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3D modelling of geoelectrical resistivity data to determine the direction of landslides in Kastoba Lake, Bawean Island, Indonesia.

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Abstract: Landslides are one of the factors caused by subsurface structures that are not compact, and have low density or resistivity values due to changes in groundwater. Rainwater that infiltrates into the ground will reach to an impermeable layer which is identified as a slip plane. This research was conducted in the Kastoba Lake area, Bawean Island, Indonesia. The purpose of this study is to determine the slip plane and the direction of the landslide in the studied area. Data acquisition was carried out based on a preliminary study of residual anomaly contour analysis from gravity data, then geoelectric data acquisition was carried out in the studied area. The results of lithological analysis on 3D geoelectric resistivity modeling in this study obtained three layers of subsurface structures, namely topsoil, clay, and lavas. The slip plane of the study area is above the clay layer (7.25 meters depth). The results of the 3D interpretation indicated that the direction of the landslide was towards the north, as evidenced by the existence of public information that the area studied had landslides with the avalanche direction towards the north. For further analysis, a factor of safety analysis is needed based on the analysis of the bore hole drilling method in the studied area.

Keywords: Geoelectrical resistivity, Gravity, Slip zone, landslide, Kastoba Lake.

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Introduction

Disaster is a series of events caused by control factors and trigger factors, causing damage and natural losses. The control factor is a factor that is influenced by the condition of the material. Such as geological conditions, faults, lithology, joint rocks and slopes. Trigger factors are factors that cause material movement such as rainfall, earthquakes, slope foot erosion and human activities. One of the disasters that often occur in Indonesia is landslides. East Java Province which is geologically very complex, natural disasters often occur, especially landslides and land subsidence (Susilo et al., 2021).

The disaster-prone map that has been mapped by the Gresik Regency Regional Disaster Management Agency (BPBD) is one of the government's parameters in disaster mitigation. The landslide hazard or threat map is one of the disaster-prone maps, which is made to determine the risk of landslides and to mark slope areas that have the potential for landslides. On the map, the Kastoba lake area is mostly in the high category of landslide hazard. One of the indication of a

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potential landslide area is the formation of a slip plane along the slope (BPBD, 2021) This slip plane is due to the difference in the top layer which is easily infiltrated into the slope. Infiltrated water often cannot penetrate deep into the soil because there is an impermeable layer that forms the boundary of the slip plane (Muchlis, 2014).

Kastoba Lake on Bawean Island, Indonesia is a tourist attraction that has a high level of vulnerability to landslides. Based on public information, in the Kastoba lake area, landslides have occurred both on a small and large scale (Karimah et al., 2022). Geologically, Lake Kastoba tourism on Bawean Island, Gresik Regency, Indonesia has a stratigraphy composed of the Balibbak (Qv) volcano. Balibbak volcano is a volcanic rock consisting of interspersed lava, volcanic breccia and tuff of Pleistocene age. The Bawean masalembu sheet has a hilly and mountainous morphology with an altitude ranging from 200 to 645 meters above sea level. High weathering conditions and complex geology make the Kastoba lake area prone to geological disasters such as landslides (slide planes) (Aziz, 1993).

Based on the description above, related to the determination of the subsurface structure model using the slip plane, then geophysical methods are used. The geophysical methods used are the gravity method and the resistivity geoelectric method of the dipole-dipole configuration. The gravity method has been carried out previously as a preliminary study on the resistivity data collection. The gravity method has been widely used as a regional study (Hi et al., 2014) and the geoelectric resistivity method has been used as a local study.

Research that has been carried out by Sutasoma (2017) in the Dampit Subdistrict, which aims to determine the boundary of the avalanche slip plane and the direction of the avalanche. The results obtained from 3D geoelectric resistivity data processing namely the depth of the slip plane equal to 10.5 meters and the direction of the landslide to the southeast (Sutasoma et al., 2017). Research conducted by muhajirin (2020) in Pining sub-district, Gayo Lues, obtained the results of the identification of the slip plane located in a thick layer of sediment above the bedrock (arenite) which consists of soil, clay, and gravel that easily absorbs water, causing landslides (Muhajirin, 2020).

