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IDENTIFICATION SLIP SURFACE USING RESISTIVITY AND VLF-R MODE IN GOA KISKENDO YOGYAKARTA INDONESIA

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ABSTRACT: In the tourism area of Goa Kiskendo, Jatimulyo Village, district Girimulyo of Kulonprogo, Yogyakarta province which is quite popular for naturally cave tourist destination. In November 2017, there was a landslide that broke the transportation route to the Goa Kiskendo, Yogyakarta-Central Java province tourism area. Based on the Center of Volcanology for Disaster and Geological Mitigation map of soil movement in Girimulyo district, Jatimulyo Village is in the medium to high-risk movement zone. To anticipate aftershocks of a landslide in the same area, it is necessary to map areas that are potentially landslide occurs. For mapping, this area, the geophysical surveys using resistivity method with dipole-dipole configuration and electromagnetic very low frequency (VLF) resistivity mode were conducted in Goa Kiskendo area to identify the slip surface based on the contrast resistivity value. From the results of resistivity data processing, and 3D visualization it is obtained a contrast of different resistance values consist of two layers. The first layer, which is in the range of 10 Ωm-79 Ωm, is identified as soil and the second layer, which is in the range of 0,15 Ωm-10 Ωm is interpreted as water saturated limestone. Water saturated limestone is identified as the slip surface or bedrock in the depth of 3 m – 25 m, and the soil movement when the landslide occurs, the materials will move from the north to southeastward.
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Keywords: Slip surface, Resistivity, Dipole-dipole, VLF resistivity mode

1. INTRODUCTION

One of an area in Java Island is in Yogyakarta Special Region (DIY province) that has high soil movement phenomena is in Kulonprogo. One of the districts in Kulonprogo that has landslide vulnerability is Girimulyo Subdistrict, Sibolong Jatimulyo village (Fig.1). Based on the classification made by PVMBG (Center for Volcanology for Disaster and Geological Mitigation), Girimulyo Subistrict is classified to be the district that potential to have medium-high landslide vulnerability [1]. On November 29, 2017, access to Goa Kiskendo Road, precisely in Sibolong Village, Jatimulyo, Girimulyo Subdistrict, Kulon Progo Regency, DIY province had a landslide due to high rainfall. Goa Kiskendo is a cave in karst area for a tourism destination. which is quite popular for naturally cave tourist destination The collapsed road is 75 m long with a depth of about 1.5 m, as shown in Fig. 2 [2]. The road is the only access road to the tourist area of Jatimulyo that has 9 natural tourism potentials. The road is also the provincial border road between DIY and Central Java. In order to anticipate the next landslide at the same area, it is necessary to map areas that are potentially landslide using a geophysical method such as dipole-dipole geoelectrical and electromagnetic very-low-frequency resistivity mode (VLF-R). These methods are very sensitive to variations in resistivity or conductivity of the medium.

Landslide is one of disaster often occur in Indonesia. Indonesia is located in the tropical climate that has high intensity of rain causing high landslide susceptibility. Landslide is the downward movement from the soils, rocks, and other materials because of the gravitational force [3]. A landslide can occur because of steep slopes, water unsaturated slip surface under subsurface and water-saturated soils on water unsaturated layer (slip surface) [4]. Controlling factors causing a slope becomes susceptible to landslides such as morphology, stratigraphy, geohydrology, and land use [5]. Weathering results from the rocks on the surface form the soil which when the hills or ridges with the slope of > 10^0 has the potential to cause soil movement [6]. Based on geological conditions (Fig. 3), the Goa Kiskendo location is on the Jonggrangan Formation. The main lithology on this formation is limestone. Van Bemmelen [7] described Jonggrangan Formation consist of marl agglomerates and marine tuff-sandstone with molluscs and mudstone with lignite lenses [8].

