Chapter

Analysis of Landslide and Land Subsident Using Geophysical Method in the East Java Province, Indonesia

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Abstract

East Java Province, which is geologically very complex, often occurs natural disasters, especially landslide and land subsidence. The area of East Java is divided into 3 parts, namely the southern part which is the result of volcanic lahar, and also the uplift from the southern sea. Those two kinds of sediment, geologically is quarter and tertiary volcanic deposits age, and limestone. The Middle part, is a cluster of active volcanoes that are quarter old, which provide quarter-aged sediments and these area is rich in geothermal. The Northern part, which is a sediment from the Java Sea and the Madura Strait, with several limestone mountains, is an area rich in hydrocarbons. The area to be studied is the Southern area, namely the quarter sediment from volcanic lava and the lifting of limestone which has the potential to occur landslides and land subsident. The landslide and land subsident symptoms will be analyzed using the geophysical method, to predict the landslide volume and also the dangerous areas with regard to the land subsident.

Keywords: Sediment, Landslide, land subsident, Geophysical Method, Indonesia

1. Introduction

Indonesia is a country that often experiences hydrometereological disasters, including disasters caused by climate change and weather [1]. The National Disaster Management Agency (BNPB) noted that, in the period of 2020, Indonesia has experienced 2,925 natural disasters, starting from Wednesday (1/1/2020) to Tuesday (28/12/2020). According to data compiled by BNPB, the disasters that occurred throughout 2020 were dominated by hydrometeorological natural disasters such as floods, flash floods, landslides, hurricanes, droughts, forest and land fires. Based on the details of hydrometeorological disaster data, flood events have occurred up to 1,065 events throughout 2020. Disasters caused by hurricanes have occurred as many as 873, landslides as many as 572 events. Furthermore, for forest fires there have been 326 incidents, tidal waves and abrasion have occurred 36 events, and droughts have occurred as many as 29 events. For the types of geological and volcanic disasters,

Figure 1.
Map of East Java [2].

there are 16 and 7 events, respectively. There were 370 people who died as a result of the natural disaster, 39 people were missing and 536 people were injured.

East Java, is one of the provinces in Indonesia, which is on the island of Java. This province is located in the west of the province of Bali and in the east of the province of Central Java, **Figure 1**.

East Java has the largest area among 6 provinces on the island of Java (about 407,803 km^2), and has the second largest population (40.67 million people). Based on province, West Java province has the largest population in Indonesia in 2020, which is 48.27 million people. Meanwhile, East Java province is bordered by the Java Sea in the north, the Bali Strait in the east, the Indian Ocean in the south, and Central Java Province in the west. Several small islands, namely the islands of Madura, Bawean, Kangean and a number of small islands in the Java Sea (Masalembu) and the Indian Ocean (Sempu Island and Nusa Barung) are also the East Java Region.

Administratively, the total number of Districts and Municipalities in East Java is 38, as seen in **Table 1**.

2. Disaster in East Java

Cumulatively, based on calculations from the records of the National Disaster Management Agency (BNPB), from 2013 to 2019, in East Java there have been 2676 hydrometeorological disasters. The details are: floods as many as 743 cases, land-slides 514 cases, drought 66 cases, forest fires 361 cases, tidal waves 22 cases and strong winds as many as 970 cases. When viewed from a case-by-case approach, it can be seen that every year there is an increase in the number of disasters. Between 2013 and 2014 there were about 233 cases, then increased to 297 cases in 2015, increasing again in 2016 by 404 cases, 2017 around 434 cases, 2018 increasing to 455 cases and increasing rapidly in 2019 with the number of cases amounting to 620 cases. The trend of increasing hydrometeorological disasters in each type of disaster has undergone significant changes. This condition can be checked by conducting media studies, by looking for disasters that occurred in the period 2019 to 2020. Around 50 more local journalists wrote about hydrometeorological disasters, from floods, landslides, forest fires, droughts, tidal waves and droughts in East Java.