The gravity method is used as an initial study, by mapping the contours of the Bouguer anomaly (using satellite gravity data). Anomaly gravity data is carried out to determine anomalies with low, medium and high density. The relationship between the gravity anomaly value and the rock density value namely the higher the gravity anomaly value, the higher the density value of the constituent rocks. This shows that anomaly with low density indicates the presence of cavities or rocks that can accommodate water (Karimah et al., 2020). So that more detailed measurements are carried out using the geoelectrical resistivity method. From the variation of different resistivity values at the measurement point, it can be seen the subsurface layer and the boundary of the slip plane in the studied area (Sutasoma et al., 2017).

This research is expected to have a 3D soil resistivity cross section which aims to determine the boundary of the slip plane and the direction of the landslide in the studied area. This provides recommendations on suitable slope stabilization methods.

Method

Reference studies are carried out with previous studies on landslides that have occurred. Including information on local residents, geology, geomorphology, geological structure, engineering geology, land use, population and others. The steps taken in this research are data collection of Gravity and Geoelectric data, and 3D modeling of Resistivity data.

Data acquisition

GGMplus (Global Gravity Model Plus) Gravity Data Acquisition

The data used is GGMplus gravity data which is downloaded from the website of http://murray-lab.caltech.edu/GGMplus/index.html. The data obtained namely the position of latitude, longitude, elevation, and gravity data which have been corrected to free air correction (karimah et al., 2020). The research was conducted at coordinates 5°45'54" South Latitude - 5°47'20.4" South Latitude and 112°39'32.4" East Longitude - 112°41'06" East Longitude, with the survey design of the research trajectory shown in Figure 1.

Geoelectrical Data Acquisition

Dipole-dipole configuration Geoelectric method is used in data collection in the studied area. The dipole-dipole configuration has the ability to read the subsurface conditions with good sensitivity, both vertically and horizontally (Loke & Barker, 1996). The physical parameters obtained in the acquisition of geoelectrical data are carried out to determine the geological modeling of the subsurface layer (Hasan et al., 2018).

The research was carried out at coordinates 5°46'32.50" South Latitude - 5°46'34.50" South Latitude and 112°40'08.42" East Longitude - 112°40'08.42" East Longitude, with the survey design of the research trajectory shown in Figure 1. The physical parameters obtained are K, i and V (Loke & Barker, 1996).. 3-D results are obtained from data acquisition on 4 intersecting paths. The length of the trajectory obtained ranges from 100 m - 150 m, the electrode space distance is 10 meters, and the measurement is carried out until it reaches the 13th (n) datum point.

Figure 1. Gravity and geoelectrical resistivity data acquisition.

Data Processing

Gravity data processing

The satellite gravity data obtained still requires several processes. First, the latitude correction is performed. Second, the bouguer correction is performed using calculations in Microsoft Excel. Third, terrain correction, and the process of separating regional anomalies and residual anomalies is carried out. Latitude correction was performed using Microsoft Excel. Terrain correction is carried out due to topographic differences, so that upward continuation or separation of anomalies is carried out up to a height of 300 meters above the surface using surfer 12 software. The results obtained from the separation of anomalies namely regional gravity anomalies and residual anomalies (Hirt et al., 2013).

Residual anomaly data obtained are interpreted by considering the geological information of the research area and other supporting data (Hirt et al., 2013). Residual anomaly data (from gravity data) obtained aims to determine low density anomalies, as a preliminary study. Anomalies with low density and geological information of the research area are carried out to determine the landslide area in the study area.

Geoelectrical data processing

The data obtained is in the form of dipole-dipole configuration Geoelectric Resistivity, then the data is processed using Oasis Montaj software to obtain 3D modeling. 3D modeling is carried out based on resistivity data from the result of the oasis montaj software inversion. 3D data is carried out to determine the subsurface layer of the soil, and to determine the distribution of layers that experiencing subsidence horizontally and vertically. The 3D tools interface provides all the 3D mapping tools, functions, and settings. The 3D appearance process is conducted by opening the display/group tools. The 3D Viewer consists of interactive dialogs, with five main Menus which are used to change or edit the 3D view. Oasis montage processing requires a licensed version of the Mapping System to support 3D viewing (Geosoft, 2015).

3. Data Interpretation

Interpretation of gravity data and geoelectrical resistivity data correlated with the geological map of research area of the Bawean and Masalembu sheets. A simple Bouguer anomaly interpretation was carried out to determine the low density value, which was indicated as a permeability layer (Karimah et al, 2020).. The resistivity table and geological map of the research area of the Bawean and Masalembu sheets are correlated with the results of the 3D resistivity data interpretation, carried out to determine the subsurface layer, slip plane boundary and depth. 3D geoelectrical data are interpreted to determine the direction of the landslide in the studied area (fitrianto et al., 2017).

