6	19.53			

Table 6. Observation data at coordinates 7°56'49.83" S 112°36'57.00" E [14]

N	ρ (Rho)	h	d	Alt
1	9.845	0.9	0.9	-0.9
2	7.901	1.054	1.954	-1.9541
3	12.61	2.289	4.243	-4.2426
4	18.35	4.969	9.212	-9.2116
5	14.95	10.79	20	-20
6	10.1			

Table 7. Observation data at coordinates 7°56'49.57" S 112°36'57.21" E [14]

N	ρ (Rho)	h	d	Alt
1	9.825	0.9	0.9	-0.9
2	7.941	1.054	1.954	-1.9541
3	12.59	2.289	4.243	-4.2426
4	17.87	4.969	9.212	-9.2116
5	16.45	10.79	20	-20
6	9.095			

The methodology used in this research is a literature review. The research was conducted by collecting and analyzing data from various literature sources relevant to the research topic. The literature sources used include scientific journals, articles, books, and publications related to landslide mitigation, geological structures, and the geoelectric resistivity method. The first step in this methodology is identifying the research topic and understanding the background of the problem regarding the role of geoelectrics in landslide mitigation strategies in Malang City.

Then, the authors conducted a literature search using scientific databases and digital libraries to gather relevant sources. After collecting sufficient literature, the authors performed reading and analysis of each literature source. The data obtained from the literature were recorded and organized according to relevant subtopics, such as the working principles of the geoelectric resistivity method, geoelectric resistivity data analysis, and landslide mitigation strategies. Next, the authors evaluated and synthesized information from the collected literature to compile the discussion.

In this discussion, the authors explain in detail the working principle of the geoelectric resistivity method, including the use of tools and measurement techniques. In addition, the authors also analyze the geoelectric resistivity data obtained from previous research and explain how these data can be used to identify potential landslide risks. The results and discussion also include a discussion regarding landslide mitigation strategies in Malang City. The authors identify actions that can be taken in landslide disaster mitigation, including the identification of areas potentially affected by landslide hazards, early warning, and coordination with related agencies.

The authors also explain how the use of the geoelectric resistivity method can be an alternative solution in overcoming the landslide problem in Malang City. Finally, the authors conclude the relevant discussion results based on findings from the literature review. The authors also include a bibliography which contains the literature sources used in this research. The working principle of the geoelectric method is by studying the electrical flow in the earth based on the electrical properties of rocks.

Examples of these properties are specific resistance, conductivity, dielectric constant, and the ability to generate self-electric potential. The way this method works is by inserting an electric current through two current electrodes and measuring the resulting potential distribution using potential electrodes on the earth's surface. The geoelectric method is used in subsurface natural exploration [15]. The tools used in this research include a geoelectric device used to measure rock resistivity at the research location and a GPS system to determine the coordinates of the geoelectric measurement points.

Measurements are carried out with computed direct current to prevent polarization and using a resistivity meter to measure the potential difference. This tool must be used in completely dry conditions to provide accurate results. The use of certain configurations, such as the Wenner configuration, is often applied specifically to analyze resistivity contrast in areas with critical slope inclinations as an initial step to identify potential ground movement [16]. The geoelectric data from the measurement results are used as a reference to determine the landslide point in the data collection area, and information regarding the resistivity value and the stretch length from the geoelectric method can provide a picture of the subsurface conditions [13].

3. RESULT AND DISCUSSION

3.1. Geoelectric Resistivity Data Analysis

In a certain area, if the soil has a rough and loosely bound structure or texture, such as sand and gravel, and contains excessive water that reduces the adhesion between soil grains, then the area can be considered prone to landslides. Based on Table 1, it is known that at a depth of 5.46-8.19 meters there is a clay layer, at 8.19-29.37 meters there is a sand layer, at 63.74-104.10 meters there is a sand layer, and at 104.10-110 meters there is a gravel layer. At a depth of 63.74-104.10 meters, there is groundwater with a resistivity of 95.92 Ωm. This indicates that the first observation location is an area vulnerable to landslides, starting from a depth of 5.46 meters, with the most vulnerable area located at a depth of 63.74-104.10 meters.

