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THE ANALYSIS OF SLIDING SURFACE IN ALO WATERSHED, GORONTALO DISTRICT, INDONESIA

Abstract. Alo watershed is the sub-watershed within the system of Limboto watershed which directly disembogues to Limboto Lake. Land degradation happened in the Alo watershed is caused by the agricultural system that does not apply land conservation techniques such as terracing and mounds and it triggers erosion and landslide. The method used in this research is geoelectric method with Wenner Alpha configuration; while the data analysis utilizes resistivity imaging method which produces two-dimensional cross-sectional images. In total, there are seven trajectories with a length of 170-180 meters each. The result of the research presents the slip surfaces of 7 locations are located in 3-17 meters depth with the inclination of 11° -79° trending dominantly northwest and one location trending southeast.

Keywords: Alo Watershed, Gorontalo, Sliding Surface

Introduction. There are not many pieces of research covering landslides in Gorontalo province. The latest research shows that the landslides occur in there are rotational slide, planar slide, slide flow, and rock block slide. The landslides are commonly affected by the slope and surface shape of the slope [1]. Alo watershed is the sub-watershed located in Limboto basin system which directly disembogues into Limboto Lake. Alo watershed is one of the largest sediment contributors to Limboto Lake of 0.0342 kg/sec. According to the latest survey conducted by JICA study team, annual sediment volume is estimated around 5.04 x 106 m^3/year (or 5,500 m^3/km^2/year). Therefore, if the incoming sediment volume cannot be controlled, it is predicted that within 25 years the Limboto Lake will be filled with sediment [2]. Alo watershed has the biggest sediment contribution of 947,187.87 ton and its SDR reaches 0.59. It reveals that 59% of the eroded sediment will get into Limboto Lake. As the result, the lake will be a land because of silting process. Alo watershed located on Tibawa sub-district has various levels of erosion ranging from very low, low, medium, and high risk. The trigger of these levels of erosion risk is inappropriate utilization of the land [3].

According to the Regional Geological Map of Tilamuta Sheet, scale 1:250,000 [4], Alo watershed is composed from tertiary and quaternary rocks. The rock formations in the Alo watershed are Diorite Bone (Tmb), Bilungala volcanic rock (Tmbv), Dolokapa Formation (Tmd), Pinogu Volcanic Rock (TQpv), and Reef Limestones (Q1). Referring to the latest research, the name of new limestone formation is Limboto Limestone Formation. This formation consists of two to three microfacies with shallow marine paleobathymetry that have undergone tectonic uplift [5,6]. The slope on Alo watershed is dominated by gentle slopes with slopes ranging from 8 – 15% with a percentage area of 3.14%, and slopes of 15 – 25% are 25.74%. Land usage in Alo watershed is dominated by arid agricultural land with an area percentage of 38.07%, secondary forest of 21.29%, plantation of 14.78%, shrubs of 20.30%, paddy field of 4.17%, and residential area of 1.38%. In general, the practice of agricultural land management in this area has not applied a land conservation technique. The social condition of Alo watershed community in terms of educational level, education level of people residing in Alo watershed is said to still low. Many people agree that farming areas are open. In addition, many people do not quite know about erosion, but many claims to know about erosion. Habits are carried out from generation to generation in cultivations / agricultural practices. There are 78% of the people living in the Alo watershed who agree to log to create farming areas. In cultivating agricultural area, 86% of farmers do not make changes in land cultivation practices and only 14% of farmers follow the advancement of land processing techniques [7].