Result and Discussion

Result

Complete Bouguer Anomaly is a gravity anomaly which is generally used for estimating subsurface structures. Based on Figure 3, it can be seen that the complete Bouguer anomaly value range is 97.107 mGal to 43.971 mGal.

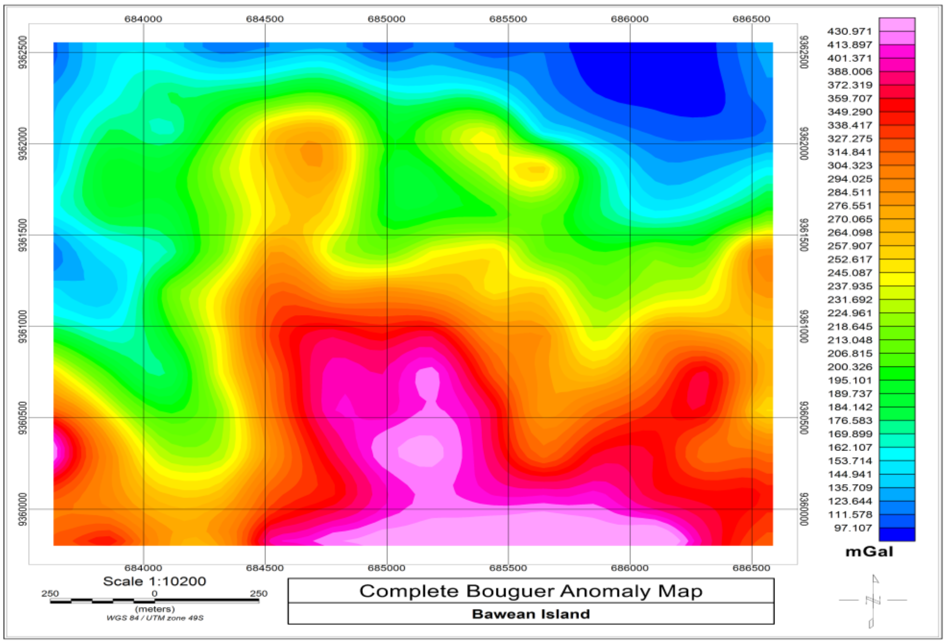

Figure 2. Complete Bouguer Anomaly Map in the Kastoba Lake Area.

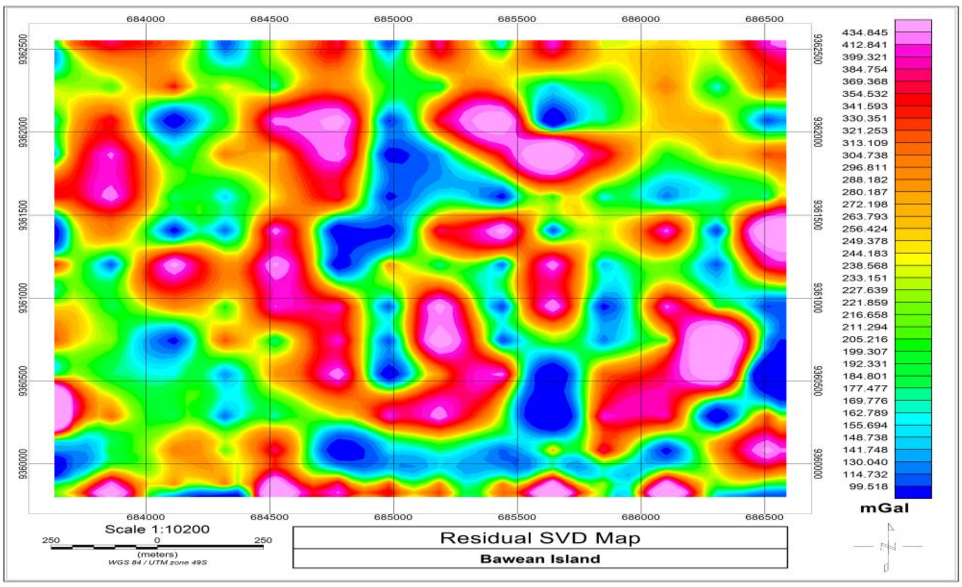

Figure 3. Residual Anomaly Map in the Geotourism Area of Kastoba Lake.

