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Abstract. Landslides problems that often occurred at Mertelu Village, Gedangsari District, Gunungkidul Regency, DIY are caused by several factors. In addition to the fact that the village is located in a fairly steep area, there is also a slip surface from the existing soil type. The purpose of this research is to gather the slip surface information based on resistivity method using Dipole-dipole configuration. The initial stage is done by taking 4 representative lines, which each line is 300 meters long, spaced 20 meters and using n = 1-8. The results showed that rock resistivity varied from 2 to 200 Ohm-m also divided into very low, low, medium and high resistivity. The interpretations are very low resistivity (2-8 Ohm-m) as claystones and or siltstones, low resistivity (8-20 Ohm-m) as muddy sandstones, medium resistivity (20-50 Ohm-m) as sandstones and high resistivity (> 50 Ohm –m) as massive sandstones. In general, the bedding begins with a very low resistivity at the top and high resistivity at the bottom. The slip surface is marked as a very low resistivity which lays above a higher resistivity. The landslide analysis indicates that the Gedangsari area is dominated by rotational landslide.

Keywords: landslide, slip surface, resistivity, dipole-dipole configuration

1. Introduction

Landslide is a slide of a rock mass or soil down the slope due to the loss of balance force which caused by several factors closely related to geological conditions. Furthermore, landslide is often defined as the movement of a mass of rocks, debris, or earth down the slope [1,2]. Landslides are a type of ground motion influenced directly by gravity of the Earth. As for other factors are physical and chemical influences. One of chemical influence is the dissolution of clay in sand and conglomerate.

Another factor that can cause the occurrence of landslide is the increase of load on the slope. The added weight of the load on the slopes can occur naturally as well as from human activities. The load increase occurs naturally from the infiltration of rainwater into the soil on the bare slopes (without vegetation cover) in which causing the water content in the soil to increase, the soil becomes water saturated, so that the soil weight increases and the load on the slope becomes heavier. The increase of artificial weight (due to human activities) is caused by the inappropriate use of land. One of the example is the existence of settlements, other is illegal logging that should not be done. Both can make the land located on the slopes become bare so that rainwater will be directly absorbed by the soil [3].

Landslides occur due to the disturbance of the force balance that acts on the slope of shear strenght and shear stress [3]. Landslides are divided into 6 types [4]. First, Translational landslide, which is the movement of soil and rock mass on the slip surface of a roughly planar surface with little rotation or backward tilting. Second, Rotational landslide, which is the slip surface had a shape of concave (Figure 1). Third, Block slide, which is the moving mass consist of a single unit. Fourth, Rockfall, which occurs when large numbers of rocks move downwards by free fall, generally occurs on the very steep slopes. Fifth, Creep, which is a slow-moving landslide type. The soil type is coarse and fine grain. This type of landslide is almost unrecognizable. Sixth, Debris flow, which occurs when the mass of the soil moves driven by water. The flow velocity depends on the tilt of the slope, volume and pressure of the water, and the type of material. The movement of debris flow can occur along the valley and was able to reach hundreds of meters away. In some places debris flow can be up to thousands of meters, ie debris avalanche of a volcano. This particular type of landslide can claim quite a lot of victims.

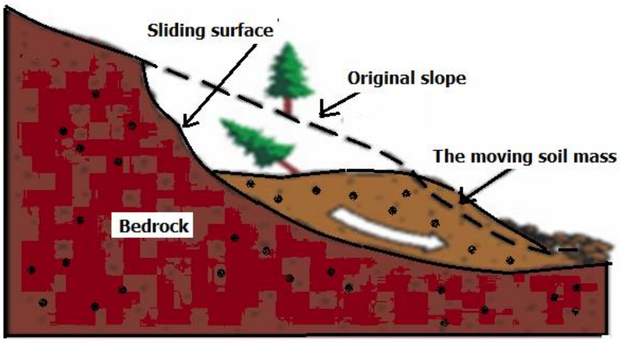

Figure 1. Rotational landslide illustrations on steep slopes.

Landslides occurred in Indonesia usually take place on the steep topography with a slope angle of 15^o – 45^o [5]. According to the Center of Volcanology and Geological Hazard Mitigation (PVMBG), there are 154 districts in Indonesia that have the risk of landslides, especially in Java. Furthermore, it is mentioned that the vulnerability of landslides is increasing with the grow of human activity which is not environmentally friendly. One of the example is deforestation in the hills, even making it an open area for plantations and settlements. Landslide often occurs on slopes with poor soil structure conditions and steep slope geometry, with a factor value of slope stability is less than 1.2[6].

