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Integrate of Geoelectric and Geomagnetic Methods to Construct Subsurface Model as Early Landslides Mitigation in Kalirejo, Kokap, Kulonprogo

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Abstract

Kalirejo, Kokap, Kulonprogo area is part of Yogyakarta in the west which borders the Province of Central Java. In general, the geomorphology of this research area consists of hills with varying slopes ranging from 15º - 60º, lithology consists of massive andesite intrusion with intense weathering, this can be a mass movement. The study uses geoelectric and geomagnetic approaches to identify components that allow mass movement or landslides to occur. Based on the response of geoelectric data, it is known that andesite rocks that have impermeable properties can become a slide plane having a resistivity contrast between 100 - 3000-ohm meters. Geoelectric data also describes the presence of surface aquifers which can be an important component in landslides. The water-saturated lithology has a resistivity range of 10 - 40-ohm meters. Based on the analysis of geomagnetic data with a magnetic intensity value range ranging from -400 - 1400 nT, it is known that the research area has a fairly high structural intensity. Analysis of geoelectric data shows that the thickness of the unconsolidated sediment is thick enough and the layer underneath is an impermeable rock layer, so it can be concluded that has a high potential for landslides.

Keywords: geoelectric geomagnetic, resistivity, slide plane, landslide

I. INTRODUCTION

The type of weathering soil that is often found in Indonesia is the result of volcanic eruptions. This soil has a composition of mostly shale with little sand and is fertile. Weathering soil that is on top of the impermeable rock on hills/ridges with moderate to steep slopes has the potential to cause landslides in the rainy season with a high quantity of rainfall. If the hills do not have strong and deep roots, the area is prone to landslides. One of the areas with a large potential for landslides in Yogyakarta is Kalirejo village, Kokap, Kulonprogo. especially Kalibuko 1 and Kalibuko 2 areas which are recorded to have a population of 5,639 people. Therefore, an initial step is needed in disaster mitigation by mapping and evaluating the potential for landslide disasters in the area. (Mubekti, dan Alhasanah, 2008).

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The most feasible and good approach to mapping the potential for landslides is to use the integration of geoelectric and geomagnetic methods. The geomagnetic method that is mapping straightness pattern associated with the fault in the study area which can be a major trigger in soil movement, the geoelectric method to determine the thickness of the water-saturated layer and the position of the slide plane layer which is also the main control in a combination landslide disaster (Fetter, 1994). Both of them if combined with slope data can be used as a reference in determining locations with high potential for landslides. The results of this research can be early landslide mitigation that aims to reduce the risks that impact the communities around the area.

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II. LITERATURE REVIEW

II.1. Geoelectrical Method

Resistivity can be defined as a quantity that can characterize electrical properties because it only depends on the type of material. Resistivity is also often referred to as resistivity, which is the ability of a medium to inhibit an electric current. Factors that can affect rock resistivity include metallic and non-metallic mineral content, fluid and saltwater content, differences in rock texture, differences in rock porosity, differences in rock permeability, and differences in temperature.

In the case of geoelectric exploration, to calculate the resistivity of the rock derived from the electric current in a homogeneous medium of half infinite space, this analogy is as an infinite half-space medium because the electrode distance is much smaller than the earth's radius. However, due to the nature of the earth that is generally layered (especially near the surface), the assumption of a homogeneous earth medium is not fulfilled. Therefore the measured resistivity is not true resistivity, but what is measured is apparent resistivity symbolized by ρ_a.