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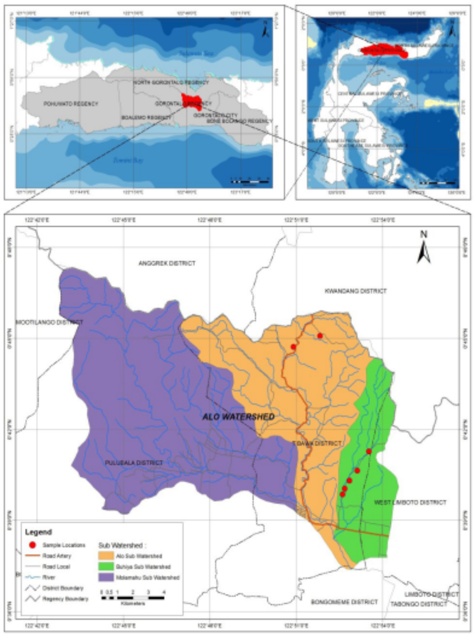

Figure 1. Map of research location in Alo Watershed, Gorontalo District

Methodology. The Alo watershed in the Gorontalo district, with an area of 24,222.41 acres, located at the coordinates of N 00o44' 52.715" and E 122o 49' 33.206' to N 00o 39'59.192" and E 122° 49'12.778" shall be chosen as the research site. The sampling location is in the Tibawa and Limboto sub-districts (Figure 1). Research data is a slip surface that occurs in the Alo sub- watershed. The measurement itself is conducted in seven locations, namely North Isimu Village and Labanu Village, Tibawa Subdistrict, Gorontalo District. Geoelectric measurements are carried out using the Electrical Resistivity Tomography (ERT) method to estimate the boundary or sliding surface below the surface. The ERT method is often used for landslide investigations because the main factors affecting resistance are soil type, porosity and water content [8,9,10,11].

ERT can present 2D and 3D cross-sections of soil and rock resistance distribution, with maximum resolution and depth of measurement depending on the configuration of the electrode [12]. The depth measurement target that can be achieved is approximately 1/5 of the maximum stretch length, i.e. the distance from the first electrode to the last electrode in one line [13]. One measurement line uses the Wenner-Alpha electrode configuration with a stretch length of 180 m for a depth target of about 35 m. Additionally, the acquisition of ERT measurements uses the Wenner-Alpha electrode configuration. The data analysis technique used in this study was a 2D inversion using the 3.54.44 version of RES2DINV based on the least - squares optimization method [14]. Landslide field analysis was performed by adding topographic data to the 2D inversion model using the RES2DINV program [15]. In addition, drill holes BH-01 and BH-02 were added for the calibration and correlation of subsurface resistance prices.

Result and Discussion. The measurement result of the resistivity value and rock type at the research location are shown in Table 1. The data in Table 1 shows that the rock types at 7 locations consist of clay, gravel, sand, limestone and dacite.Geoelectric measurement in research area refers to the inversion result of 2D resistivity imaging on the lines in seven location shown in Figure 2.

Location 1: Geoelectric measurements at location 1 are in North Isimu Village, 180 meters long, with a southwest-northeast trend. The slip plane is usually characterized by a contrasting field between high and low resistance values. Based on the rock resistance value, the slip plane at location 1 is estimated to be in the limestone layer as a layer with a high resistance value. The upper layers of the slip plane with resistance values of less than 674 Ωm were detected or suspected to be clay, gravel and sand layers. The limestone layer, which is a boundary plane or a slip plane, is detected at a depth of about 5-7 meters and has a high resistance of between 674-10,950.5Ωm with an apparent slope of about 8° to the southwest. On the basis of the apparent slope, the actual slope is 47° to the northwest.

Location 2: Geoelectric measurement at location 2 is at North Isimu Village, 180 meters long, with a south-north trend. Based on the rock resistance value, the slip plane at location 2 contains layers of clay, gravel, sand, limestone and dacite. The slip plane at location 2 is estimated to be in the plane of contrast between low and high resistance values. The upper layers of the slip plane with resistance values of less than 692Ωm are thought to be rock layers, i.e. clay, gravel and sand layers. The limestone layer, which is a slip plane, was detected at a depth of about 3 meters and has a high resistance of 692-9,479 Ωm with an apparent slope of about 11° southwest. Based on the apparent slope, the actual slope to the northwest is 79°.