The East Java Regional Disaster Management Agency (BPBD) revealed that in 2019 there had been floods covering 15 districts, namely: Madiun, Nganjuk, Ngawi, Magetan, Sidoarjo, Kediri, Bojonegoro, Tuban, Probolinggo, Gresik, Pacitan,

No.	Region Name	Capital city	Area
1	District Bangkalan	Bangkalan	1,001.44 kms (2.10%)
2	District Banyuwangi	Banyuwangi	5,782.40 kms (12.10%)
3	District Blitar	Kanigoro	1,336.48 kms (2.80%)
4	Bojonegoro	Bojonegoro	2.198,79 kms (4.60%)
5	District Bondowoso	Bondowoso	1.525,97 kms (3.19%)
6	District Gresik	Gresik	1.191,25 kms (2.49%)
7	District Jember	Jember	3.092,34 kms (6.47%)
8	District Jombang	Jombang	1.115,09 kms (2.33%)
9	District Kediri	Ngasem	1.386,05 kms (2.90%)
10	District Lamongan	Lamongan	1.782,05 kms (3.73)
11	District Lumajang	District Lumajang	1.790,90 kms (3.75%)
12	District Madiun	Caruban	1.037,58 kms (2.17%)
13	District Magetan	Magetan	688.84 kms (1.44%)
14	District Malang	Kepanjen	3,530.65 kms (7.39%)
15	District Mojokerto	Mojosari	717.83 kms (1.50%)
16	District Nganjuk	Nganjuk	1,224.25 kms (2.56%)
17	Ngawi	Ngawi	1,295.98 kms (2.71%)
18	District Pacitan	Pacitan	1,389.92 kms (2.91%)
19	District Pamekasan	Pamekasan	792.24 kms (1.66%)
20	District Pasuruan	Bangil	1,474.02 kms (3.08%)
21	District Ponorogo	Ponorogo	1,305.70 kms (2.73%)
22	District Probolingge	Kraksaan	1,696.21 kms (3.55%)
23	District Sampang	Sampang	1,233.08 kms (2.58%)
24	Sidoarjo	Sidoarjo	634.38 kms (1.33%)
25	District Situbondo	Situbondo	1,669.87 kms (3.49%)
26	District Sumenep	Sumenep	1,998.54 kms (4.18%)
27	District Trenggalek	Trenggalek	1,147.22 kms (2.40%)
28	District Tuban	Tuban	1,834.15 kms (3.84%)
29	District Tulungagung	Tulungagung	1,055.65 kms (2.21%)
30	Municipality, Batu	Kota Batu	136.74 kms (0.29%)
31	Municipality, Blitar	Blitar	32.57 kms (0.07%)
32	Municipality, Kediri	Kediri	63.40 kms (0.13%)
33	Municipality, Madiun	Madiun	33.92 kms (0.07%)
34	Municipality, Malang	Malang	145.28 kms (0.30%)
35	Municipality, Mojokerto	Mojokerto	16.47 kms (0.03%)
36	Municipality, Pasuruan	Pasuruan	35.29 kms (0.07%)
37	Municipality, Probolinggo	Probolinggo	56.67 kms (0.12%)
38	Municipality, Surabaya	Surabaya	350.54 kms (0.73%)

Table 1.
The district and major cities in East Java.

Tranggalek, Ponorogo, Lamongan and Blitar. The worst flooding occurred in the Madiun area. The disaster affected 12,495 families from the population of 15 districts in East Java. In 2019, BPBD recorded areas affected by drought and lack of clean water covering 22 districts, 128 sub-districts and 450 villages. Meanwhile for forest and land fires, where East Java has 8 active volcanoes, forest fires occur when entering the peak of the dry season. The mountains are Arjuna, Welirang, Kawi, Kelud, Wilis, Semeru, Bromo, and Ijen. According to the Ministry of Environment and Forestry (KLHK) there were approximately 23,655 hectares of forest area and land burned in 2019.

In 2020, there are several records related to disasters such as strong winds that hit Ponorogo, landslides that occurred in Lumajang and floods that hit Pasuruan, Mojokerto, Jombang, Madiun and Trenggalek. In 2020, according to data from the Ministry of Environment and Forestry, there were around 19,148 hectares of land and forest burned in East Java. Throughout 2020, there were around 31 regions in East Java that experienced drought and lack of clean water. Meanwhile, in early 2021, East Java was faced with floods that hit several areas, the worst occurred in Jember which almost affected 7 sub-districts.

3. Field site study

This research was conducted in two places, namely Jawar Hamlet, Srimulyo Village, Malang Regency and Banaran Village, Ponorogo Regency, both of which are in East Java. These two areas have experienced land subsidence and landslides, as well as flash floods.