The higher part consists of reef limestone, globigerina limestone, and marl. The characteristics of the top layer are coral limestone, have complex porosity. Quantitative analysis to calculate the highest coral limestone porosity ever identified is

68.22% (samples with a large variety of fossils) and 44% (samples with low sample variation) [9]. The porosity of this coral limestone is tough to affect the ability of bedrock to absorb water, especially in the rainy season, thus affecting the total resistivity value in the bedrock layer.

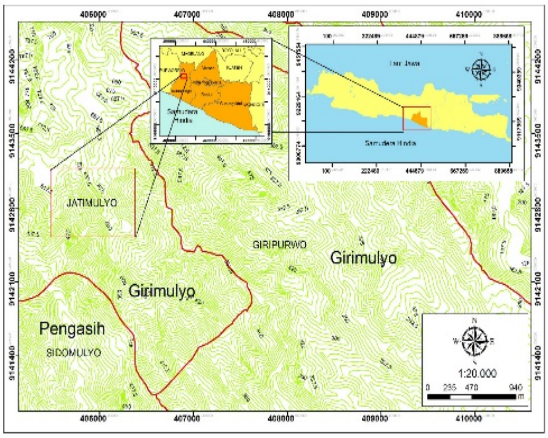

Fig. 1 Study area in Jatimulyo Village, Girimulyo district, Kulonprogo, Yogyakarta province.

Fig. 2 Landslides that cut off the main road to Goa Kiskendo. The ring fence that appears is the upper ring fence of the Goa Kiskendo park [2].

Landslide disaster may cause many risks for human life. It makes people who live in a landslide disaster area to understand, prevent, and overcome natural disasters. Maryanto [10] has conducted a geological survey in Goa Kiskendo to predict the development of their depositional environment. Based on limestone petrography analysis, it shows that Goa Kiskendo is located on Jonggrangan Formation, composed of several kinds of limestone. It is not able to obtain the physical properties of limestone to identify the slip surface. One of the ways to overcome is by mapping, predicting and analyzing the slip surface and the structure of subsurface. Geophysical methods that can be used are resistivity method with dipole-dipole configuration and VLF R-mode method [11].

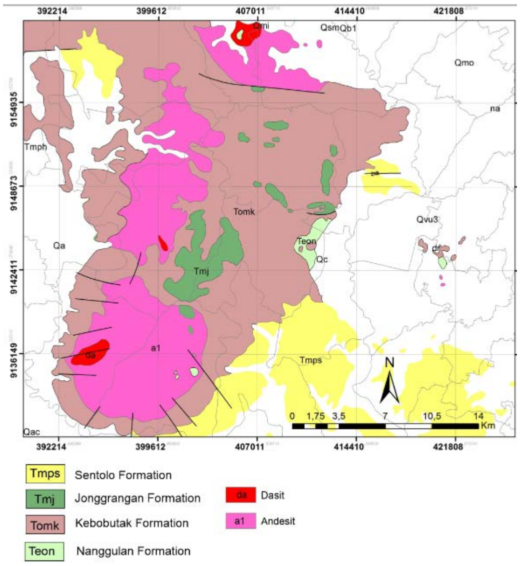

Fig. 3 Geological map of Kulonprogo mountain [8].

2. RESEARCH METHOD

The study in Sibolong, Jatimulyo Village, Girimulyo Subdistrict, Kulonprogo geographically located at 110º07’50,75” - 110º08’01,61” E and 7º44’44,41”-7º44’55,91” S. The research location map and measurement points are shown in Fig. 4.

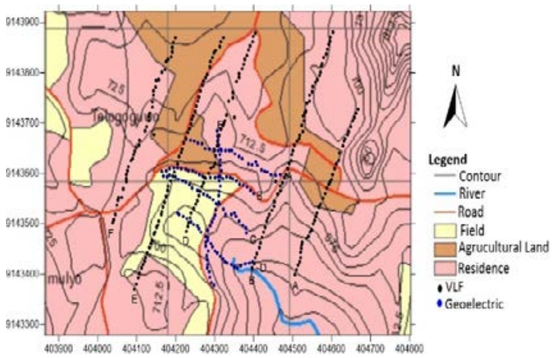

Fig. 4 Line surveys design resistivity and VLF method.