Location 3: Geo-electric measurement at location 3 North Isimu Village with a length of 170 meters trending southwest − northeast. Based on the rock resistance value, the slip plane at location 3 is estimated to be in the contrasting plane between low and high resistance values, i.e. in the limestone layer. A layer of clay, gravel, and sand is thought to be the upper layer of the slip plane, which has a resistance value of less than 796Ωm.The limestone layer, which is a slip plane, is detected at a depth of about 5-8 meters and has a high resistance of 796-10,552.5Ωm with an apparent slope of about 7° to the southwest Based on the apparent slope, the actual slope is 74° to the northwest.

Table 1. Electrical Resistance Value and Types of Rock Layers at the Research Location

No	Location 1 North Isimu Village 1 (0°39'52.6" N, 122°52'36.7" E) - (0°39'55.5" N, 122°52'41.6" E)		Location 2 North Isimu Village 2 (0°40'3.5" N, 122°52'41.4" E) - (0°40'9" N, 122°52'43.3" E)		Location 3 North Isimu Village 3 (0°40'19.6" N, 122°52'51.26" E) - (0°40'24.9" N, 122°52'55.19" E)		Location 4 North Isimu Village 4 (0°40'39.1" N, 122°53'7.1" E) – (0°40'36" N, 122°53'1.89" E)		Location 5 North Isimu Village 5 (0°41'17.41" N, 122°53'31.6" E) - (0°41'21.4" N, 122°53'28.2" E)		Location 6 Labanu Village 1 (0°44'43.3" N, 122°50'57.2" E) - (0°44'45.3" N, 122°50'51.8" E)		Location 7 Labanu Village 2 (0°45'05.2" N, 122°51'07.3" E) - (0°45'05.5" N, 122°51'01.7" E)	
	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer	Electrical Resistance (Ωm)	Type of Layer
1	0 – 27.9	Clay	0 – 13.7	Clay	0 – 7.11	Clay	0 – 15.8	Clay	0 – 4.29	Clay	0-0.89	Clay	0-3.44	Clay
2	27.9 – 54.3	Clay	13.7 – 32.15	Clay	7.11 – 16.5	Clay	15,8 – 34.25	Clay	4.29 – 11.695	Clay	0.89-2.05	Clay	3.44-8.22	Clay
3	54.3 – 80.6	Clay	32.15 – 50.6	Clay	16.5 – 25.9	Clay	34.25 – 52.7	Clay	11.695 – 19.1	Clay	2.05-3.21	Clay	8.22-13	Clay
4	80.6 – 156.8	Clay	50.6 – 118.8	Clay	25.9 – 60.05	Clay	52,7 – 114.35	Clay	19.1 – 51.85	Clay	3.21-7.36	Clay	13-30.9	Clay
5	156.8 – 233		118.8 – 187		60.05 – 94.2	Clay	114,35 – 176		51.85 – 84.6	Clay	7.36-11.5	Clay	30.9-48.8	Clay
6	233 – 453.5	Gravel and Sand	187 – 439.5	Gravel & Sand	94.2 – 218.6		176 – 381	Gravel & Sand	84.6 – 230.3		11.5-26.5	Loamy Sand	48.8-116.4	Gravel & Sand
7	453.5 – 674		439.5 – 692		218.6 – 343	Gravel & Sand	381 – 586		230.3 – 376	Gravel & Sand	26.5-41.5	Loamy Sand	116.4-184	Gravel & Sand
8	674 – 1,310.5	Limestone	692 – 1,122	Limestone	343 – 796		586 – 1,269.5	Limestone	376 – 1,023		41.5-95.25	Gravel & Sand	184-438	Gravel & Sand
9	1,310.5 – 1,947	Limestone	1,122 – 2,562	Limestone	796 – 1,249	Limestone	1.269,5 – 1,953	Limestone	1,023 – 1,670		95.25-149	Gravel & Sand	438-692	Gravel & Sand
10	1,947 – 3,788	Limestone	2,562 – 6,020.5	Limestone	1,249 – 2,898.5	Limestone	1,953 – 4,233	Limestone	1,670 – 4,544.5	Dry Gravel	149-342.5	Gravel & Sand	692-1,649.5	Limestone
11	3,788 – 5,629	Limestone	6,020.5 – 9,479	Limestone	2,898.5 – 4,548	Limestone	4,233 – 6,513	Limestone	4,544.5 – 7,419		342.5-536	Gravel & Sand	1,649,5-2,607	Limestone
12	5,629 – 10,950.5	Limestone	9,479 – 22,277	Dacite	4,548 – 10,552.5	Limestone	6,513 – 14,113	Limestone	7,419 – 20,188		536-1,232.5	Limestone	2,607-6,214	Dacite
13	10,950.5 – 16,272	Dacite	22,277 – 35,075	Dacite	10,552.5 – 16,557	Dacite	14,113 – 21,713	Dacite	20,188 – 32,957	Dacite	1,232.5-1,929	Limestone	6,214-9,821	Dacite
14	16.272 – 31.656	Dacite	35,075 – 82,430	Dacite	16,557 – 38,418.5	Dacite	21,713 – 47,052.5	Dacite	32,957 – 89,681	Dacite	1,929-4,432.5	Dacite	9,821-23,406.5	Dacite
15	31.656 – 47.040	Dacite	82,430 – 129,785	Dacite	38,418.5 – 60,280	Dacite	47,052.5 – 72,392	Dacite	89,681 – 146,405	Dacite	4,432.5-6,936	Dacite	23,406.5-36,992	Dacite
16	> 47.040	Dacite	> 129,785	Dacite	> 60,280	Dacite	> 72,392	Dacite	>146,405	Dacite	> 6,936	Dacite	> 36,992	Dacite