The apparent resistivity value depends on the resistivity of the layers forming the formation and the distribution of the medium as a result of subsurface geological conditions, electrode spacing, and arrangement. So that the equation (1) applies,

$$\rho = 2\pi \frac{\Delta V}{I} \frac{1}{G} \qquad (1)$$

where the $\frac{2\pi}{G}$ factor is given the symbol K which indicates the geometric factor of the electrode configuration used in the measurement. This shows the position function of the current and potential electrodes, so that equation (1) can be written as,

$$\rho = K \frac{\Delta V}{I} \qquad (2)$$

The corrected resistivity value getting by a more complex geometric correction approach (topographic effect) is still needed by using a modeling technique approach (forward and inversion). This is done to approach the true resistivity value. The focus of this research is to examine the contrast of the resistivity value resulting from rock formations that contain fluid by providing a resistivity response which tends to be lower to the surrounding rocks.

II.2. Wenner-Schlumberger Array

Wenner-Schlumberger array has a good ability to provide an overview of subsurface configurations vertically and also provides good resolution laterally. This configuration is a configuration that combines two types of electrode configurations to get a good picture of the subsurface (Loke, 2004). Figure 1. Wenner - Schlumberger array electrode design.

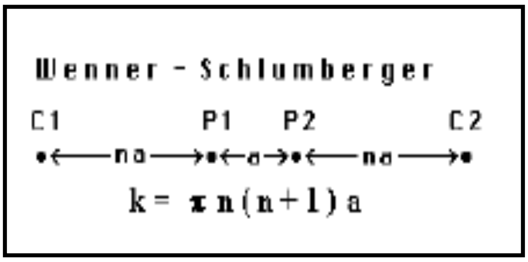

Figure 1. Wenner-Schlumberger Array (Loke, 2004)

This research was conducted by 2D mapping with a track length of 470 meters with a space between the electrodes of 10 meters. The measurement results are in the form of the apparent resistivity value of the rock which is then carried out by 2D inversion modeling which produces a resistivity cross-section. Based on the 2D cross-section, an interpretation is then carried out to detect the presence of lithology and an estimate of the slide plane through variations in the resistivity value of the rock. The results of the interpretation are then correlated on each measurement path to obtain the distribution of rock formations that have the potential to become loose material and the slide plane/landslide.

II.3. Geomagnetic Method

Geomagnetic is a geophysical method that measures variations in the intensity of the magnetic field at subsurface caused by variations in the distribution of magnetized rocks (Fajri, et.al., 2019). Minerals that are magnetic in rock will affect the size of the magnetic susceptibility value obtained.

The measurement target of the geomagnetic method (magnetic anomaly) is the variation in the magnetic field measured on the surface that arises from the susceptibility contrast (the ability of the rock to be magnetized) of the rock against its surroundings. Measurement of the geomagnetic method is useful for knowing the prospect of target areas such as geological structures, faults, folds, igneous intrusions. Geomagnetic interpretation is a reference for determining the distribution of the fault structure which is one of the triggers for landslides.

The basic concept of the geomagnetic method is the Coulomb force (Telford et.al., 1976) which is generated between two magnetic poles m^1 and m^2 which are separate r, can be written in equation (3)

$$\vec{F} = \frac{m_1 m_2}{\mu r^2}\,\hat{r} \qquad (3)$$

Where $\vec{F}$ is Coulomb Force (N), μ is magnetic permeability ($4\pi \times 10^{-7}$ w/A.m in a vacuum), m_1, m_2 is mass (kg), and $\hat{r}$ is the distance of the two poles (m).

II.4. Landslide Characterization

Landslide is the movement of slope-forming material or soil in the form of rock, debris, soil, or mixed material moving down or out of the slope. The process of landslides can be caused by water seeping into the ground which will increase the soil load. If the water seeps in until the soil is impermeable, the soil becomes slippery and the weathered soil at the top will move along the slope (Nisa et.al., 2019)

There are 6 types of landslides, namely: translation landslides, rotational landslides, block movements, rock debris, soil creeping, and the flow of scrap materials. The types of translational and rotational landslides occur mostly in Indonesia. Meanwhile, the landslide that has claimed the most human lives is the flow of scrap materials. They are translational landslides, rotational landslide, block movement, rock crash, soil termites, shredded material flow