Geoelectrical method is one of the geophysical methods that utilize the electrical properties of the rock. The studies about utilizations of geoelectrical method for environmental and geotechnical problems are already done by many researchers. The mapping of areas vulnerable to landslide based on the boundary of bedding [7]. The application of this method for groundwater contamination [8,9]. Application of resistivity method in the deliniation of avalanches because of the existence of the sliding surface at subsurface. The landslide slopes composed of hard and coherent rock are in general characterized by the occurrence of stress that is different from that of slopes occupied of weathered rock or soil. Slope of soil is much weaker and looser than slope of rock [10]. The stability of slopes occupied by soil are totally influenced by shear strength of the soil, while the stability of slopes composed by rocks, stability is affected by the shear strength of the rock and influenced by the presence of geological structures [2]. The presence of rock discontinuities constituting the slope for some cases often trigger potential avalanche [11,12]. By injecting the current and measuring the voltage difference, the resistivity can be calculated. The resistivity value depends on the type of rock, the presence of water, and the condition of the rock. By using that concept, this research will try to identify the existence of slip surface at some location in Gedangsari District which was estimated to have landslide potential.

2. Location and Morphology Of The Research Area

The research area is located in Mertelu Village, Gedangsari District, Gunung Kidul Regency, Yogyakarta (Figure 2). Morphologically, Gunung Kidul is located in the hills of Mount Sewu at an altitude of 200 - 600 meters above sea level. Some of the districts at Gunung Kidul Regency sustains potentially landslide hazard, namely Gedangsari, Patuk, Semin and Ponjong Districts. Based on the Regional Spatial Planning (RTRW) of Gunung Kidul Regency on the year of 2010-2030, Gedangsari District is the most prone area of landslide hazard which should become a preserved area. One of the factors that determine the landslide potential is the presence of a slip surface on the slopes of the hills. The tilt of slope in Gedangsari District varies from (2-8)%, (8-15)%, (15-25)%, (25-40)% and (>40)%. Most of the area is dominated by a very steep slope, while the gentle slope is occupied on small percentage of area (Figure 3). Even in the research area of Mertelu Village, almost all areas are possessed steep slopes of (25-40)% and (>40)%.

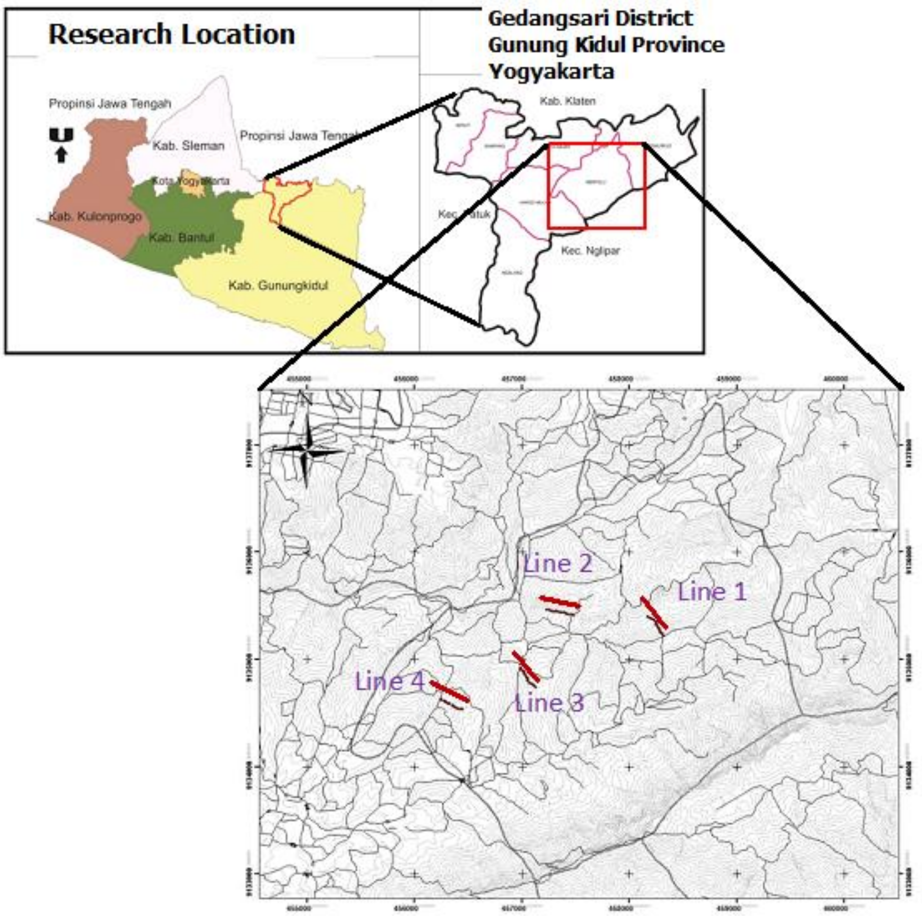

Figure 2. Location of research area in Mertelu Village, Gedangsari District, Gunung Kidul Regency of DIY and lines of data acquisitioned.