Jawar Hamlet, Sri Mulyo Village, Dampit Subdistrict, Malang Regency is one of the villages prone to landslides in East Java Province [3], Preliminary Study of Landslide In Sri Mulyo, Malang, Indonesia Using Resistivity Method And Drilling Core Data). On January 24, 2006, there was a landslide in the village which caused 1 house to be destroyed, 14 houses cracked on the walls and foundation. In addition, the landslide also resulted in 3 large landslide areas, and 12 small landslides that cut off access to village roads as deep as 60 cm. The area where the landslide occurred, after being examined geologically, was found to be located above weathered breccia rocks that lay on top of the limestone of the Wonosari Formation. When viewed from the angle of inclination, the landslide area actually has a slope of 12^0–20^0 or not too steep. The landslide incident showed that the cause of the landslide was not purely due to the slope, but because the area was located in a gravity fault area, which is thought to have caused the landslide of limestone, which is located at the bottom of the landslide area [4].

The village of Sri Mulyo, Dampit subdistrict (**Figure 2**) is geographically located at 8.2928 ^{0} SL 112.7991 ^{0} EL. Administratively, Sri Mulyo village in the north is bordered by Bumirejo Village, Ampelgading Sub-District in the east, Sumbermanjing Wetan Sub-District in the west, and Sukodono Village in the south. In general, the soil structure in Sri Mulyo village is podzolic soil, where the topography is plains and mountains with an altitude of 400–790 meters above sea level, and the slope of the slope is less than 40%. The average annual rainfall is 5229 millimeters. The majority of the population is coffee and salak farmers.

The second research area is Banaran village. Banaran village is located in Ponorogo Regency, East Java (**Figure 3**). Banaran village has a land area of 2827,713 ha divided into four small villages (hamlet), namely Krajan, Gondang Sari, Tangkil, and Sooro. Banaran Village is one of 18 villages in Pulung District. The locations of Banaran village is: In the west it is bordered by Bekiring Village, Pulung Sub-District; in the east bordering the Tambang Village, Pudak Sub-District; In the north it is bordered by Talun Village, Ngebel Sub-District and in the south by Wagir Kidul Village, Pulung Sub-District.

Figure 2.
Geoelectrical resistivity measurement survey design, Sri Mulyo Village.

Figure 3.
Banaran Village, Ponorogo regency, Indonesia (Google maps, 2018).

One method to analyze a landslide is to use geophysical methods. Geophysical method is a method to determine the subsurface conditions of the earth based on physical parameters. The resistivity method is one of the most widely used geophysical methods in the fields of hydrogeology, disaster mitigation, and archeology [5–9]. Several previous studies has shown that the resistivity method is effective for knowing the subsurface conditions of landslide-prone areas [4, 10–14].

It is important to conduct research in the Jawar Hamlet, Sri Mulyo Village, Malang Regency and Banaran Village, Ponorogo Regency so that the area's vulnerability to landslides is known. This landslide analysis was carried out as one of the disaster mitigation efforts, because the area had experienced landslides in the past. The core drilling method was also carried out to confirm the results of the geoelectrical interpretation, especially for the Jawar hamlet area. The landslide analysis is expected to provide an overview of subsurface conditions supported by Turen and Ponorogo Geological Map, and it can determine the landslide fields as well thickness of landslide potential material at the study site.

4. Method

4.1 Sri Mulyo Village

The resistivity method basically utilizes the electrical properties of the earth, by interpreting the apparent resistivity parameters of subsurface rocks. This method is an active method, where an electric current is injected into the earth through two current electrodes (C1 and C2) then the resulting potential difference is captured by two potential electrodes (P1 and P2). By considering the geometry factor of the configuration used, it can be calculated the apparent resistivity of the rock below the surface.

In this study, the configuration used is dipole–dipole (**Figure 4**). Measurements are made by moving the potential electrode in a path with a fixed current electrode. Next, the current electrode is moved at a distance to the next “n”, which is followed by moving the potential electrode along the cross-section. This is done until between C1 and P1 has a distance of “na”, according to the conditions of the surface in the study area.