Acquisition data was conducted on five lines for the resistivity method (blue dot). Four lines in the direction of east-west with a length of 250 m. One line in the direction of north-south with the length of 340 m. 2D resistivity method was conducted with dipole-dipole configuration. Two electrodes of current AB and two electrodes of potential MN have the same space 10 m, and then two pairs of electrodes were separated as far as $1 \leq n \leq 6$ [10], n is spacing factor of electode pair. The horizontal position of pseudo resistivity value of measurement results is defined in the middle point of configuration; meanwhile, vertical position is defined in a proportional distance toward distance of electrode extend. The measurement of 2D resistivity method was conducted by using resistivity meter OYO Model 2115 McOHM that has specification such as maximum current reaches 200 mA measurement potential about ±2500 mV.

Some software such as Microsoft Excel, Notepad, Res2dinv and Rockwork.16 to interpret data of 2D and 3D conducted the processing data of the resistivity method. The processing data was used to get data with the lowest error in order to get a geological model that close to the field condition.

S*oftware* RES2DINV [12] is software of the inversion model of 2D resistivity data. All data are used to conduct forward modeling and inverse modeling in the first step, then the comparison result of measured and calculated pseudosection to get RMS error. If the RMS *error* still shows high, it is cut and edited on resistivity. The result of inverse modeling is geological modeling. The geological modeling close to a geological condition in the field, the lower resulted, because RMS error is the comparison of two pseudosections. Meanwhile, the software Rockwork 16 is to visualize and display the modeling result in three dimensions.

An electromagnetic VLF-R mode was carried out in April (7-11 May 2018). Based on the survey design map (Fig. 4), the 5 VLF lines (black dot) are made almost perpendicular to the strike slope, with the N25^{o}E azimuth adjusting to the transmitter used, namely Australia (NWC) with a frequency of 19800 Hz. There are five lines, where the length varies between 400 m-550 m.

Data interpretation using software 2layinv. The 2layinv program is used to interpret geophysical, electromagnetic VLF-R data (resistivity and phase) measured along a single profile at a single frequency. This program utilizes the inverse 1D two-layer earth model, using Occam inversion [13]. The data obtained in the VLF acquisition resistivity mode are apparent resistivity, phase difference, magnetic field, and electric field. While the input data on 2layinv software is apparent resistivity and phase difference.

3. RESULT AND DISCUSSION

Resistivity Method

1. Line A

2D inversion results are apparent resistivity values and the relationship between path length and measured depth in cross section A (Fig. 5). The result of the inversion process is a resistivity cross-section model that describes the actual subsurface resistivity value. The iteration process is carried out 10 times so that shows the condition of the subsurface structure model of the study area.

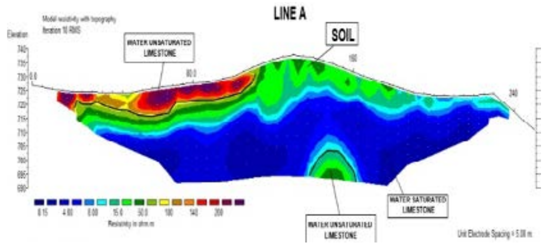

Fig. 5 2D Cross-sectional model of line A.

The 2D resistivity model Fig. 5 shows that the material has a range of resistivity values from 0.15 Ωm to 10 Ωm marked with easy blue to dark blue suspected as water-saturated limestone. Materials with a range of resistivity values of 15 Ωm to 79 Ωm are identified as soil while materials with a range of resistivity values of 80 Ωm to 200 Ωm are marked with orange to dark purple colors thought to be limestone not saturated with water. Outcrops seen in the field at 55 m to 100 m can prove this unsaturated limestone. On cross section A, there is a resistivity contrast between the soil and the water-saturated limestone, this resistivity contrast is identified as a slip field at a depth of 7 m to 10 m.

