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Study of Soil Stratification in Landslide Areas on Bantuas Road Using the Resistivity Geoelectric Method

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Abstract

A landslide is a natural disaster that often occurs in the Palaran sub-district, Samarinda, East Kalimantan. This sub-district with an area of 221.29 km^2 is considered strategic as a buffer area for the National Capital City (IKN). Construction of toll roads, ports, factories, and housing has begun to be carried out here. However, in Palaran there are still many roads damaged due to landslides, one of which is Bantuas Road. To study soil stratification on the Bantuas Road section, research has been carried out using the dipole-dipole configuration of the resistivity geoelectric method. The data acquisition process was carried out at two locations, namely at the first landslide (STA 7+150) and the second landslide (STA 9+450), with each location consisting of three lines. The data processing uses Res2Dinv software to produce a two-dimensional model. Based on the resulting model, it is known that the landslide area at STA 7+150 is at a distance of 48 to 96 meters with the slip area at a depth of around 11 to 12 meters. Meanwhile, at STA 9+450, the landslide area occurred at a distance of 48 to 80 meters with the slip area at a depth of 8 to 10 meters. The slip area in the first landslide is interpreted to have occurred at the contact area between unconsolidated material and dense sand, while in the second landslide, it occurred at the contact area between weak silty sand and dense sandy clay.

Introduction

Indonesia is one of the countries that frequently experiences hydrometeorological disasters, namely land movement disasters caused by climate and weather changes. According to Sassa *et al.* [1], land movement disasters known as landslides are natural phenomena that are generally caused by rain (57%), induced earthquake vibrations (20%), weathering and erosion (9%), and human activities (6%). Based on this data, rain and earthquake vibrations are the biggest causes of landslides. Rain is related to saturated fluid in rocks which can damage the bonds between grains in the soil. Meanwhile, the vibrational energy that propagates in the rocks will cause movement in the soil grains, and if these grains move on a large scale it will result in damage to the bonds between the grains.

One of the provinces in Indonesia with quite high rainfall intensity is East Kalimantan. The average rainfall in East Kalimantan between 2020 and 2022 was recorded at 3,284.7 mm/year. Meanwhile, Samarinda City, the capital of East Kalimantan Province, is also an area with relatively high rainfall, namely 2,730.7 mm in 2022 [2]. These conditions make Samarinda City very at risk of landslides. Even though Samarinda City is relatively safe from the risk of earthquakes and tsunamis which often claim lives, landslides can also become a serious threat if not handled quickly. Several landslides that have occurred in Samarinda include the Sungai Pinang area [3], the Samarinda – Bontang axis road [4], and the Ring Road II [5]. The potential risk of landslides in Samarinda and its surroundings must of course be a concern for all parties, this is related to the location of Samarinda which is a buffer area for the new National Capital (IKN) of Indonesia.

One of the sub-districts in Samarinda which has a very strategic location is Palaran. This sub-district with an area of 221.29 km^2 [2] is the gateway to IKN with toll road facilities and plans to build a passenger port. Based on these conditions, it is necessary to carry out research to assess the potential for landslides in the Palaran sub-district with a case study on Bantuas Road. This research was carried out as an initial step in the process of mapping areas prone to landslides in Samarinda.

Theory and Calculation

Geological Setting

Based on the geological map sheet of Samarinda [6], the constituent rocks at the research location include the Balikpapan Formation (Tmbp), the Kampungbaru Formation (Tpkb), and the Pulaubalang Formation (Tmpb). According to Supriatna *et al.* [6], The Balikpapan Formation (Tmbp) has a lithology in the form of sandstone and mudstone, intercalated with siltstone, shale, limestone, and coal. The depositional environment is in shallow seas with a thickness of around 800 m. Meanwhile, the Kampungbaru Formation (Tpkb) has lithology in the form of quartz sandstone with intercalations of mudstone, shale, siltstone, and lignite, generally soft and easily crushed. This formation was deposited in a delta and shallow sea environment with a formation thickness of around 700 – 800 m. Furthermore, the Pulaubalang Formation (Tmpb) has lithology in the form of interbedded quartz sandstone intercalated with limestone, mudstone, coal, and dacite tuff. This formation was deposited in a shallow sublittoral environment with a thickness of around 900 m. The regional geological map of the study area is shown in Figure 1.