3. Methods

3.1 Resistivity Measurement Techniques
Rock resistivity varies greatly which is determined by porosity, water content, and water quality. The higher the porosity of the water-saturated rock, the lower the resistivity is. The water-saturated rock will have a lower resistivity than the dry rock. Based on the assumption that rock can be regarded as a conductor medium, this research is carried out using resistivity method.

The subsurface geology can probably have a form as beddings with different resistivity. The resistivity measurements made on the surface show a results called apparent resistivity [13]. The measurement is done by injecting the current through current electrodes (C_1C_2) on the ground surface and measuring the potential in potential electrodes (P_1P_2) (Figure 3).

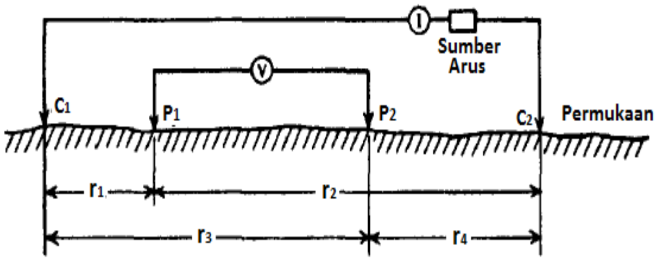

Figure 3. Configuration of current electrodes (C_1C_2) and potential electrodes (P_1P_2) at ground [13].

The apparent resistivity of rocks is calculated by using equation (1).

$$\rho = \frac{\Delta V}{I}\left[\frac{2\pi}{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}}\right] \quad (1)$$

In which ΔV is the potential difference between P_1 and P_2, I is the currents flowed through the current electrodes (C_1-C_2), r_1 is the spacing between C_1 and P_1, r_2 is the spacing between C_2 and P_1, r_3 is the spacing between C_1 and P_2, r_4 is the spacing between C_2 and P_2. The unit of r_1, r_2, r_3 and r_4 is meters, so resistivity of Equation (2) result is in Ohm-m units. The result of this measurement is an apparent resistivity located in the center point between potential electrodes.

Furthermore, there is an equation: $\left[\frac{2\pi}{\frac{1}{r_1}-\frac{1}{r_2}-\frac{1}{r_3}+\frac{1}{r_4}}\right] = K$, called the geometry factor [14] that depends on the spacing and the arrangement of electrodes. By substituting the geometry factor K, equation (1) can be written into equation (2).

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

Equation (2) is the basic formula for calculating the apparent resistivity of rocks. Equation (2) gives the true resistivity when the medium is homogeneous. The geometry factor for the Dipole-dipole electrodes arrangement is written in equation (3).

$$K_d = \pi a n(n+1)(n+2) \quad (3)$$

In which a is the spacing of the electrodes and n = 1 - 8 or more.

The dipole-dipole configuration is often used for mapping purposes which observe changes in resistivity laterally. The determination of a relatively shallow slip surface becomes the target of measurement in this study. The Dipole-dipole final results are resistivity profiles either horizontally or vertically. Thus, in one Dipole-dipole line we will get a 2-dimensional of subsurface resistivity model. This resistivity model will become the basis for conducting analysis and interpretation of the existence of the slip surface.

Geoelectrical data acquisition was conducted in July and August 2017. There are 4 lines which have 300 meters length of each and are located at Mertelu Village, Gedangsari District, Gunungkidul Regency, DIY Province. The parameters of Dipole-dipole configuration used are a = 20 meters and n = 1- 8. The interpretation is estimated to reach a target depth up to 50 meters by using these parameters. The equipments used in the aqcuisition consist of: Resistivitymeter IP Syscal Junior, metal electrodes and porouspot electrode filled with $CuSO_4$ solution and also some supporting equipment.

3.2 The Concept of Pseudosection

The results of field data measurements will present a pseudodepth section which is a vertical cross section of the line where there are plotting points illustrated in different depths based on the position of current electrodes and potential electrodes. The points form an angle of 45° and lay between the center of receiver and transmitter positions which varied with the *n* density (Figure 4). The results of the data processing can be shown in the form of pseudodepth section where the apparent resistivity value depends on the spacing of the electrodes. The penetration obtained at a certain depth provides in Table 1.