The research in Jawar Hamlet, Sri Mulyo Village was carried out in 2015 which is located at the coordinates of $08^{0}18'44,86''$ - 08011′05,16” SL and 112049′22,02″-112041′56,47” WL. There are 5 measurement lines for the resistivity method (**Figure 3**). Lines 1, 2, and 3 with a track length of 180 meters, 200 meters and 100 meters, respectively, and the spacing between electrodes is 10 meters. Lines 1 to 3 are measured from Southeast to Southwest. Line 4 with a track length of 200 meters with an electrode spacing of 10 meters while line 5 with a line length of 300 meters and an electrode spacing of 15 meters. Lines 4 and 5 are measured from West to East.

In this study, drilling points were also carried out. This drilling point is carried out in the red and yellow lines. This core extraction is used as a sample for laboratory tests in determining soil characteristics. Drilling was carried out at two points, namely point 1 located on the 60 meter track line 1 and point 2 located 70 meter line length line 2. The results of the drilling were used as supporting data for landslide analysis for the resistivity method. Geoelectric data processing is done with Re2dinv software. Interpretation is carried out by correlation with the Geological Map of the Turen Sheet.

4.2 Banaran Village, Ponorogo District

The method used in this research is geo-electric resistivity method, sama seperti yang dilakukan di desa Srimulyo. There are many configurations used in this method. In this research, we used a modified Wenner-Schlumberger configuration (**Figure 5**) with fixed electrode potential and the current electrode to obtain Vertical Electrical Sounding (VES). To obtain the lateral direction variation, the VES through interpolation dots are measured. This configuration is the right choice if the desired target is the VES with optimal field effectiveness and reduction accumulation error. Measurements were made at 12 points. The selection of this measurement point is based on the fact that the area is still relatively flat and the results of the interpretation can be correlated from one location to another.

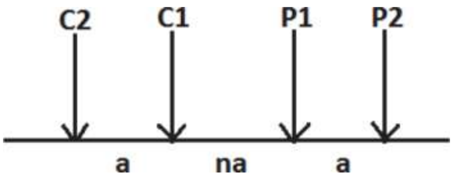

Figure 4.
Dipole–dipole configuration with, “a” spacing between electrodes (m), “ΔV” potential difference (mV), “I” injected current (mA), “n” number of layers, “ρ_a” apparent resistivity of rocks (ohm.m), and “k” geometry factor (m).

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Figure 5.
Distribution of geo-electric resistivity measurement points.

5. Result and discussion

5.1 Jawar Hamlet, Srimulyo Village, Malang regency

Based on the results of resistivity data processing and information on the Turen Sheet Geological Map, it can be seen that Jawar Hamlet, Dampit Subdistrict is composed of three rock layers. The lithology of the local area is composed of clay (9,28–85,8 Ω.*m*), tuff (178–779 Ω.*m*) and breccia (≥ 1629 Ω.*m*). **Figure 6**, is 2D cross-sections of resistivity data processing, where the dotted line indicates the estimated landslide slip area at the study site, and **Figure 7** is 2D cross sectional. The slip plane in this study is the boundary between clay and tuff.

Figure 7 shows the presence of clay dominance on the three parallel lines. It is seen that clay predominates to a depth of about 10 meters below the ground surface. This will result in the weight of the soil during the rain will be even greater, due to the infiltration of rainwater into the soil which does not easily come out, due to the very low permeability of the clay. As a result, the boundary between clay and tuff will become increasingly slippery. If this continues for a long time, and if the slope is not able to withstand a large load, there will be a movement of soil down the slope which is commonly referred to as a landslide. The potential for landslides is also higher because the vegetation above the surface of the research site is in the form of seasonal plants (coffee), whose roots are not too deep. This type of plant (coffee), has roots that are not strong enough to bind soil grains.

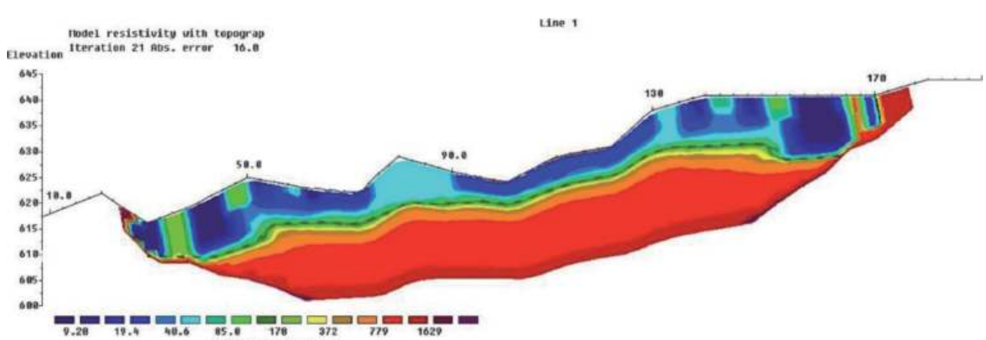

Figure 6.
2D cross section of resistivity line 1.