Source: Analysis Result in 2021

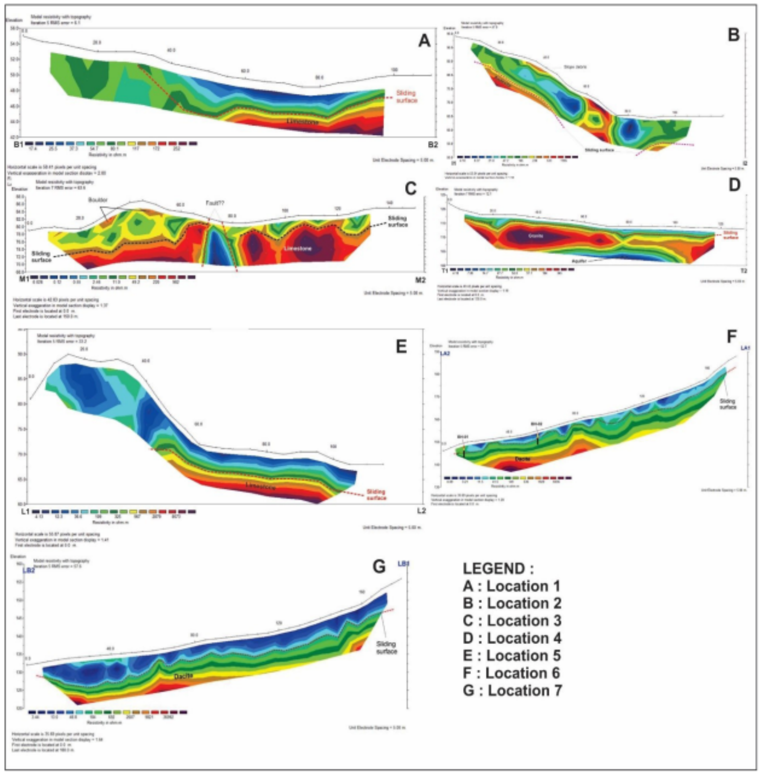

Figure 2. Cross section of 2D resistivity imaging at 7 lines at the research location

Location 4: Geo-electric measurement at location 4 in North Isimu Village with a track length of 180 meters trending northeast - southwest. The limestone layer which is a slip plane is detected at a depth of about 4-5 meters which has a high resistivity ranging from 586-14,113-m with an apparent slope of about 3° to the southwest. Based on the apparent slope, the actual slope is 56 ° trending the northwest.