Table 1. Depth of points in meters according to [15] for a *a* = 20 meters, *n* = 1-8

n	1	2	3	4	5	6	7	8
Depth (meter) d=(n+1)a/2	20	30	40	50	60	70	80	90

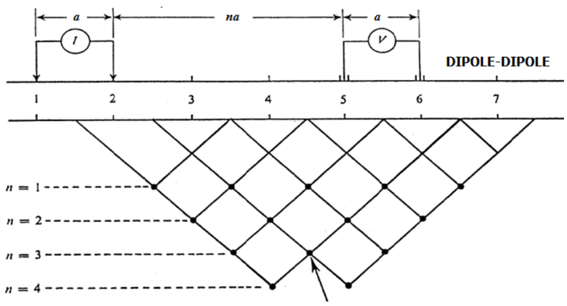

Figure 4. The arrangement of Dipole-dipole electrodes for 2-D geoelectrical survey and the sequence of measurements used to build up a pseudosection.

Plotting and initial processing can be done by using Surfer. The true resistivity on each line is obtained from the modeling by using Res2DInv [16] and the process is 2D inversion. Interpretation is executed by analyzing the characteristics or trend of resistivity value gained from the modeling results of Res2DInv. This trend need to be correlated with the surface geological information. The interpretation results in better understanding of the location of slip surface. The slip surface is usually characterized by a rather striking resistivity contrast which can be from low to high or vice versa.

4. Result and Analysis

4.1. Lithology and the range of resistivity

Res2DInv inversion process produces a true resistivity model of subsurface. The analysis shows resistivity ranges from 2 to 200 Ohm-m. Based on the range of resistivity, the lithology in the study area are divided into four as presented on Table 2.

Table 2. Resistivity range and interpretation of lithology of Mertelu Village, Gedangsari, Gunung Kidul, Yogyakarta.

No	Resistivity range (Ohm-m)	Type	Interpretation of lithology
1	2-8	Very low	claystones and or siltstones
2	8-20	Low	muddy sandstones
3	20-50	Medium	sandstones (with a low resistivity there may be bearing water)
4	>50	High	massive sandstones

Based on the interpretation of lithology, slip surface is the contact between claystones and massive sandstones. However, it is also possible that the slip surface lies under claystones (low resistivity) and above the sandstones (high resistivity). Apart from the difference in resistivity, the existence of slip surface should also be seen from the form and geometry of the contact plane.

4.2 Determination of slip surface

The true resistivity distribution of each line is obtained from inversion process by using Res2DInv [19]. The analysis is performed on true resistivity to determine the geometry of contact between lithology. This geometry of contact between lithology is analyzed to determine the location of the slip surface on each line. The results of all lines are shown in Figure 5.

The resistivity value in Line-1 varies considerably from very low to high. This value shows the four types of rocks beneath the surface. Regarding to the model, it can be concluded that sandstones are quite dominant. In addition, the slope at Line-1 is not too steep, ranging from 20^0 to 30^0. By considering the contact between lithology, the slip surface is positioned on meter of 65 to 105. The form of the slip surface is a curve-shaped from the surface to the depth 10 meters (Figure 5a). Thus, the type of landslide that may occur is a rotational landslide. Vertically, the expanse area of landslide is about 250 m^2. The volume can be calculated by estimating the width of the slip surface. From the slope angle and the area of landslide, the landslide vulnerability in Line-1 is included as medium vulnerability.

