Application of Soil Resistivity Testing using Geoelectrical Method For Landslide Identification

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Abstract. Vulnerable area is an area whereas landslide materials move. One of avalanche causes is slip surface or shear surface. Geoelectrical Method is measuring potential different of voltage and current caused with electrical current injection into ground through a pair of current electrodes. Potential different is measured through a pair of potential electrodes. This study aims to calculate Resistivity-Values from underground soil layer, so it is used to get soil resistivity map and determine whether an area/road is susceptible for landslide by using Dipole-Dipole Configuration in Geoelectrical Method and Res2Dinv-Software. This research is conducted in Muara Lembu Village, Riau Province as far as 80 meters from both sides of road. Each value of Soil Resistivity can be represented with certain colour of Natural Material. Resistivity-Values from Top Soil at 0.854m–4.62m depths upto Lowest Layer at 11.8m–17.9m depths are smaller. Resistivity-Value from Trajectory-I Top Soil is H>328.5Ωm, whereas A<15.85Ωm Lowest Soil Layer, whereas Trajectory-II Top Soil is H>350.5Ωm and A<21.05Ωm Lowest Layer. Resistivity-Values from both sides of road can be different but Natural Material form them are same. As conclusion, Top Layer upto Lowest Layer of Trajectory-I and Trajectory-II are in Middle-Conductor Range, means these areas are susceptible for landslide.

1. Introduction
Muara Lembu Village is in Kuantan Singingi Regency, Riau Province. Topographically, Muara Lembu located in wavy plateau. This area has many landslide disasters due to unstable soil structure and high rainfall. Rainfall can be a major factor in soil slip activation. The amount of conductivity and resistivity is significantly affected by the water content.

In Geophysics, application of soil resistivity mapping can be analyzed to find if any skid trajectory/field. Skid trajectory/field could be vulnerable soil. Vulnerable soil area is an moving area of many landslide materials. Vulnerable Soil area is one of the landslide causes that very influential.

In general, landslide can occur on a slope is caused by an imbalance between the load and the shear strength of slope compositer material. Ground movement is the transfer of mass of soil, rock, or regolith in upright, horizontal, or sloping direction from the previous position [1].

One of the causes of landslides is the presence of mouldy rocks that move through skid field. Rocks that act as skid field have different resistivity from other rocks [2].

One of the landslide cause factors that very influential is the presence of slippery surfaces. Another factor that also affects the occurred landslide is the slope. Slope can occur when soil is less compactness or thickness during rain. When it rains, rain water will seep and penetrate soil up to the waterproof layer [3].

The principle of Geoelectrical Method measurement is electrical current characteristic under ground and how to detect it on the ground. By this method, potential different of voltage and current...
caused by injected electrical current into earth with a pair of current electrodes are measured. So, the potential differences are measured through a pair of potential electrodes.

Based on this Geoelectrical Method, identification of skid trajectory, is performed to obtain electrical parameter values, deepness and thickness of soil layers in preventing and mitigating landslide efforts in landslide areas using Geoelectrical Method. Therefore, measurement of soil’s deepness and thickness are carried out to get electrical parameter values. The value of soil’s deepness and thickness are revealed in soil resistivity map by using Res2Dinv Software. These values can be used to determine whether a skid trajectory or skid field can be classified as Vulnerable Soil that can cause landslide in that area.

Aim of this research is determine a skid trajectory or field in one area as Vulnerable Soil that can cause landslide in that area based on Geoelectrical Method to measure soil’s deepness and thickness that revealed in soil resistivity map by using Res2Dinv.

2. Literature Review

2.1. Soil Resistivity

Soil Resistivity is important parameter to identify soil characteristic dan its inside content, so condition arounds that soil can be analyzed. Distribution of Resistivity Values under ground are produced based on the ability of rocks to conduct electricity [4].

Generally, Natural Materials in the universe have their own specific resistivity value. The resistivity value can be measured with a geo-electric tool. Electrical characteristic of a rock is characteristic from rock in delivering electrical current. However, it can not be said as electrical medium, so it has Resistivity. Rock Resistivity is obstacle from its rock toward electrical current. Electric current in rock can be classified into electronically conduction, electrolyt conduction and dielectrical conduction [5].