Based on Table 2, it is known that at a depth of 11.44-21.86 meters there is a clay layer, at 21.86-33.43 meters there is a sandy silt layer, at 45.76-91.92 meters there is a gravel layer, at 91.92-121.56 meters there is a sand layer, and at 121.56-150 meters there is a gravel layer. At depths of 33.43-45.76 meters and 91.92-121.56 meters, there is groundwater with resistivities of 29.48 Ωm and 93.03 Ωm, respectively. This shows that the second observation location is also a landslide-prone area, starting from a depth of 11.44 meters, with the most vulnerable area located at a depth of 91.92-121.56 meters. Based on the processing results of the subsurface material resistivity cross-section data at the Jatimulyo mini football field, Lowokwaru, Malang City, it can be seen that at a depth of 0-5.179 meters, there is a clay layer with a resistivity value range of 8.859-11.2 Ωm.

At a depth of 5.179-10 meters, there is a sandy clay layer with a resistivity value range of 11.29-12.59 Ωm. At a depth of 10-37.28 meters, there is a sand layer with a resistivity value range of 12.74-15.85 Ωm. At a depth of 11.5-37.28 meters, there is an alluvial layer with a resistivity value range of 16.24-18.33 Ωm. At a depth of 13.89-37.28 meters, there is a rocky sand layer with a resistivity value range of 19-20.69 Ωm.

Furthermore, from the results of the data processing, it can also be seen that each research point has material layers of different lengths and thicknesses. The top layer at each point contains a clay layer with an average thickness of 5.179 meters. The second layer at each point contains a sandy clay layer with an average thickness of 4.821 meters. The third layer at each point contains a sand layer with varying thicknesses at each respective point.

The fourth layer is only found at points 1, 2, and 3 with an average length of about 30 meters and a relatively similar thickness in each layer, which is 25.78 meters. The fifth or bottom layer is found at points 1, 2, and 3 with an average length of 30 meters and varying thicknesses at each point. In relation to landslides, the results of this data processing can be used as a basis to determine locations prone to landslides, especially in material layers with varying thicknesses at each point and in sand layers whose resistivity value range is between 12.74-15.85 Ωm. In addition, an understanding of the stratigraphy of the research area is also important to determine how the distribution and characteristics of subsurface materials can affect slope stability and construction feasibility in the area.

3.2. Landslide Mitigation Strategies

Landslides are natural disasters that can occur in various regions, including Malang City. To overcome this disaster, it is necessary to implement an integrated mitigation strategy. Based on the provided information, there are two landslide-prone sample locations in Malang City, namely the first location at a depth of 5.46 meters and the second location at a depth of 11.44 meters. One of the mitigation strategies to reduce landslide risks in Malang City is the mapping and identification of landslide-prone areas, which can be done using the geoelectric method.

The concept of spatial hazard mapping is an essential pillar in integrated mitigation strategies, and its principles are also widely adopted in mapping other geological disaster vulnerabilities, such as seismic hazard probability and maximum ground acceleration for regional spatial evaluation [17], [18], [19]. This method studies the flow of electricity in the earth based on the electrical properties of rocks, such as specific resistance, conductivity, dielectric constant, and the ability to generate self-electric potential. The results of the geoelectric method can provide an overview of subsurface conditions and can be used as a reference to determine landslide points in the data collection area. Land use control is an effective mitigation strategy to reduce landslide risks, which includes regulating development in landslide-prone areas, managing agricultural land, and regulating human activities in those areas.