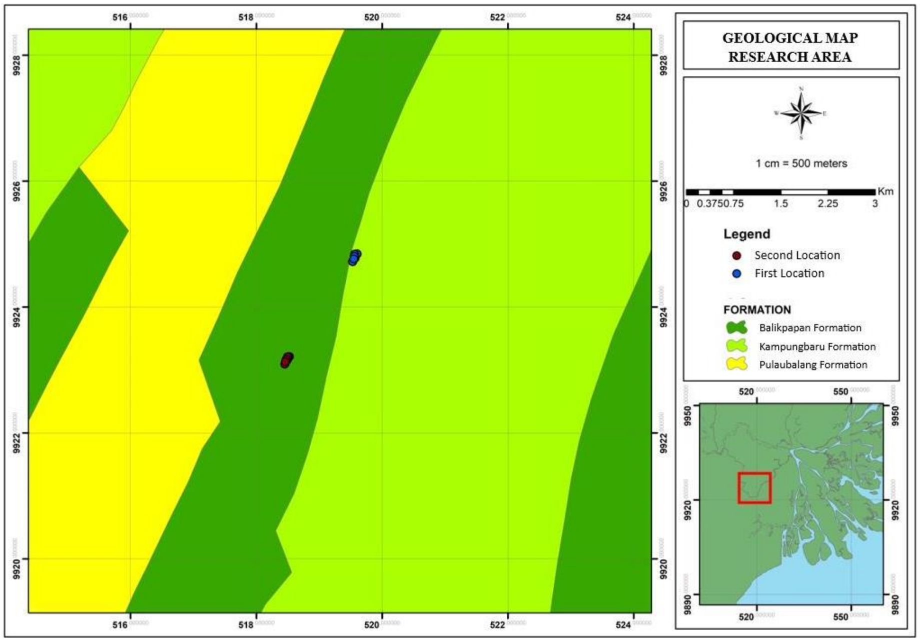


Figure 1. Geological Map of Research Area.

Landslide

Landslides can be defined as the downward movement of soil or rock masses that are caused and triggered by natural factors such as rainfall, rock structure and layering, slope, and vegetation cover. This movement process can be sliding, rolling, falling, or flowing. Landslides usually occur on hilly land and mine excavation areas. Landslides occur because the slope is unstable, so the material/rock on the slope then moves downhill. Slope instability can be caused by several reasons, the main one is the saturation of the material by water. Due to the influence of gravity, water flow that cannot be accommodated, and also the contact boundary between stable and unstable material which is known as the slip area, this unstable material moves down the slope until it reaches an area where the influence of gravity no longer has an impact [7].

Factors that cause or trigger landslides include slope, rock type [8], rainfall [9], disturbance by human activities, and seismic activity such as earthquakes and volcanic eruptions, or any combination of these factors. In Samarinda, which has no volcanoes or a history of earthquakes, rainfall and human activities are the main trigger for landslides.

Geoelectric Method

The resistivity geoelectric method is one of the geophysical methods used to study the resistivity properties of rock layers below the surface. The basic concept of this method is Ohm's Law, namely the relationship between potential voltage *(V)* and electric current *(I)*. The working principle is to flow an electric current into the earth through two current electrodes and measure the magnitude of the resulting potential. Based on the resulting current and potential difference values, the resistivity value of subsurface rocks can be calculated using the following equation [10]:

$$\rho_a = \frac{\Delta V}{I}\, k \tag{1}$$

with parameter k is a geometric factor whose value depends on the distance setting of each electrode.

Several electrode configurations can be used in the resistivity method, namely Wenner, Schlumberger, Pole-dipole, and Dipole-dipole configurations. In this research, the configuration used is dipole-dipole where the electrode arrangement looks like in Figure 2, while the geometric factor (k) is calculated based on equation (2) [10]. In Figure 2, C_1 and C_2 are current electrodes, P_1 and P_2 are potential electrodes, while parameter $\boldsymbol{a}$ is the distance between electrodes, with n = 1, 2, 3, ...