Based on Figure 2, it can be seen that the complete Bouguer anomaly value ranges namely 99.518 mGal to 434.845 mGal. The complete bouguer anomaly values for satellite gravity data can be grouped into 3 categories (table 1). Anomalies with low density are indicated by the presence of cavities or rocks that can hold water.

Table 1. Bouguer Anomaly Value

No	Color/body	Density (mGal)
1		99.518 – 162.776
2		162.776 – 280.187
3		280.187 – 434.845

The physical parameters (from the Bouguer anomaly data) obtained in the gravity acquisition are used as a The data obtained is in the form of dipole-dipole configuration Geoelectric Resistivity, then the data is processed using Oasis Montaj software to obtain 3D modeling. The results of the inversion of 3D geoelectrical data correlated with geological data and reference to determine the geological modeling of the subsurface layer with 3D geoelectrical data. resistivity tables are three subsurface layers. Tuff is indicated as a layer with a high resistivity value, clay is indicated as a layer with a medium resistivity value, and top soil is indicated as a layer with a low resistivity value, along with varying depths.

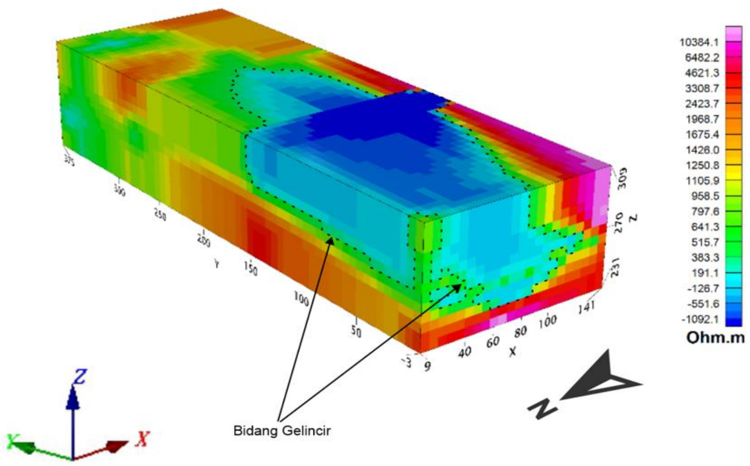

Figure 4. 3D Interpretation

Table 2. Resistivity Value

Rock type	Resistivity (Ωm)	Depth (m)	Thickness (m)
lava	910 - 7500	237 - 275	29.25
clay	90 – 910	240 - 270	31.5
top soil	0 – 90	254 - 284	7.5

Discussion

The results from the residual anomaly map are correlated with the results of the 3-D geoelectric interpretation (as shown in Figure 5) which has continuity. The low density value and low resistivity value have a large porosity, so the correlation of the two methods provides information related to the subsurface structure of the tenntang permeability layer in the study area (Rahmauni, 2014; Rolia & Sutjiningsih, 2018). Based on the results of research conducted by Jinadasa and de Silva (2009), it shows the correlation that low resistivity can be interpreted as underground water. Based on the low density value, resistivity table and geology of the research area, it is found that the constituent materials are top soil, clay and lava rock.

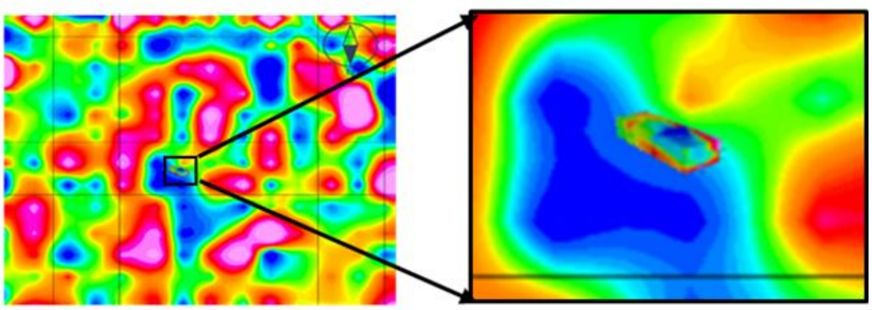

Figure 5. Correlation of bouguer anomaly maps and resistivity 3D results.