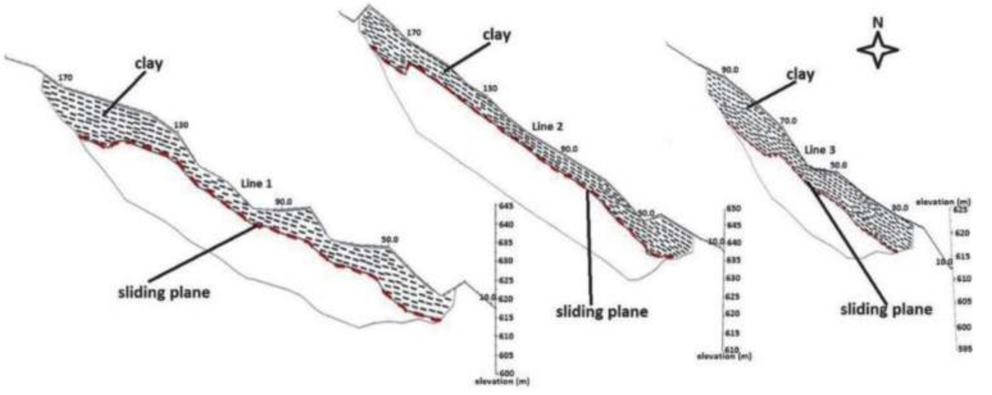

Figure 7.
Correlation of 2D cross-sectional resistivity lines 1, 2 and 3 respectively.

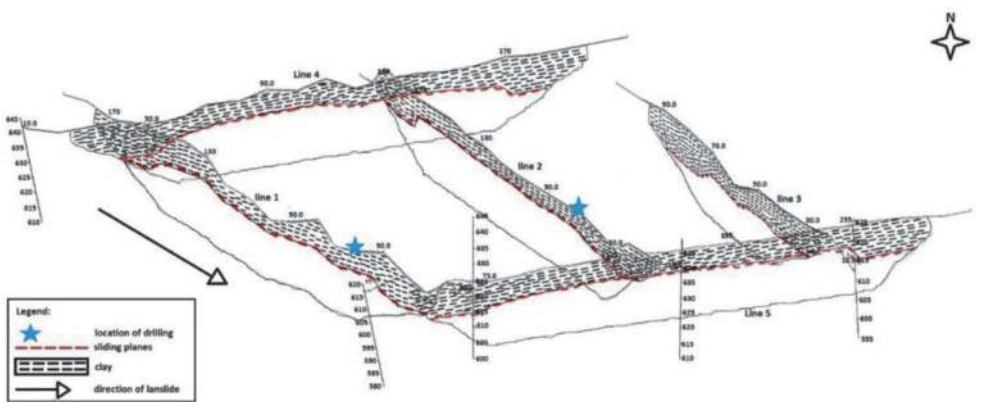

Figure 8.
Correlation of 2D resistivity and drilling points.

Figures 8 and **9** show the correlation between the resistivity data and the drilling data. Drilling was carried out on two measurement lines, namely line 1 and line 2 with a depth of 8 meters, which indicates that up to a depth of 8 meters the soil type at the study site was predominantly clay. This, in accordance with the interpretation of resistivity data from the five measurement lines, indicates that to a depth of about 10 meters, the study site is dominated by clay. The correlation of the five measurement lines shows that the avalanche direction is from Northwest to Southeast this is due to the difference in height between lines 4 and 5. When viewed from the results of the study, that the landslide area is relatively flat and the research location is relatively not steep, then the type of landslide in the research location is likely to be a creep type. This type of avalanche is a type that moves slowly down the slope.