2. Line B

The first material layer has a resistivity range of 15 Ωm to 79 Ωm identified as soil. Awalani [1] said that the access road to Goa Kiskendo slided along 75 m with a depth of 1.5 m visible on the surface. The measurement results show that the depth of landslides in this line as shown in Fig.6 at a depth of 5 m to 10 m.

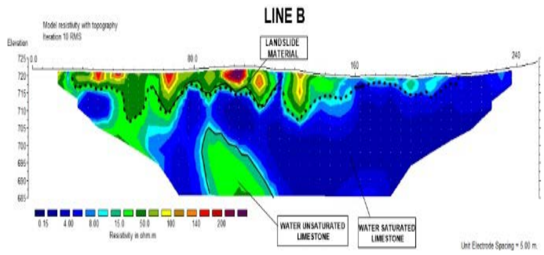

Fig. 6 2D Cross-sectional model of line B.

The second material layer shown on the scale of light blue to dark blue is identified as water-saturated limestone. Water-saturated limestone in this study has a range of resistivity values from 0,15 Ωm to 10 Ωm. This water-saturated limestone has very low resistivity because limestone in the research sites have special characteristics where the surface porosity of the limestone becomes increasingly larger [13]. With this porosity enlarged, the ability of water to fill a material is greater, so that the limestone is filled with water. Water has a very low resistivity that causes the measurement results to show a low response value.

3. Line C

The result of the inversion process is a resistivity cross-section model that describes the actual subsurface resistivity value is shown in Fig. 7. In this line, the soil is identified as a layer on the surface with a range of resistivity values of 15 Ωm to 79 Ωm. The second layer shown in dark blue with a range of resistivity values from 0.15 Ωm to 10 Ωm is identified as water-saturated limestone.

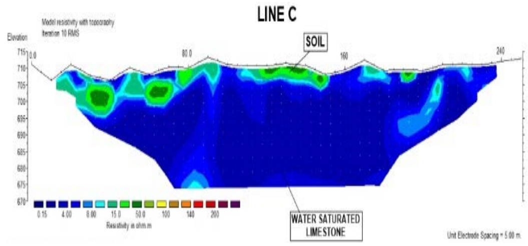

Fig. 7 2D Cross-sectional model of line C

4. Line D.

The layer that has a green to light orange color in Fig. 8 is identified, as soil with a range of resistivity valuesat 15 Ωm to 143 Ωm. Soil seen in this cross-section is a landslide material that experiences movement. Based on the soil resistivity value in this section C, it is suspected that this soil comes from limestone weathering so that it still has a high resistivity.

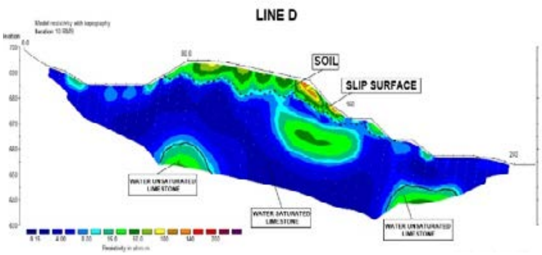

Fig. 8 2D Cross-sectional model of line D

The second layer indicated by a light blue to dark blue is identified as water saturated limestone with a range of resistivity values from 0,15 Ωm to 10 Ωm. the contrast of resistivity values between water-saturated limestone and soil is identified as a slip field in this study. The slip field is visible at a depth of 5 m to 1 m. The third layer with a range of resistivity values of 10 Ωm to 50 Ωm is identified as limestone not saturated with water. This layer is below the water-saturated limestone layer.

5. Line E

Line E is the line that intersects the 4th previous lines is shown in (Fig. 9).