Top soil layer indicated as a layer that has a high level of vulnerability to slip planes. The slippery field is a slippery and easy-to-move foundation (Sutasoma, 2017). Based on the results of research conducted by Nuryanto (2019), it shows top soil which is a product of rock weathering mixed with organic material or leaf decay so that the surface in the research area is more easily weathered. In the research area, there are traces of dry river flows. River flows are formed due to the flow of water from below the surface through rock fractures. The low anomaly is due to the fact that the subsurface rocks have been partially filled with water, so that the density of the area is low, according to the relationship between mass density and the value of gravity and the degree of saturation which is directly proportional (Naryanto, 2019). Low resistivity values are marked with a dark blue to light blue color (permeability limit). The most vulnerable areas are in the central area to the west up to the north, the area has the thickest top soil, little/only vegetation cover with shallow roots/banana trees and the soil is very weathered (figure 6 (a)). In Figure 6 (b) the slow flowage is evidence of soil movement caused by water-saturated material (Helmiadi, 2015).

(a) (b)

Figure 6. (a) Vegetation condition of the studied area, (b) slow flowage in the studied area

The results obtained from 3-D processing (figure 4) and visual images (figure 8) are the direction of the slip plane in the study area showing the movement of the soil from south to north which is marked in dark blue to light blue. The slip area of the study area is located at an average depth of 14.5 meters or the boundary between soil and clay. In Figure 7, obtained the volume of the low resistivity value is ± 110x80x70 meters^3.

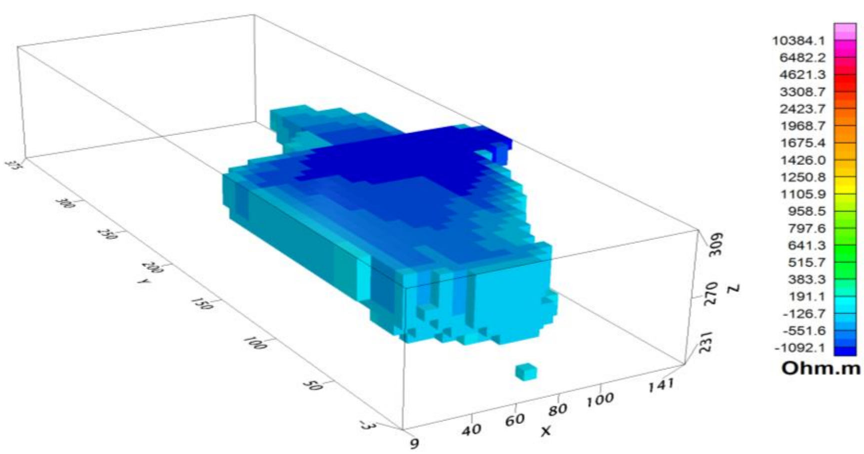

Figure 7. The results of the 3D interpretation of the distribution of low resistivity values.

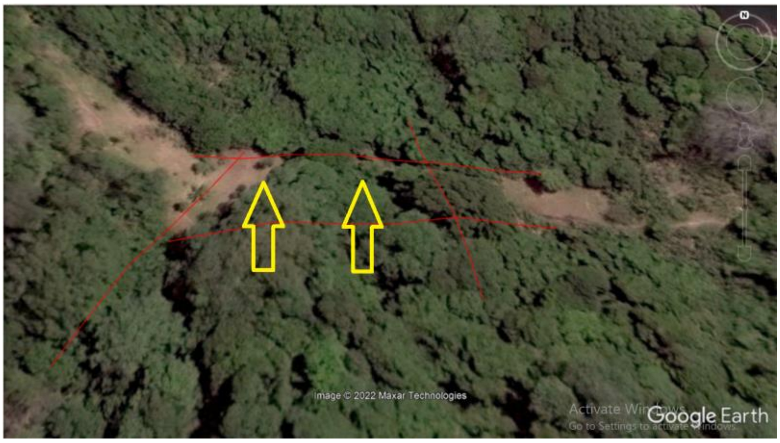

Figure 8. Landslide direction based on visual observation

Conclusion

Based on the contour value of the Bouguer anomaly, the research area has a low density value. The low density value is estimated to be the permeability layer. This is evidenced by public information (about former landslides), the existence of former water flows and has easily weathered vegetation, The research area is estimated to be an area prone to landslides. Based on the interpretation and analysis of the dipole-dipole configuration resistivity geoelectric in the study area obtained 3 types of soil layers namely topsoil, clay and lavas. The slip plane is the plane that forms the basis for the movement of the soil mass. The soil layer that becomes the slip plane in this study is the boundary layer that has a low resistivity (top soil layer) in 3D modeling of resistivity data. The results of 3D interpretation obtained the result of the continuation of the landslide to the east with a depth of ±14.5 meters.

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