Rock has dielectrical conduction toward electrical current, so rock has a little bit of free electron, even nothing. However, electrical field has impact from outside, so electron in rock moves and gather separately from its core. As a result, polarization occured. Based on Electrical Resistivity Value, rock can be classified into three, namely [6]:
- Good Conductor : $10^{-8} \Omega m < \rho < 1 \Omega m$
- Middle Conductor : $1 \Omega m < \rho < 10^{-7} \Omega m$
- Isolator : $\rho > 10^{-7} \Omega m$

If Resistivity Values from a certain area/road are in Good Conductor range, so this area has small value of Soil Resistivity and it is susceptible toward landslide. If Resistivity Values from a certain area/road are in Middle Conductor range, so this area has bigger value of Soil Resistivity and it is not susceptible toward landslide. If Resistivity Values from a certain area/road are in Isolator range, so this area has biggest value of Soil Resistivity and it is absolutely not susceptible toward landslide.

Electrical current consists of the movement of electrical load that is represented by electrons or ions. The ion itself moves in liquid in the rock pores. The result of research show that electrical current moves through rocks geological formation which are affected by the amount of water very extremely[7].

2.2. Dipole-dipole Configuration

Dipole-dipole configuration is one of geo-electric exploration configurations, whereas distance between current electrodes with potential voltage electrodes is same. Electrode arrangement of dipole-dipole current electrode and potential voltage electrode is separated by $na$ distance, whereas $a$ is the space or distance of its each feet’s electrode ($C2 = C1, P1 = P2$). Dipole dipole configuration is shown in Figure 1 [8].
In this configuration, the current is injected through $A$ and $B$ electrodes. The potential voltage difference is measured through $M$ and $N$ electrodes, whereas Geometric Factor Values of Dipole-dipole Configuration can be calculated using Equation 1 [8].

$$K = 2\pi \left( \frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4} \right)^{-1}$$

$$K = 2\pi \left( \frac{1}{na} + a - \frac{1}{2na + a} \right)^{-1}\left( \frac{1}{na + a} + \frac{1}{2na + a} + \frac{1}{na + a} \right)^{-1}$$

$$K = \pi \cdot an (n+1)(n+2)$$

Resistivity can be calculated by using Equation 3:

$$\rho = K \frac{\Delta V}{I} = \pi \cdot an (n+1)(n+2) \cdot \frac{\Delta V}{I}$$

Whereas:
- $K$ = Geometry Factor
- $a$ = Electroda’s Space
- $n$ = Multiplier number
- $I$ = Injected current (mA)

To increase the penetration depth, so distance between Current Dipole and Potential Dipole is extended, while current electrode distance and voltage electrode distance is fixed. The advantage of this configuration that it is very good for depth penetration. The sensitivity of soil resistivity is very high in horizontal direction, so it can produce deeper 2D longitudinal of soil resistivity [9].

Depth Penetration is measured depth from electrical current injection into ground, so longer disquisition electrode, deeper measured of current and voltage values. Caused of that, obtained resistivity value can be more sensitive. In Geoelectric Measurement, depth of 2D longitudinal plane is determined by configuration shape and electrode disquisition distance that produce deeper depth penetration [9].

2.3. Geoelectrical Method

Geoelectrical Method is one of the Geophysical Methods which aims to determine the electrical properties of rock layers under ground by electrical current injection into the ground. The main purpose of this method is to look for resistivity rocks actually. Resistivity or resistance type is a quantity or parameter that shows level of resistance to electrical current. Rocks that have greater resistivity value, indicate that the rocks are difficult to be flowed by electrical current. Rock resistivity can be measured by inserting an electric current through two electrode points into ground and two other points to measure the potential voltage different at the same surface [4].

If a single electrode flowed electrical current is injected into homogeneous isotropic surface of earth, so flowing current will radiate under ground radially. If the air above the surface has zero conductivity, so potential voltage lines are shaped as half as ball. The shape of potential voltage lines is shown in Figure 2 [4].
Potential Voltage different between $MN$ are caused by current injection in $AB$ from Fig. 1, is calculated by using Equation 4 [10].

$$\Delta V = V_m - V_n$$  \hspace{1cm} (4)

Whereas the factor $4\pi$ becomes $2\pi$ as a result of the current distribution that is only found in half-space as half as ball. In this case, the equipotential current and surface distribution are shown in Fig. 2 [4].

$$A = \frac{I_r}{2\pi}$$  \hspace{1cm} (5)

Obtained:

$$V = \left(\frac{I_r}{2\pi}\right) \frac{1}{r} \text{ atu}$$

$$\rho = \frac{2\pi \cdot \Delta V}{I}$$  \hspace{1cm} (6)