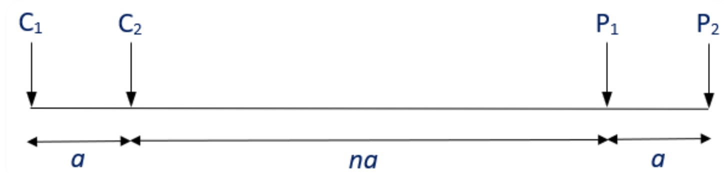


Figure 2. Electrode array for dipole-dipole configuration.

$$k = \pi\, n\, a\, (n + 1)(n + 2) \tag{2}$$

The use of the dipole-dipole configuration was carried out by considering the topographic conditions and vegetation of the research area in the form of bushes. Apart from that, the data acquisition process using this configuration is relatively easy to do with the available equipment. The equipment used in the research is MAE Multichannel Resistivity as shown in Figure 3.

Figure 3. MAE Multichannel Resistivity

The resistivity values of rocks/materials below the surface are not unique, meaning that different materials can have the same resistivity values. Therefore, in carrying out the interpretation, sufficient geological knowledge is required so that the results of the model interpretation are close to the actual conditions. Table 1 shows the resistivity values of various rocks and minerals.

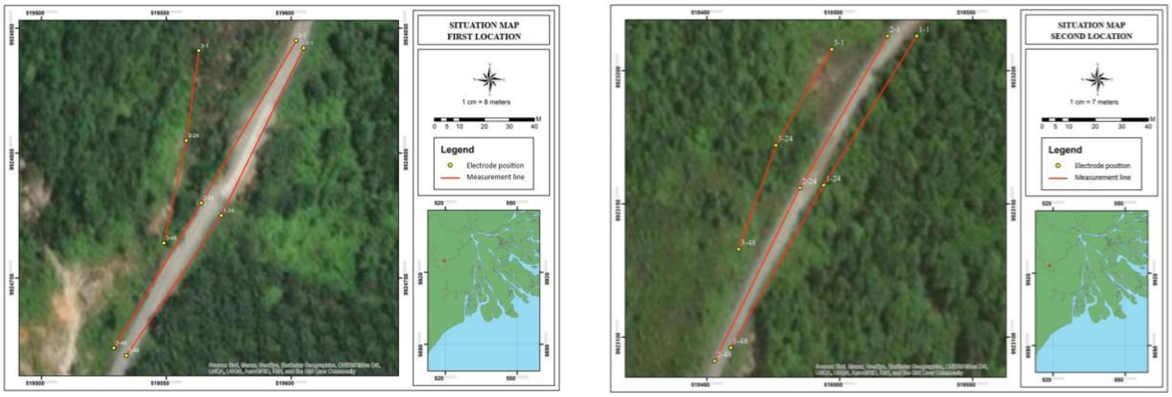
Table 1. Resistivities of common rocks and minerals [10]

Material	Resistivity (Ωm)
Granite	$5 \times 10^3 - 10^6$
Basalt	$10^3 - 10^6$
Sandstone	$200 - 5 \times 10^3$
Shale	$20 - 2 \times 10^3$
Limestone	50 – 400
Clay	1 – 100
Sandy clay	30 – 215
Sand	60 – 400
Alluvium	10 – 800
Groundwater	10 – 100
Seawater	0.2

The resistivity geoelectric method is a method that is relatively easy to carry out both in the data acquisition process and data processing, so this method is widely used for various purposes, not only in Indonesia but also throughout the world. Several studies have utilized resistivity methods, including those used to investigate geothermal sources in Lebong District [11], identify the distribution and thickness of coal [12], estimate the distribution of groundwater [13], and those related to identifying landslides [3, 4, 14–16].