Common symptoms of landslides can be seen from several indications, namely the appearance of cracks on the slopes parallel to the cliff direction, usually after rain, the emergence of new springs suddenly, and brittle cliffs and gravel starting to fall. In principle, landslides occur when the driving force on the slope is greater than the bearing force. The holding force is generally influenced by rock strength and soil density. While the driving force is influenced by the magnitude of the angle of the slope, water, load, and the density of the rocky soil. the factors that cause landslides are rain, steep Slopes, less dense and thick soil, rocks that are not strong enough, type of land use, and vibration (Misstear,2006; Kodoatie, 2012)

The appearance of landslides can be seen from several indications, namely cracks on the slopes parallel to the direction of the steep cliffs, after the rain usually the emergence of new springs suddenly, and brittle cliffs then materials such as gravel, gravel, and soil begin to move down. Landslide occurs when the driving force on the slope is greater than the bearing force. The holding force is generally influenced by the strength of the rock and the density of the soil. Meanwhile, the driving force is influenced by the magnitude of the slope angle, water, load, and density of the ground rock. The factors causing landslides are rain, steep slopes, less dense and thick soil, less strong rocks, types of land use, and vibrations (Misstear, 2006; Kodoatie, 2012)

III. RESEARCH METHODOLOGY

The first stage is 8 lines resistivity data collection by Wenner-Schlumberger array using IRIS Syscal 48 Channel Resisitivitymeter and continued with more 130 geomagnetic data collection using PPM Geometric instrument. The second stage is data processing consisting of 2D resistivity sections and a magnetic anomaly distribution map based on geological information in Kalirejo, Kokap, Kulonprogo, and surrounding areas. Slope topographical conditions can be seen in Figure 2.

Figure 2. Slope topographical conditions at Kalirejo, Kokap, Kulonprogo

Interpretation is done both qualitatively and quantitatively, where the concept of geoelectric interpretation is based on the resistivity value of the rock-influenced by several factors. These factors can make a rock or object have a high or low resistivity value. Some of these factors include density, porosity, water content, and mineral composition. Rocks that have a high density (rigid) can be ascertained to have a low porosity value, this low porosity will also be directly proportional to the water content in a lithology, this condition will make a lithology have a high resistivity value. Geomagnetic interpretation is based on the magnetic anomaly contrast depicted in the form of contour density so that it can predict the fault continuity pattern in the study area that triggers landslides.

The final stage is to integrate 2D resistivity sections with the distribution map of the structure from the geomagnetic analysis. Based on the lithology layer, it produces a cross-section that provides information about the presence of loose material (soil) and the slide plane that has the potential for landslides during the rainy season as well as the distribution pattern of the fault structure in the study area.

IV. FINDING AND DISCUSSION

In this research, there are several components that can cause mass movement which can be described properly using this geoelectric method. The first component in this case is the impermeable layer under the surface which functions as a slip plane and which is the main control for the saturation level of the soil or loose material.

In this case, which is an impermeable layer is an andesite, the response of this andesite stone is to have a high resistivity value with a resistivity order between 102 - 104 ohm.meters. Then the components that cause soil mass movement that can be described well using the geoelectric method are the thickness of the cover or lose material, the resistivity of the soil has a low value with a resistivity order of 50 - 100 ohm.meters. The next component that can be interpreted from the geoelectric cross-section is the presence of a water-saturated layer that allows mass movement on the surface, the resistivity order of the layer that has high water saturation is 10 - 40 ohm.meters.