Location 5: Geo-electric measurement at location 5 in North Isimu Village with a track length of 180 meters trendingsoutheast - northwest. The slip area is estimated to have low and high resistance values, namely in the dacite layer. The upper layers of the slip plane with resistance values of less than 20,188 -m are thought to be layers of clay, gravel, sand and dry gravel. The igneous rock layer of the dacite, which is a slip plane, was detected at a depth of about 17 meters, which has a high resistance of >20,188 -m, with a true dip of about 11° to the southeast.

Location 6: Geo-electric measurement at location6 in Labanu Village with a track length of 180 meters trendingeast - west. The slip area is estimated in low and high resistance values, namely in the dacite layer. The upper layers of the slip plane with resistance values of less than 536Ωm are thought to be layers of clay, loamy sand, gravel and sand. The limestone layer, which is a slip plane, was detected at a depth of about 2 meters, which has a resistance of > 536Ωm, with a true dip of about 13° to the east.

Location 7: Geo-electric measurement at location 7 in Labanu Village with a track length of 180 meters trending east - west.The slip area is estimated in low and high resistance values, namely in the dacite layer. The upper layers of the slip plane with resistance values of less than 692Ωm are thought to be layers of clay, gravel and sand. The limestone layer, which is a slip plane, was detected at a depth of about 2-5 meters, which has a resistivity of > 692Ωm, with a true dip of about 11° to the east.

Conclusion. Based on the results of the interpretation and analysis, it can be concluded that the two-dimensional cross-section of the track at locations 1, 2, 3, 4 and 7 is thought to be the structure of the subsurface soil in the form of clay, gravel and sand. The line at location 5 has a subsurface layer of dry gravel under the sand. The track at location 6 has a sub-surface layer of loamy sand under the layer of clay. The slip plane is interpreted as a limestone layer in lines 1, 2, 3, 4, 6 and 7, while the slip plane in line 5 is assumed to be in a dacite igneous rock layer. The results showed that the landslide slip fields at 7 locations were approximately 3-17 meters deep with a slope angle of 11o -79^{o} with trending dominantly northwest and one location with a southeast trend.

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АЛО СУ ҚОЙМАСЫНДАҒЫ СЫРҒАНАУ БЕТІН ТАЛДАУ, ГОРОНТАЛО АУДАНЫ, ИНДОНЕЗИЯ

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АНАЛИЗ ПОВЕРХНОСТИ СКОЛЬЖЕНИЯ В ВОДОРАЗДЕЛЕ АЛО, РАЙОН ГОРОНТАЛО, ИНДОНЕЗИЯ

Аннотация. Водораздел Ало - это суб-водораздел в системе водораздела Лимбото, который непосредственно сливается с озером Лимбото. Деградация земель, произошедшая в водосборном бассейне Ало, вызвана сельскохозяйственной системой, которая не применяет методы сохранения земель, такие как террасирование и насыпи, что вызывает эрозию и оползни. Метод, используемый в этом исследовании, является геоэлектрическим методом с конфигурацией Альфа Веннера, в то время как анализ данных использует метод визуализации удельного сопротивления, который создает двумерные изображения поперечного сечения. Всего существует семь траекторий, длиной 170-180 метров каждая. В результате исследования представлены поверхности скольжения в 7 местах, расположенных на глубине 3-17 метров с наклоном 11о-79^{o}, направленным преимущественно на северо-запад, и в одном месте, направленном на юго-восток.

Ключевые слова: водораздел ало, Гронтало, поверхность скольжения.

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