Methods

The data acquisition process was carried out in two locations, namely Bantuas Road STA 7+150 (first location) and STA 9+450 (second location), where each location consisted of three lines. Data acquisition in the field was carried out from 1st to 3rd June 2023, while data processing was carried out at the Geophysics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman. The situation map of the first and second locations is visually shown in Figure 4, with the direction of the line parallel to the direction of the road. On line 1 and line 2, the interval between electrodes is three meters with a total of 48 electrodes, so the track length is 141 meters. Meanwhile, on line 3, the interval between electrodes is only two meters, so the track length is only 93 meters. Complete data on coordinates and spacing between electrodes for the first location and second location can be seen in Table 2.



(a) **(b)**

Figure 4. Situation map of research locations at (a) first location and (b) second location.

Data processing to obtain a two-dimensional (2D) model was carried out using Res2Dinv software [17]. The next step is the process of interpreting the 2D model of each line in the form of contours of the distribution of resistivity values for rocks or subsurface materials. The process of determining rock types based on resistivity values is correlated with geological information obtained from the regional geological map of the Samarinda sheet [6].

Table 2. Data of coordinate and electrode spacing for each location

STA 7+150			STA 9+450		
Line	**Coordinate (X/Y)**	**Electrode Spacing (m)**	**Line**	**Coordinate (X/Y)**	**Electrode Spacing (m)**
Line 01	E01: 519605 / 9924842 E24: 519572 / 9924775 E48: 519534 / 9924719	3	Line 01	E01: 518529 / 9923213 E24: 518494 / 9923157 E48: 518459 / 9923096	3
Line 02	E01: 519602 / 9924845 E24: 519564 / 9924780 E48: 519529 / 9924722	3	Line 02	E01: 518518 / 9923213 E24: 518485 / 9923156 E48: 518453 / 9923091	3
Line 03	E01: 519563 / 9924841 E24: 519558 / 9924805 E48: 519549 / 9924764	2	Line 03	E01: 518497 / 9923208 E24: 518476 / 9923172 E48: 518462 / 9923133	2

Result and Discussion

First Location (STA 7+150)

The 2D model produced at the first location for each track is shown in Figure 5. Based on the model on lines 01 and 02, in general, the soil structure at the research location is composed of three lithologies, namely unconsolidated sandstone, sand, and sandy clay with resistivity values of more than 500 Ωm, 100 – 500 Ωm, and less than 100 Ωm respectively. The resistivity model lines 01 – 03 show similar lithology and structure. The resistivity values in the three models are dominated by values of more than 500 Ωm. This value correlates with the material in the form of unconsolidated sandstone. The soil layer near the surface is less compact rock so it tends to move due to the low cohesive of the soil.

The landslide area in the first location is at a distance of around 48 meters to 96 meters which can be seen in the resistivity cross section of lines 01 and 02. The 2D resistivity model shows a relatively upright stratification pattern where the resistivity value in the landslide area is relatively lower compared to the flanking areas on both sides.

The slip area is interpreted to occur at the contact area between unconsolidated sandstone and sand at a depth of around 11 – 12 meters with a relatively translational pattern. The sharp slope and loose material triggered ground movement in this landslide area. The handling process needs to be carried out by considering the geotechnical properties and slope.