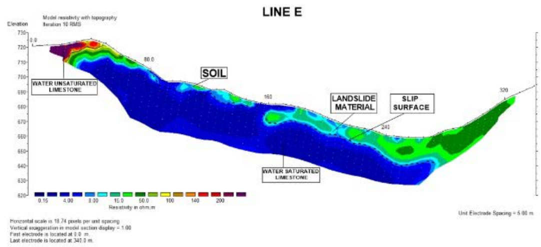

Fig. 9 2D Cross-sectional model of line E

The first layer on the surface with a range of resistivity values of 10 Ωm to 79 Ωm was identified as soil. Soils are identified as landslide material at depth. The second layer is indicated by an easy blue to dark blue scale identified as water-saturated limestone with a range of resistivity values from 0.15 Ωm to 10 Ωm. This water-saturated limestone has a small resistivity because getting to the surface, the limestone in the study area has a large porosity [13]. Water will be easier to fill material that has a large porosity. The slip surface on the E section is seen at a depth of 6 m to 25 m.

6. Visualization in 3D

The five lines can be visualized in three dimensions. The intersection of the five trajectories can be seen in the Fig. 10. Fig. 11 and Fig. 12 are for low resistivity only (soil) and high resistivity only (limestone as bedrock).

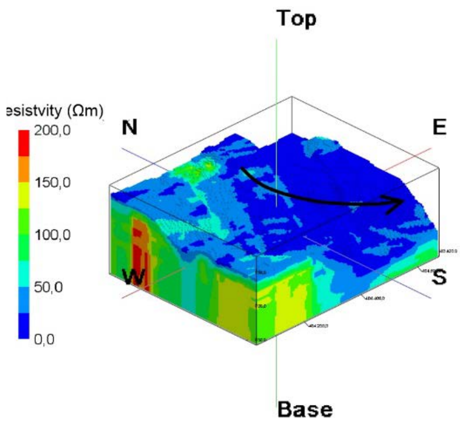

Fig. 10 Five lines in 3D visualization

The Fig. 10 shows the topography of the study area which has a fairly steep slope. The slope becomes the controller of ground movement. Line D and line E are steep slopes. The resistivity contrast is clearly seen on the D and E lines, where the landslide material will moves towards the southeast.

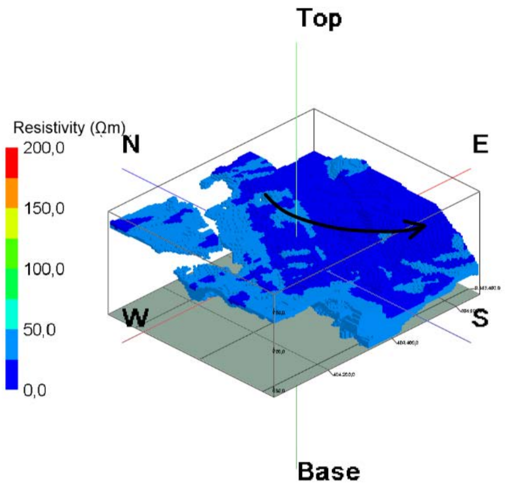

Fig. 11 The low resistivity mass of soil in (1-70) Ωm.

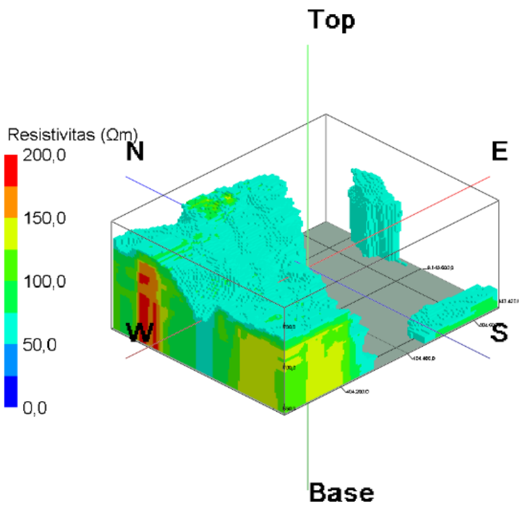

Fig. 12 The high resistivity of bedrock > 70 Ωm.