From Equation 4 :

$$\Delta V = V_m - V_n$$

Whereas :

$$V_m = \left(\frac{I_r}{2\pi}\right) \frac{1}{r}$$

$$\frac{1}{r_1} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ \end{pmatrix}$$

$$\frac{1}{r_2} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ \end{pmatrix}$$

$$\Delta V = \left(\frac{I_r}{2\pi}\right) \left[ \frac{1}{r_1} \frac{1}{r_2} \right]$$

$$\frac{1}{r_1} = \begin{pmatrix} 1 & AM \\ BM & -1 \\ \end{pmatrix}$$

$$\frac{1}{r_2} = \begin{pmatrix} 1 & AM \\ BN & -1 \\ \end{pmatrix}$$

$$\rho = \frac{2\pi \Delta V}{I \left[ \frac{1}{r_1} \frac{1}{r_2} \right]}$$  \hspace{1cm} (7)

$$\Delta V = \frac{2\pi \rho}{I \left[ \frac{1}{r_1} \frac{1}{r_2} \right]}$$  \hspace{1cm} (8)

If \( \frac{2\pi}{1 - \frac{1}{r_1} \frac{1}{r_2}} = K \) Equation 8 becomes:

$$\rho = K \frac{\Delta V}{I}$$  \hspace{1cm} (9)

Whereas:
- $\rho_n$ = Pseudo Resistivity (Ωm)
- $K$ = Geometry Factor
- $\Delta V$= Potential Electric Different (mV)
- $I$ = Injected Current (mA)

2.4. Res2Dinv Software

Res2Dinv Software is a computer program that automatically determines the 2D resistivity model under ground based on Geoelectrical al survey data. This program is used to produce rock’s resistivity map underground by displaying the contrast colour that differrent its soil resistivity. As a result, each colour represents a certain range of soil resistivity value [11].

2.5. Literature References

The Geoelectrical Method has been used in various objects and functions. Using Geoelectrical Method, Ulfah [12] and Radulescu et al [7] mentioned that value of subsurface resistivity can be
determined/known. Sy and Budiman [3] revealed that in Geophysics, analysis of soil resistivity application reserves scientific disciplines can be applied in finding slip field which is a vulnerable land. Santoso [11] stated that raw data obtained from results of Geoelectrical Measurements are still the result of apparent Resistivity Values using Res2Dinv inversion software is performed. Lanto [6] revealed that distribution of resistivity values under ground based on rocks ability is to conduct electricity.

In this paper, based on Geoelectrical Method is determined a skid trajectory or field in one area as Vulnerable Soil that can cause landslide in that area by measuring soil’s deepness and thickness that revealed in soil resistivity map by using Res2Dinv

3. Methodology

The research method consists of several stages, namely:

1. Location of research: Geoelectrical data collection is done by measuring values of soil resistivity using Dipole-Dipole Configuration, so Resistivity Values of the soil are obtained. This research was conducted on July 11th – 12th, 2019 in Muara Lembu Village, Kuantan Singingi Regency, Riau Province as far as 80 meters. The trajectory used are both sides of the road.

2. Data processing: After measurements of Soil Resistivity Values, process raw data from the measured V and I values to display maps of soil resistivity results with a different visual colour from each Resistivity Value of the soil layers by using Res2Dinv software. Location of the research can be seen in Figure 3.

4. Results and Discussion

4.1. Trajectory I

This research is held on Muara Lembu Village, Kuantan Singingi Regency, Riau Province. There are two trajectories are discussed in this research. The first trajectory, the 0 m point is at 0º21'59.9”S and 101º20'42.7”E, whereas 80m point is at South Latitude Coordinate 0º22'1.1” and East Coordinate 101º20'41.7”, depth measured based on Res2Dinv software is 17.9 meters with at A < 15.85 Ωm and H > 328.5 Ωm resistivity range value. Mapping of soil resistivity on Trajectory I using Res2Dinv software, can be seen in Figure 3.

Figure 3. Location of the research

Figure 4. Mapping of soil resistivity on Trajectory I
From the Figure 4, Natural Material can be classified based on colour and soil resistivity value. Classification of natural material is shown in Table 1.