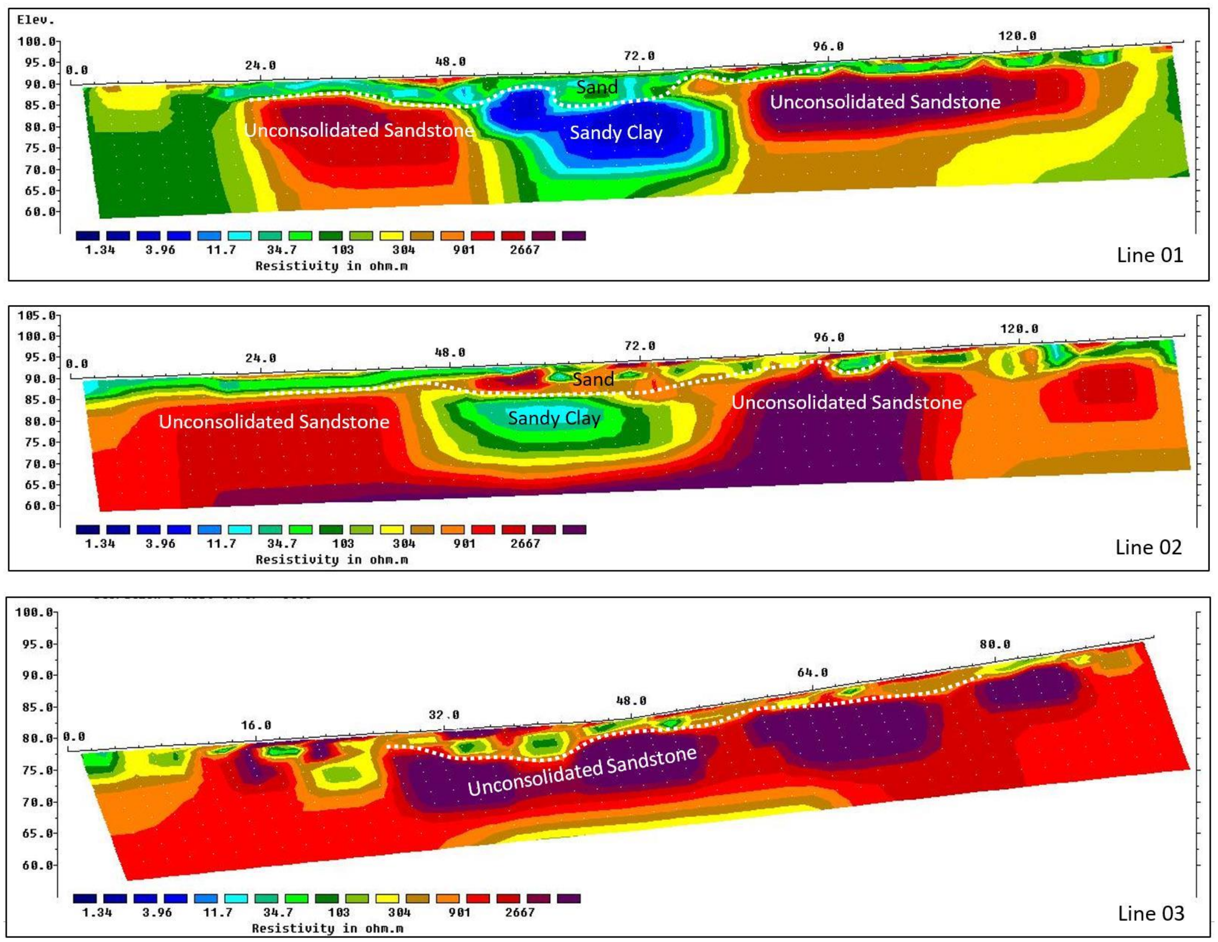


Figure 5. Two-dimensional model for the first location (STA 7+150)

Second Location (STA 9+450)

The resistivity cross-section of the 2D model for the second location (STA 9+450) is shown in Figure 6. In general, the lithology at the second location is still the same as the first location, namely unconsolidated sandstone, sand, and sandy clay. This is because the distance between the first location and the second location is not too far, namely only around 2 km. At the second location, the resistivity value is still dominated by values greater than 500 Ωm which can be interpreted as uncompacted unconsolidated materials, especially those close to the surface.

The landslide area at this second location is at a distance of around 48 m to 80 m measured from the first electrode point (E01). Based on the two-dimensional resistivity model seen in Figure 6, shows that the stratification pattern is no longer continuous because the cracks have been changed.

The slip area is interpreted to occur at the contact area between weak sand and dense sandy clay at a depth of around 8 – 10 meters with a relatively translational pattern. The cause of the landslide is thought to have occurred due to the influence of weak material which is not compacted so it moves easily.