IV.1. Interpretation of 2D Resistivity modeling

In the 2D resistivity cross-section of trajectories 1 to 8, there are some resistivity contrasts depicted in colored closets, on this path the lowest resistivity value has a value of 0.73 - 40 ohm.meters represented in blue represented as a water-saturated layer, medium resistivity value at a value of 51.4 - 212 ohm.meters represented in green, interpreted as a layer of rock that tends to be weathered, high resistivity values are at a value of 878 - 15014-ohm meters represented by red. Based on field calibration values, andesite rocks have resistivity values of more than 125 ohm.meters.
Each line has a varying layer thickness, the following is an interpretation of each line (figure 3) :

- Line-1, fresh andesite which is the impermeable layer, is thought to be in the southern part, the closure which is thought to have andesite has a yellow to red contrast in the small electrode number (80-240 meters), the estimated elevation of andesite is 360 - 320 m.
- Line- 2, fresh andesite in almost the entire 2D model can be seen that the high resistivity closure is at the electrode 0 - 470 meters, but the loose material layer in this area is not thick and tends to be drier than the first layer.

- Line-3, the dominant lithology is composed of andesite rocks with a thick cover layer that is not too thick. In this path, there are also a few patterns of resistivity values which are thought to have a lot of groundwater content.
- Line-4, fresh andesite is thought to be at an elevation of 320 to 240 meters, on this line the low resistivity contour covers the contour that is thought to be andesite. In this path, the dimensions of the high resistivity contour, which is thought to be andesite, have a fairly large dimension (starting from electrodes 0 - 240 meters and electrodes 260 - 340 meters). The potential for mass movement can occur in the eastern part of the track which is represented by a fairly thick blue closet.
- Line-5, fresh andesite is thought to be in the eastern part of the track, the closure which is thought to be andesite has a yellow to red contrast with the estimated elevation of andesite at 300 - 240 m. It is interpreted that the material in the eastern part of the trajectory can move towards the west due to the thickness of the non-consolidated layer which tends to be water saturated
- Line-6, fresh andesite has quite large dimensions and is represented in green, yellow to red cladding with an estimated elevation of the presence of andesite at 340-260 meters. The tendency of the soil mass movement to the east of the track is due to the thickness of the soil which is water-saturated
- Line-7, fresh andesite is thought to be in almost the entire track as indicated by green to yellow closets which are suspected of being andesite at an elevation of 440 - 320 meters. The tendency of soil mass movement to the east of the trajectory is due to the thickness of the soil which is water-saturated
- Line-8. fresh andesite is thought to be in almost the entire track as indicated by green to yellow closets which are thought to be andesite at an elevation of 380 - 360 meters. The tendency of landmass movement to the east