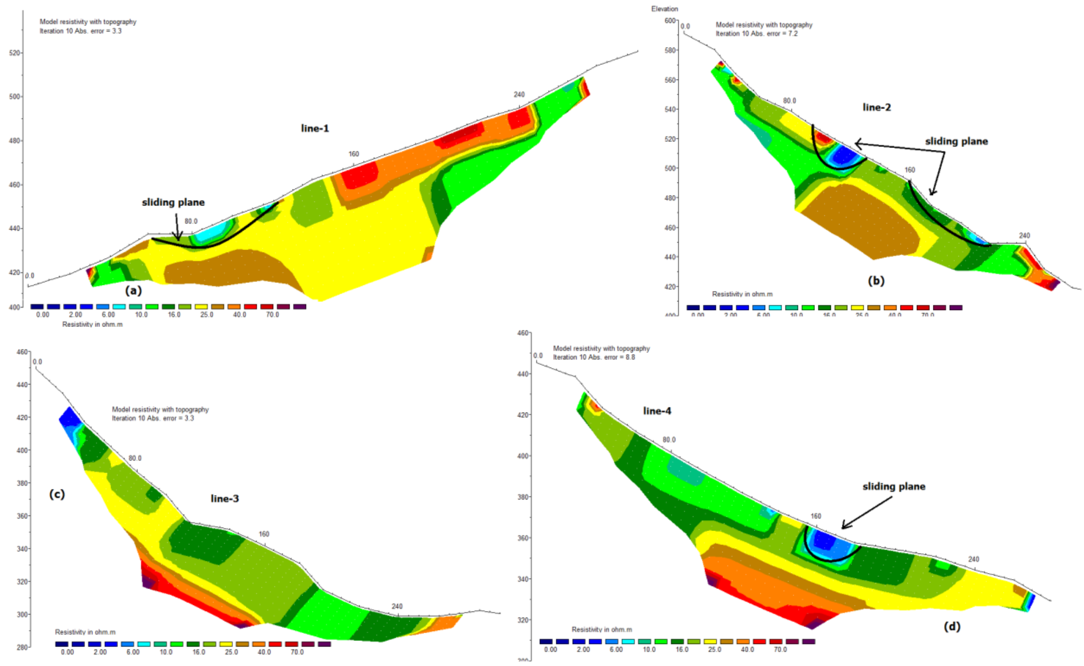

Figure 5. The true resistivity model and interpretation of the slip surface using Dipole-dipole configuration on Line: a) 1, b) 2, c) 3, and d) 4. There is no sliding plane in Line-3.

The resistivity in Line-2 varies from very low to high, with sandstones present dominantly (Figure 5b). The tilt of the slope at Line-2 is quite steep, ranging from 40^0 to 45^0. Considering the geometry of the contact of lithology, 2 slip surfaces are presumed in this line. The first slip surface is situated on the meter of 95 to 135, with a curved shape from the surface to a depth of 20 meters. The expanse area of the landslide of this slip surface is estimated to be about 600 m^2, with the landslide type being a rotational landslide. By looking at the resistivity value, the lithology that is suspected to be able to slide is claystones and massive sandstones. The second slip surface lies in meter of 200 to 225. This slip surface is also curve-shaped from the surface to a depth of about 8 meters, with the expanse area of landslide is about 100 m^2. As in the first plane, the landslide type in the second slip surface is a rotational landslide, with the type of rock that is likely to slide is a claystones laid above the sandstones. When combined between the existence of slip surface, expanse area of landslide and slope angle, the landslide vulnerability of Line-2 belongs to the category of very vulnerable.

As Line-1 and 2, the resistivity in Line-3 varies from low to high, where sandstones are dominant. The angle of the slope at Line-3 is steep enough (40^0 to 45^0) at the top, medium in the middle, and gentle at the bottom (10^0 to 20^0). Regarding to contact between lithology, it is suspected that there is no slip surface existed in this line. There are different patterns with Lines 1 and 2, in Line-3 at considerable depth (40 or 50 meters) there is a bedding with a high resistivity (> 70 ohm-m). The bedding pattern follows the tilt of slope, presumably as massive sandstones. This massive sandstones can be functioned as bedrocks, which at Line-1 and 2 are not detected because their bedrocks lied on the deeper depth. This rock generally can become slip surface, but because it is deep enough and the length of the line is insufficient for analysis of lateral distribution, it is not considered a slip surface in this study. Thus, the conclusions obtained which are on Line-3 there no slip surface existed and the landslide vulnerability included as medium category based on tilt of the slope (Figure 5c).

The true resistivity model of Line-4 shows a sufficiently variable resistivity from low to high. This model indicates four lithology existed on this line. Sandstones is quite dominant based on the results of the inversion model. The tilt of slope at Line-4 is not too steep, only in the range of 20^0 to 30^0. Considering contact between the rocks, it is presumed that there is a slip surface at the position of meter 155 to 190. The slip surface is suspected to be curve-shaped from the surface to a depth of 16 meters (Figure 5d). Thus, the type of landslide that may occur is a rotational landslide. The expanse area of the landslide vertically is estimated to be about 450 m^2. Slope angle and area of landslide show that the category of landslide vulnerability at Line-4 is considered as high vulnerability. There is a pattern of massive sandstones layer such as on Line-3 at a depth of 30 meters from the surface. Using the same analysis as on Line-3, this is not considered a slip surface.

5. Conclussions

The resistivity of the study area varies from (2-200) Ohm-m, which is categorized into four lithology, namely claystones and or siltstones, muddy sandstones, sandstones and massive sandstones. Based on the resistivity and the contact of lithology, it is indicated one slip surface at Line-1, two slip surface at Line-2 and one slip surface at Line-4. Meanwhile, there is no slip surface at Line-3. The results of this research show that landslide type is rotational landslide, with landslide vulnerability order from the most vulnerable is Line-2, 4, 1, and 3 respectively.

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