Increasing public awareness of landslide hazards is very important in reducing the risk of this disaster. Socialization campaigns that educate the public about landslide hazards, early symptoms of landslides, and how to avoid landslide-prone areas need to be carried out regularly. Infrastructure development, such as HIPPAM networks and business cooperatives, can help reduce the risk of landslides. The HIPPAM (Public Hydrant for Firefighting) network can be used to extinguish fires that appear after a landslide, while business cooperatives can help improve the local community's economy so they can be more financially stable and prepared to face natural disasters.

Structural mitigation is carried out by building structures that can withstand or reduce landslide forces, such as installing fences or retaining walls on landslide-prone slopes. The selection of structural mitigation, such as dredging landslide material or building retaining walls, must be adapted to the type of landslide and slope geometry that has been previously mapped [20]. Non-structural mitigation includes efforts that do not involve building structures, such as training, forming volunteer forums, socialization, and disaster simulations. The implementation of disaster simulations in educational institutions has proven to be very crucial for training psychomotor skills and self-rescue instincts, although its implementation must consider environmental factors and heat stress so that participants' concentration levels remain optimally maintained [21].

The implementation of mitigation strategies, both structural and non-structural, must be carried out in an integrated manner to ensure success in reducing landslide risks. In implementing mitigation strategies, good coordination and cooperation are needed among the government, the community, non-governmental organizations, and other related parties. In addition, periodic evaluation and monitoring also need to be carried out to assess the effectiveness of the mitigation strategies that have been implemented and provide input for future improvements. This evaluation process is highly ideal when combined with statistical data modeling to predict the duration of recovery or the decay of post-disaster alert status, similar to the application of Omori and Mogi statistical models relied upon by mitigation authorities to determine the estimated recovery time of the post-earthquake crisis phase [22].

By applying the right and integrated mitigation strategies, it is hoped that it can reduce the risk of landslides in Malang City and increase community resilience to natural disasters. The geoelectric resistivity method has potential as an alternative solution in overcoming landslide problems in Malang City because it can provide information regarding resistivity values and stretch lengths below the ground surface. This method can help identify landslide-prone areas and determine landslide points in the data collection area. Furthermore, the use of the geoelectric resistivity method can provide accurate results if carried out in completely dry conditions.

However, there are several limitations to the use of the geoelectric resistivity method, the first of which is that it can only measure the electrical properties of rocks and cannot provide information on soil strength and stability. Second, utilizing the geoelectric resistivity method requires fairly expensive equipment and demands specific expertise for its operation. Third, this method also possesses limitations regarding measurement depth, meaning it cannot be utilized to measure the electrical properties of rocks in deeper layers. Therefore, the geoelectric resistivity method must be combined with other methods to acquire more comprehensive information, such as integrating wide-scale non-seismic anomaly extractions like satellite gravity or double-difference relocation methods used as comparisons in applied geophysics [23], [24], [25].

4. CONCLUSION

The geoelectric resistivity method studies the electrical flow in the earth by inserting an electric current through two current electrodes and measuring the resulting potential distribution using potential electrodes on the earth's surface. A geoelectric device is utilized to measure rock resistivity at the research location, and a GPS is used to accurately determine the coordinates of the measurement points. Geoelectric data from the measurement results are then used to determine landslide points in the data collection area and provide a general overview of subsurface conditions. There are several mitigation strategies to reduce landslide risks in Malang City, including mapping and identifying landslide-prone areas, increasing public awareness, infrastructure development, and structural and non-structural mitigation.

The geoelectric resistivity method can be used as an alternative solution in overcoming landslide problems in Malang City, which is in line with modern geophysical studies confirming that electrical resistivity tomography is a reliable instrument for the early identification of slip surfaces within the disaster mitigation framework [26]. This method can provide information regarding resistivity values and subsurface stretch lengths, thereby helping to determine specific landslide points in the data collection area. However, this method has several limitations, such as needing to be carried out in completely dry conditions to provide accurate results, while also requiring quite expensive equipment and specific operational expertise. Therefore, the use of the geoelectric resistivity method must be considered carefully and compared with other methods before being used as an alternative solution in overcoming landslide problems in Malang City.

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