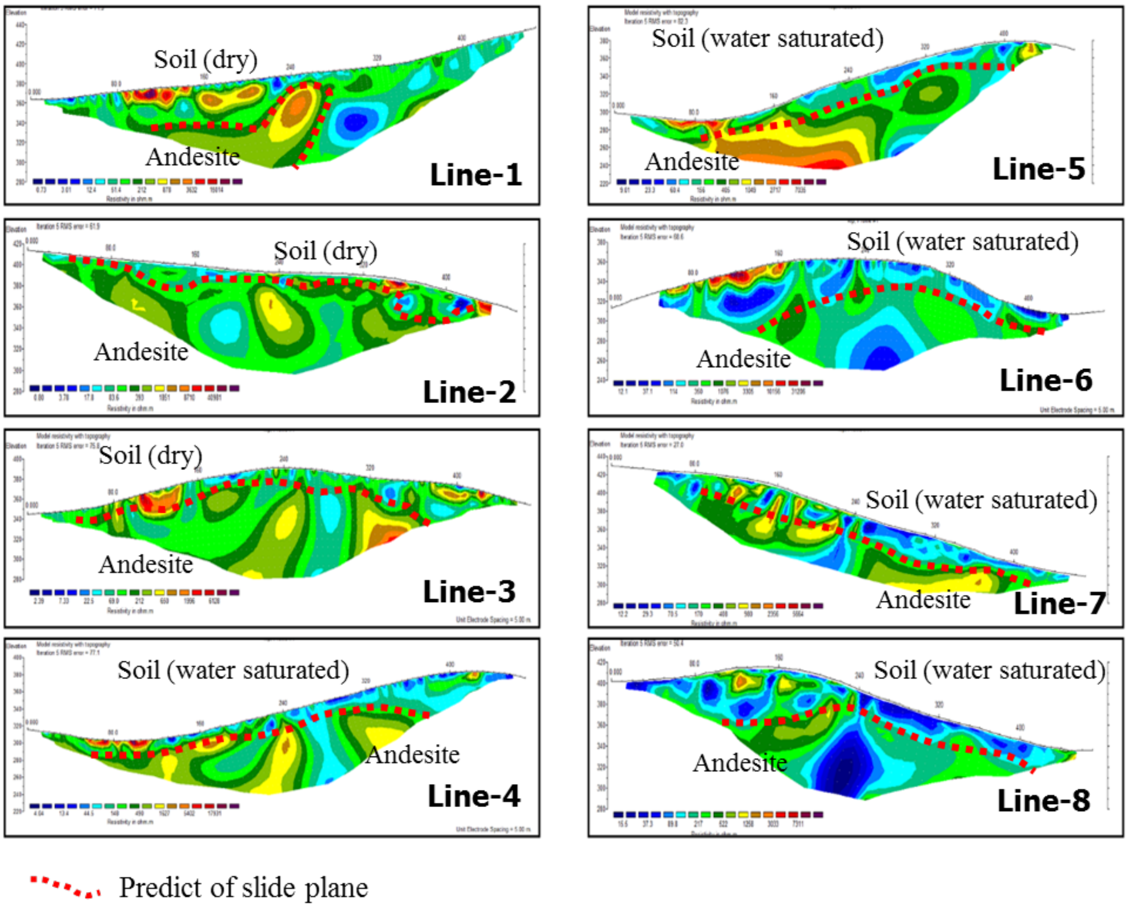

Figure 3. Predict of slide plane based on 2D Resistivity modeling section

IV.2. Structural Analysis Based On Geomagnetic Data

The result of magnetic data of the study area with a magnetic intensity value range of -400 - 1400 nT. This large range of magnetic intensity values is thought to be due to variations in lithology and the presence of structures in the research area. Rocks that experience deformation will of course undergo a demagnetization process so that it can cause the magnetic value to be low compared to the magnetism of other rocks. The map is total magnetic intensity (TMI) map which is the result of a contour of the magnetic value recorded in the field, on the map above it can be seen that there is a dense closure pattern that forms an alignment with a low closet value which is interpreted as the existence of structures/faults in the research area (figure 4a). In order for the interpretation to be more convincing, the TMI map is further processed using derivative filters to emphasize the existence of the boundary of geological objects/phenomena in the research area.

Horizontal derivative (FHD) map formed after doing the Reduction To Pole on the TMI map. In general, the map above has the same orientation as the TMI map. However, on this derivative horizontal map, the clear boundaries which can be interpreted as the boundaries of geological phenomena (faults) are more clearly visible. Based on the interpretation of the Horizontal Derivative map above, it is known that the main fault has a relative North-South orientation represented by a tight closure with a value ranging from 0 - (-2) nT / m. The minor fault is interpreted to have a relatively northwest-southeast trending orientation with the same magnetic value 0 - (-2) nT/m. (figure 4b).

To support the interpretation of the TMI and Horizontal Derivative Maps, a First Vertical Derivative (VFD) map was carried out which also has a good overview of the boundary planes that have a relative vertical direction such as the fault. The closure pattern on this map has the same orientation as the TMI map and the Horizontal Derivative map, however, the anomaly boundary looks firmer and clearer. In general, the fault patterns found on the Horizontal Derivatives map can also be seen on the vertical derivative map (figure 4c). However, on this map, there is also a fault prediction pattern that is not identified by the horizontal derivative map. Based on the analysis of this geomagnetic data, it can be seen that the research area has a high enough structural intensity, coupled with the analysis of geoelectric data which shows that the thickness of the unconsolidated sediment is thick enough and the layer underneath is an impermeable rock layer, so it can be concluded that the research area has a high potential for landslides.