**Table 1.** Type of Natural Material Based on Colour and Soil Resistivity Value on Trajectory I

| Resistivity (Ωm) | Natural Material                  | Colour |
|------------------|-----------------------------------|--------|
| A < 15.85        | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 15.85 < B < 26.3 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 26.3 < C < 43.55 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 43.55 < D < 72.15| Groundwater, Marls, Clay, Silt, Alluvium |        |
| 72.15 < E < 119.5| Groundwater, Marls, Clay, Silt, Alluvium |        |
| 11.95 < F < 198  | Volcanic Tufa, Limestone, Andesite  |        |
| 198 < G < 328.5  | Volcanic Tufa, Limestone, Andesite  |        |
| H > 328.5        | Volcanic Tufa, Limestone, Andesite  |        |

Based on the results of soil resistivity mapping on Figure 3 and Natural Material Type in Table 1, can be said that soil Resistivity Values from the top soil to the bottom soil layer are getting smaller. Resistivity Value in top soil at 0.854 m – 4.62 m depths with Natural Material such as Volcanic Tufa, Limestone and Andesite is H > 328.5 Ωm. Resistivity Value in lowest soil layer at 11.8 m – 17.9 m depth with Natural Material such as Groundwater, Marls, Clay, Silt and Alluvium is A < 15.85 Ωm. It can be concluded that top soil layer upto lowest soil layer of Trajectory I is in Middle Conductor range, means this area is susceptible for landslide.

4.2. Trajectory II

This research is held on Muara Lembu Village, Kuantan Singingi Regency, Riau Province. The second trajectory, the 0 meter point is at 0º22'00.5"S and 101º20'40.2"E, whereas 80 meters is at South Latitude Coordinate 0º21'58.1" and East Coordinate 101º20'41.5", measured depth based on Res2Dinv software is 17.9 meters with A < 21.05 Ωm and H > 350.5 Ωm resistivity range value. Mapping of soil resistivity on Trajectory II using Res2Dinv software, can be seen in Figure 4.

**Figure 5.** Mapping of soil resistivity on Trajectory II

From Figure 5, Natural Material can be classified based on colour and soil resistivity value. Classification of natural material can be seen in Table 2.
Table 2. Type of Natural Material Based on Colour and Soil Resistivity Value on Trajectory II

| Resistivity (Ωm) | Natural Material                      | Colour |
|------------------|---------------------------------------|--------|
| A < 21.05        | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 21.05 < B < 33.7 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 33.7 < C < 53.85 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 53.85 < D < 86.1 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 86.1 < E < 137.5 | Groundwater, Marls, Clay, Silt, Alluvium |        |
| 137.5 < F < 219.5| Volcanic Tufa, Limestone, Andesite     |        |
| 219.5 < G < 350.5| Volcanic Tufa, Limestone, Andesite     |        |
| H > 350.5        | Volcanic Tufa, Limestone, Andesite     |        |

Based on the results of soil resistivity mapping on Figure 4 and Natural Material Type in Table 2, can be said that soil Resistivity Values from the upper layer to the bottom layer are getting smaller. Resistivity value in top soil at 0.854 m – 4.62 m depths with Natural Material such as Volcanic Tufa, Limestone and Andesite is H > 350.5 Ωm. Resistivity Value in lowest soil layer at 11.8 m – 17.9 m depth with Natural Material such as Groundwater, Marls, Clay, Silt and Alluvium is A < 21.05 Ωm.

Based on the results of soil resistivity mapping and Type of Natural Material from Trajectory I and Trajectory II, can be concluded that the Resistivity Values from one certain road in both sides (left side and right side) can be different but the types of Natural Material that form them are same from top soil layer (Volcanic Tufa, Limestone and Andesite) upto lowest soil layer (Groundwater, Marls, Clay, Silt and Alluvium). It can be concluded that top soil layer upto lowest soil layer of Trajectory II is in Middle Conductor range, means this area is susceptible for landslide.

5. Conclusion
From obtained soil Resistivity Values and Type of Natural Material Table, each value of soil resistivity can be represented with a certain colour of a Natural Material Type.

The results of the first and second trajectories show that Resistivity Values from top soil layer upto lowest soil layer are getting smaller. Resistivity Value in top soil at 0.854 m – 4.62 m depths of Trajectory I is H > 328.5 Ωm, whereas in lowest soil layer at 11.8 m – 17.9 m depth is A < 15.85 Ωm. Resistivity Value in top soil of Trajectory II is H > 350.5 Ωm, whereas in lowest soil layer is A < 21.05 Ωm at same depth for top and lowest soil layer.

Resistivity Values from one certain road in both sides (left side and right side) can be different but the types of Natural Material that form them are same from top soil layer (Volcanic Tufa, Limestone and Andesite) upto lowest soil layer (Groundwater, Marls, Clay, Silt and Alluvium).

Based on Resistivity Value can be concluded that Top Soil Layer upto Lowest Soil Layer of Trajectory I and Trajectory II are in Middle Conductor range, means these areas are susceptible for landslide.

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