VLF R-Mode

After processing data using *2layinv* software for 5 lines, including to A, B, D, E and F, we show on Fig. 13, 14, 15, 16, and 17. The interpretation data are based on the assumption that the second layer is more resistive than the first layer.

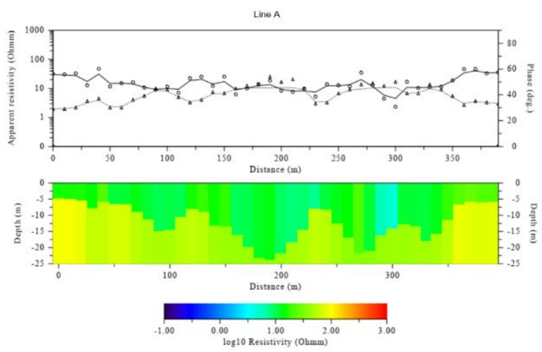

Fig. 13 Survey data and model respond of line A.

Based on pseudosection of 2-D resistivity distribution, line A (Fig. 13), the anomaly is in magenta-blue color areas that are susceptible to ground movement, at a distance of 283 m to 305 m. This fits with the conditions of the field on the steep slope. The resistivity value in the first layer is between 4.70 Ωm to 25.77 Ωm, with a depth of 5 m to 24 m. While the resistivity value in the second layer is 37.08 Ωm to 97.28 Ωm. On line B (Fig. 14), the anomaly is in magenta-blue color, at a distance of 150 m to 450 m, presumably as an area of ground movement. The first layer has a resistivity of 1.07 Ωm to 14.39 Ωm, depth of 3 m to11 m. The second layer has a resistivity value of 24.22 Ωm to 66.25 Ωm.

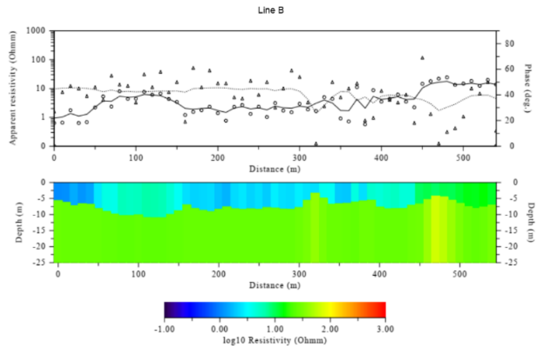

Fig. 14 Survey data and model respond of line B

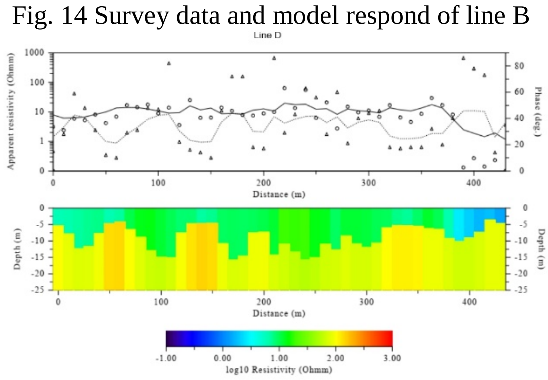

Fig. 15 Survey data and model respond of line D

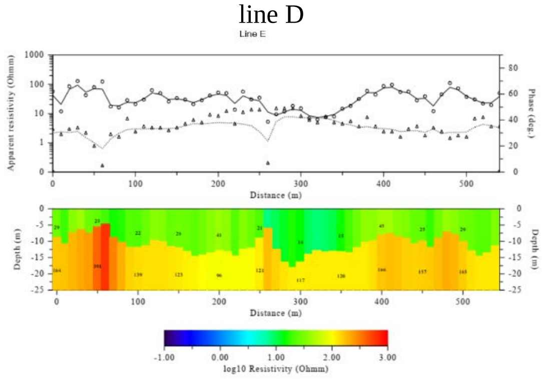

Fig. 16 Survey data and model respond of line E

In line D (Fig. 15), there are two anomalies marked green and blue at distances of 60 m to 375 m, and 375 m to 430 m. The first anomaly is thought to be a zone that is prone to soil movement because of its slope while the second anomaly is obtained due to the presence of a pool of water on the surface.