Based on the correlation of all data, the data shows that the potential for landslides in the research location has a high level of vulnerability. This is because the thickness of the clay has exceeded 5 meters with a high average annual rainfall of 5299 mm/year, so this will increase the weight of the soil when it rains. In addition, the carrying capacity of plant vegetation is inadequate at the study site, causing settlements to be unsafe from landslide hazards. The results of this study may be one of the considerations of the local government in disaster mitigation at the research location so as to minimize casualties and losses due to landslides.

5.2 Banaran Village, Ponorogo District

The results of data processing show that the subsurface conditions at the research site are divided into four constituent rocks, namely; clay (0–100 Ω.m,) tuff

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(100–1000 Ω.m), volcanic breccia (1000–3000 Ω.m), and andesitic lava (>3000 Ω.m). The depiction of the interpolation results for several depths can be seen in **Figure 10**. From the analysis results, the subsurface rock at the study site is dominated by clay. The further down, it was detected that the clay became more dominant. This indicates that the landslide material at the study site is very thick.

If the correlation is made for inline points, the following results (**Figure 11**) will be obtained:

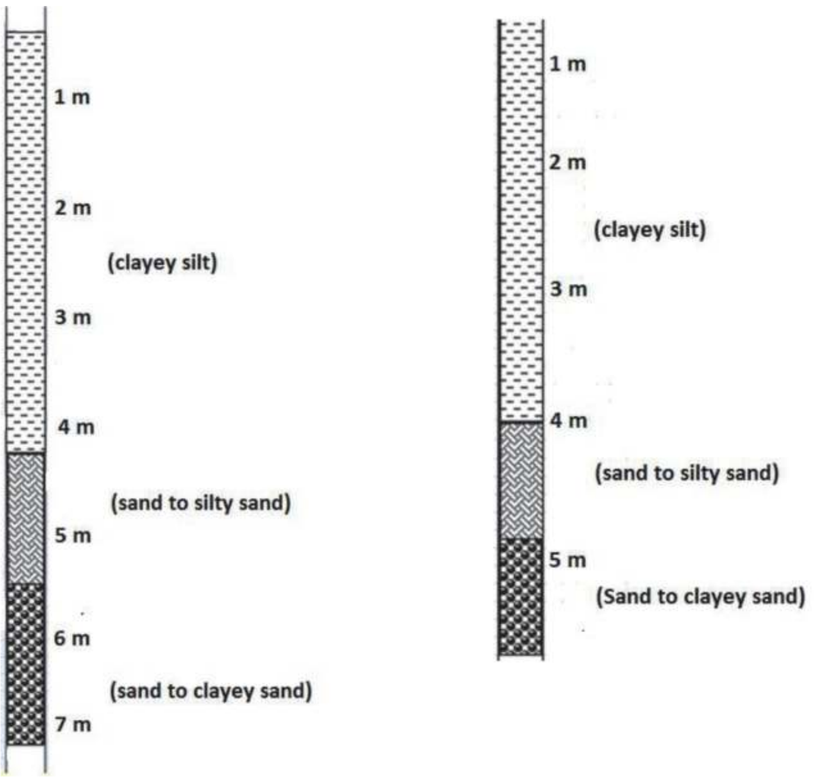

Figure 9.
Soil sample test results (a) line 1 and (b) line 2.

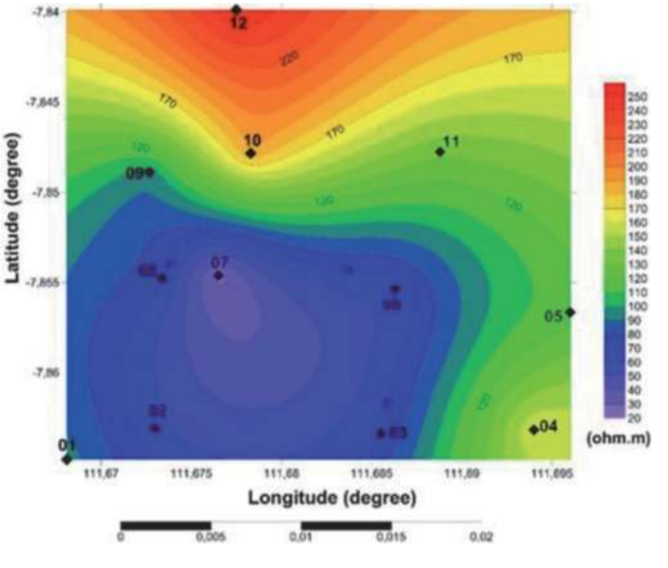

Figure 10.
Contour resistivity at 5 meters depth.