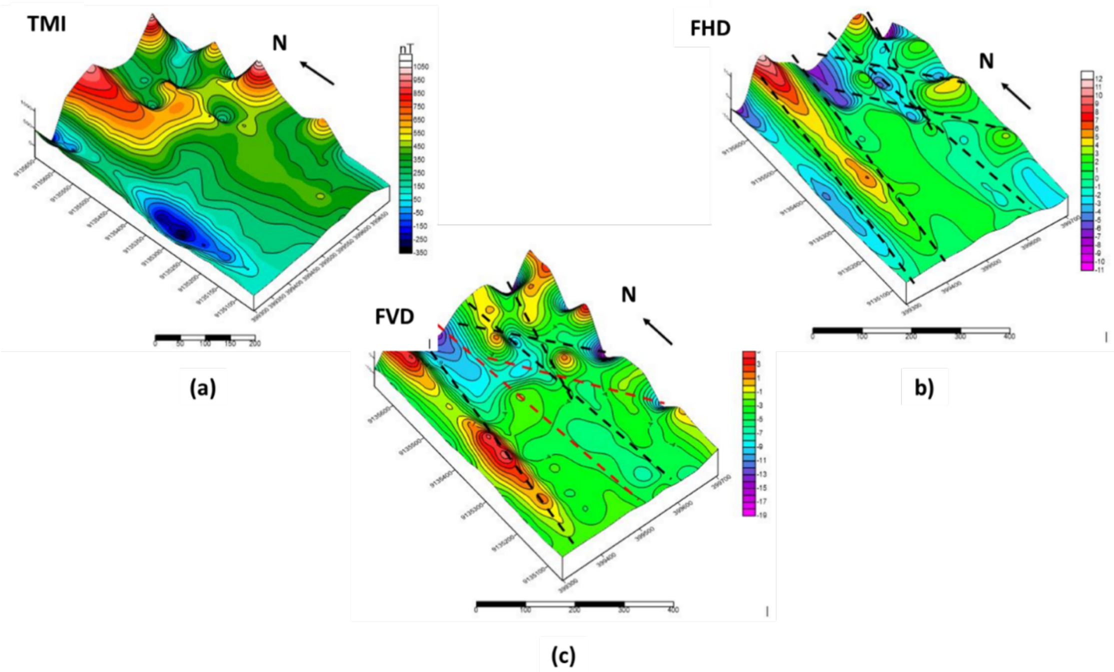

Figure 4. Structural analysis at Kalirejo, Kokap, Kulonprogo based on geomagnetic data (a) TMI, (b) FHD, & (c) VFD.

V. CONCLUSION AND FURTHER RESEARCH

Based on 2D inversion analysis and resistive parameter approach and for the analysis of the slide plane which has the potential to cause landslides in Kalirejo Village, Kokap, Kulonprogo, the following conclusions can be concluded :

1. The resistivity value of each path varies, with the lowest average resistivity value having a value of 15 - 37 ohm.meters interpreted as a water-saturated layer, moderate resistivity values at 38-100 ohm meters are interpreted as rock layers that tend to be weathered, resistivity values height is at a value of 522 - 7200-ohm meters which is interpreted as andesite rock.

2. Fresh andesite rock is thought to be in almost the entire track, it is shown that the alleged andesite is at an elevation of 440 - 320 meters. The tendency of soil mass movement to the east of the trajectory is due to the thickness of the soil which is saturated with water
3. Based on the Horizontal and First vertical derivative maps, it is known that the main fault has a dense North-South relative orientation with values ranging from 0 - (-2) nT/m. The minor fault is interpreted to have a relatively northwest-southeast trending orientation.
4. The research area has a high potential for landslides because it is influenced by the thickness of the unconsolidated sediment that is above the impermeable layer and the fault structure is quite intense.

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