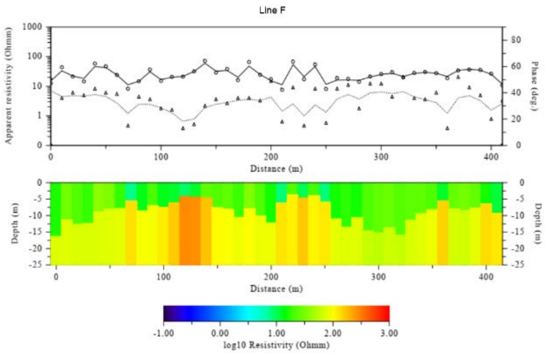

Fig. 17 Survey data and model respond of line F

The first layer in this line has a resistivity value between 1.42 Ωm to 19.17 Ωm, with a thickness of 4 m to 16.7 m. The resistivity value of the second layer, between 53.36 Ωm to 148.59 Ωm. On line E (Fig. 16) and F (Fig. 17) have similarities, the first layer does not appear anomaly because the resistivity value is not significantly different. In line E, the resistivity value on the first layer is 8.16 Ωm to 45.17 Ωm, with a depth of between 3.18 m. While the second layer has a resistivity value of 94.88 Ωm to 637.45 Ωm. In the first layer of line F, it has a resistivity value between 7.88 Ωm to 37.58 Ωm, with a depth of 3 m to 16 m, while the second layer has a large resistivity value of 59.11 Ωm to 284.17 Ωm. Then contour of resistivity 2D model from the five lines in Fig. 18.

Fig. 18 shows the contour of resistivity map, after comparing the elevation contours on survey map design (Fig. 4), a landslide potential is estimated to be around the arrow and material moves toward the southeast, same as the Fig. 10. On the contour map, it appears that areas are estimated to be prone to landslides because have a lower resistivity value than the surrounding area (blue) and on the steep slope. This low resistivity value is tough to correlate with soil resulting from limestone weathering. According to Maryanto [13] the rocks that make the uppermost layer of the Jonggrangan Formation consist of reef limestone, globigerina and marl limestone, which is water saturated because limestone has greater porosity when approaching the surface. Therefore, it is suspected that the surface slip in this research area is coral limestone.

The water saturated of coral limestone is evident on the 2D cross-section of line A, where on line A at a distance of about 60 m to 350 m the resistivity value of the first layer is not significantly different from the second layer. The same thing happened on line B at a distance of 450 m to 550 m.

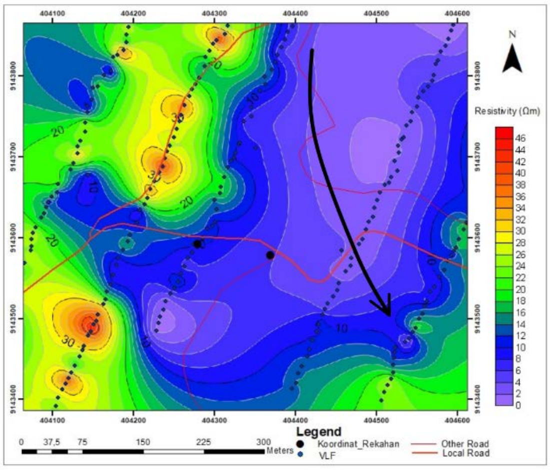

Fig. 18 The contour of resistivity value on the first layer

The result of the resistivity method and VLF method shows the differences. The first layer in the resistivity method shows higher resistivity value than the second layer, conversely for VLF method. This occurs because of differences sources used by these methods, where the resistivity method injects the current in the surface, while VLF uses electromagnetic wave from the radio transmitter to identify the conductivity then covert to resitivity value on the subsurface. After interpolating data by using RES2DINV and 2layin, both methods show the same result the depth of the slip surface. It varies from 3 m to 24 m.