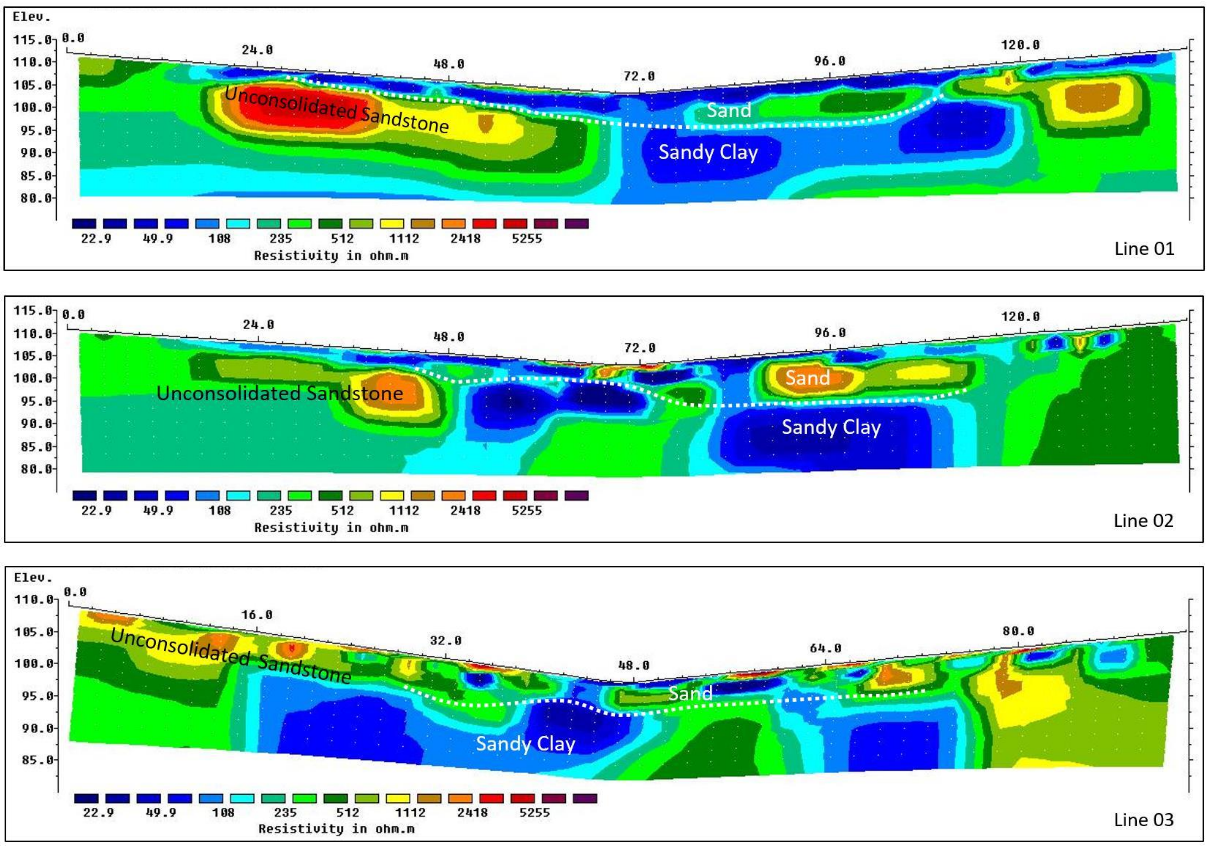


Figure 6. Two-dimensional model for the second location (STA 9+450)

At both research locations, some layers are interpreted as sandy clay. This interpretation is based on resistivity values which are correlated with the geological map of the research area. The clay layer is crucial in a landslide and slope failure occurrence [18], especially in areas with high rainfall such as Samarinda. When the clay layer is wet, it becomes very slippery, which can increase the potential for landslides. With this condition, it is necessary to be aware of the potential for landslides around the research area, considering the large amount of infrastructure development in the Palaran sub-district, as a result of the movement of IKN.

Conclusion

The lithology of the research area, both the first location and the second location, is in the form of unconsolidated sandstone, sand, and sandy clay. At the first location, the slip area is at a depth of 11 – 12 meters which is the contact between unconsolidated sandstone and sand. Meanwhile, at the second location, the slip area is the contact between weak sand and dense sandy clay at a depth of around 8 – 10 meters.

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