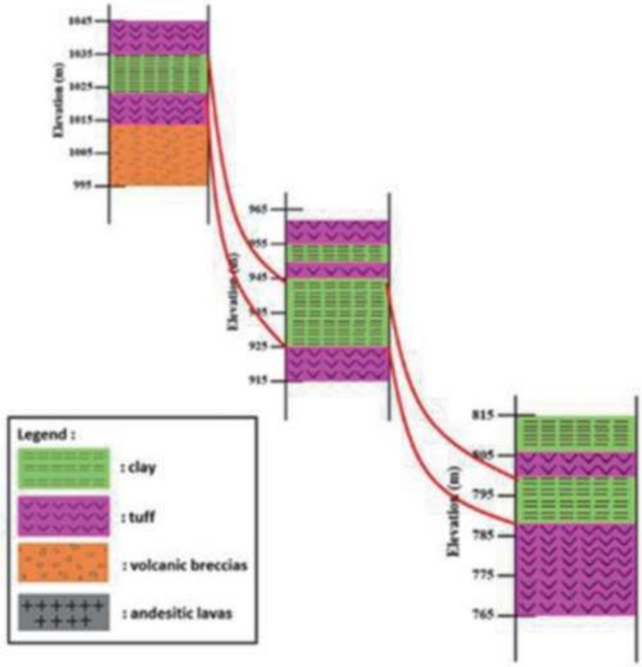

Figure 11.
Correlation of lithology of measuring points 11, 06, and 03 (from top to bottom).

The results of data processing from this resistivity method indicate that the landslide field is located at a depth of 8 to 35 meters. Tuff is indicated as a landslide field. Interpretation of resistivity data for lithological correlation shows that the upper part of the landslide area is dominated by rocks with low resistivity (conductive) and quite thick (5–35 m) which is indicated as clay. Clay is a type of rock that has very small permeability, which is 10^{-7} cm/s. In addition, the research location is a steep slope. From the interpretation of the lithological correlation, the estimated slope of the location is ≥400, and the rainfall was quite high at that time, namely 18.95 mm per day. The length of the rainy month is nine months.

The presence of clay with a thickness of more than 5 meters on steep slopes with high rainfall, will cause greater soil weight, especially when rainwater seeps into the soil. When it is found that the bottom layer is clay, the soil will be saturated with water and can no longer come out, because clay is almost impermeable. In addition, the soil which is dominated by clay will be very prone to landslides, because it is soft and slippery when it rains and cracks when it is hot. As a result, if it rains, the steep slope will accelerate the movement of the soil down the slope, which is known as a landslide. In addition, the use of land in the form of settlements and plantations of seasonal crops, such as ginger, spices and so on, makes plant roots not strong enough to withstand soil movement, and not strong enough to absorb rainwater. So, in the end there was a landslide.

6. Conclusion

The results of this study in Jawar Hamlet, Sri Mulyo Village indicate that the resistivity method can provide a good picture for investigations in locations that have the potential for landslides. The results of the correlation of resistivity data with drilling show that the research location is dominated by clay to a depth of about 10 meters. The level of vulnerability to landslides in Jawar Hamlet, Sri Mulyo

Village is high. The results of the investigation of the location's vulnerability to landslides are expected to be one of the references for the local government in efforts to mitigate landslides. One of the ways to do this is by replacing annual plants to strengthen the binding of the soil grains.

In addition, based on the interpretation of resistivity data, tuff and clay are indicated as slip planes, which are found at depths ranging from 8 meters to 35 meters. The landslide material is the part above the slip plane, which is dominated by clay with a thickness of 5–35 meters. Banaran Village, Ponorogo Regency is an area that is very prone to landslides, based on a landslide-prone area score. Parameters that actively support the occurrence of landslides at the study site are the presence of slip fields, steep slopes, high rainfall and inappropriate land use. Therefore, residents who live in the area are highly expected to be aware of landslides, which can occur at any time, especially during the rainy season. The level of vulnerability to landslides in the Banaran area is relatively high, so it is necessary to relocate residents' settlements around the Banaran area.

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