4. CONCLUSION

Based on the resistivity method using dipole-dipole and VLF-R mode, it is obtained a contrast of different resistance values consist of two layers. The first layer, which is in the range of 10 Ωm-79 Ωm, is identified as soil that easily moves to slide and the second layer, which is in the range of 0,15 Ωm-10 Ωm is interpreted as water saturated limestone.

Water saturated limestone is identified as the slip surface or bedrock in the depth of 3 m – 25 m, and the soil movement when the landslide occurs, the materials will move from the north to southeastward. Further research, it is necessary to compare measurements in the rainy season and dry season to get more information about the distribution of resistivity on those layers.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] http://vsi.esdm.go.id (5 Maret 2018). Tabel wilayah potensi terjadi gerakan tanah di kecamatan Girimulyo, Kabupaten Kulonprogo (Online).

[2] Awalani, A, (1 Februari 2018). Ambles, Jalan Goa Kiskendo Tak Bisa Dilalui Kendaraan. Sorot Kulonprogo (Online), halaman1. Tersedia: http://kulonprogo.sorot.com, 2017.

[3] Highland, M. and Bobrowsky, P., The Landslide Handbook A Guide to Understanding Landslides, USGS, 2008, pp. 5.

[4] Paimin, Sukresno, and Pramono, I., Teknik Mitigasi Banjir dan Tanah Longsor. Tropenbos International Indonesia Programme, Balikpapan, 2009, pp. 14.

[5] Karnawati, D, Mekanisme Gerakan Massa Batuan Akibat Gempabumi; Tinjauan dan Analisis Geologi Teknik, dinamika TEKNIK SIPIL, Vol. 7, nomer 2, 2007, pp. 179-190.

[6]. Karnawati, D., Bencana Alam Gerakan Massa Tanah di Indonesia dan Upaya Penanggulangannya. Jurusan Teknik Geologi, Universitas Gadjah Mada, Indonesia, 2005, pp.3.

[7] Van Bemmelen, R.W., The Geology of Indonesia Vol. IA, General Geology of Indonesia and Adjacent Archipelago, Government Printing Office, The Hague, 1949, pp. 598

[8] Rahardjo, W., Sukandarrumidi, Rosidi, H.M., 1977. Peta Geologi Lembar Yogyakarta, Jawa, skala 1:100.000. Direktorat Geologi, Bandung.

[9] Ramadhan, Organism Variety Effect on Carbonate Rock Porosity of Jonggrangan Formation. Majalah geologi Indonesia, vol. 28 No. 2013, pp. 29-40.

[10] Maryanto, S., Sedimentologi Batugamping Formasi Jonggrangan Di Sepanjang Lintasan Gua Kiskendo, Girimulyo, Kulonprogo, 2013, pp.118-119.

[11] Telford, W.M., Geldart, L.P., dan Sheriff, R.E., Applied Geophysics, second edition, Cambridge University Press, London, 1976, pp.293-297 and pp. 343-355.

[12] Loke, M.H. dan Lane, J.R., Inversion of Data from Electrical Resistivity Imaging Surveys in Water Covered Areas, Exploration Geophysics, 2004, pp. 266–271.

[13] Pirttijärvi, Markku., 2LAYINV. Laterally constrained two-layer inversion of VLF-R measurements. The University of Oulu. Department of Physical Sciences Division of Geophysics, 2006, pp.2.