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Identification of Landslide-Prone Areas Using Drones and Geoelectricity in Gang Sakal, Panjang District, Bandar Lampung

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Abstract: Bandar Lampung City is a densely populated area with a morphology influenced by steep hilly paths. High rainfall can produce hydrometeorological hazards in the form of avalanches. This study aims to examine the material vulnerability of landslides. A combination of topographic mapping using drones and subsurface imaging through ERT geoelectric. Two subsurface profiles were analyzed through the Wenner-Schlumberger configuration with a line length of 120 m and electrode spacing of 5 m. The morphological slope of the drone data processing results is 60 degrees. The dominant subsurface profile has a resistivity of 1 Ωm to >279 Ωm with a depth of 23 m in the first line and a resistivity of 1 Ωm to >343 Ωm with a depth of 23 m in the second line as pyroclastic material. The composition of constituent materials that have not undergone compaction and slope has the possibility of a landslide hazard in the two observed profiles.

Keywords: drone; geoelectric; and landslide.

1. Introduction

Bandar Lampung City is a densely populated area situated on the southern extremity of Sumatra Island, encompassing lowlands, highlands, aquatic bodies, and mountainous terrain. As indicated by the geological chart of the Tanjung Karang sheet [1], the geological makeup of Bandar Lampung bears the imprint of several active faults. The presence of these faults is visually evident in the landscape's morphology, which is predominantly marked by hilly terrain and steep slopes [2]. The lithological composition of this region can be divided into two main categories: coastal and river deposits distributed across Lampung Bay, along with weathered soil derived from recent volcanic activities near Tanjung Karang. This situation elevates the city's vulnerability to various disasters, including landslides [3]. Bandar Lampung City holds the 18th position among 179 identified districts in Indonesia that are considered prone to landslides [4].

Mass movement or avalanche is a geological phenomenon in which land or rock masses move from one place to another due to the influence of the earth's gravitational force [5]. Landslides are classified as disasters that can be influenced by various factors such as morphology and slope, rock type, land use [5], geological structure [7], and hydrogeology [8]. The occurrence of landslides is usually caused by a comparison between the pushing force with the holding force on the slope [9]. This thrust is influenced by factors such as slope, soil moisture level, and soil material weight, while the holding force depends on the density and strength of the soil [10].

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A landslide is the movement of slope-forming material in the form of rocks, robbery materials, soil, or mixed materials, moving down or out of the slope. In general, the occurrence of avalanches on a slope is caused by an imbalance between the body and the shear strength resistance of the slope constituent material [11]. Common symptoms of landslides are the appearance of cracks around the slopes parallel to the direction of the cliff, and the sudden appearance of water after rain and then brittle cliffs or gravel begining to fall [12]. The factors causing landslides include passive and active factors. Passive factors such as topographic factors, geological or lithological conditions, hydrological conditions, soil, historical previous landslides, and vegetation conditions control the occurrence of land landslides, while active factors trigger landslides, including human activities in land use and climatic factors [13].

Panjang sub-district has medium-high ground motion potential [14]. Landslide disasters often cause considerable losses. Therefore, mitigation efforts need to be made to minimize losses that occur because of landslides. One form of mitigation efforts for landslide disasters is to map the slope of land in an area that is prone to landslides using remote sensing with the help of unmanned aircraft technology equipped with sensors and cameras to take data in the form of images, commonly called drones. Specifically, this study aims to describe or model in 3D the slope level of the research area based on photogrammetry (aerial mapping) and determine the depth of the slip field of the research area using 2D geoelectric.

2. Materials and Methods

2.1. Regional Geology

Bandar Lampung City is a densely populated area situated on the southern tip of Sumatra, encompassing various terrains, including lowlands, highlands, aquatic features, and mountainous regions. An examination of the geological map for the Tanjung Karang area reveals that the geology of the Panjang District in Bandar Lampung Province is characterized by several geological formations. These formations include the Tarahan Formation (Tpot), Way Galih Schist (Pzgs), Lampung Formation (QTl), and Alluvium (Qa) (Figure 1) [1]. The Tarahan Formation (Tpot) consists of compacted tuff, breccia with rijang inclusions. The Way Galih Schist (Pzgs) is composed of green amphibole schist and amphibolite dioritan orthogenes. The Lampung Formation (QTl) primarily comprises pumice tuff, rhyolitic tuff, solid tuff tufit, tufan claystone, and tufan sandstone. On the other hand, the Alluvium (Qa) is made up of various components, such as kerakal, gravel, sand, loam, and peat [10].

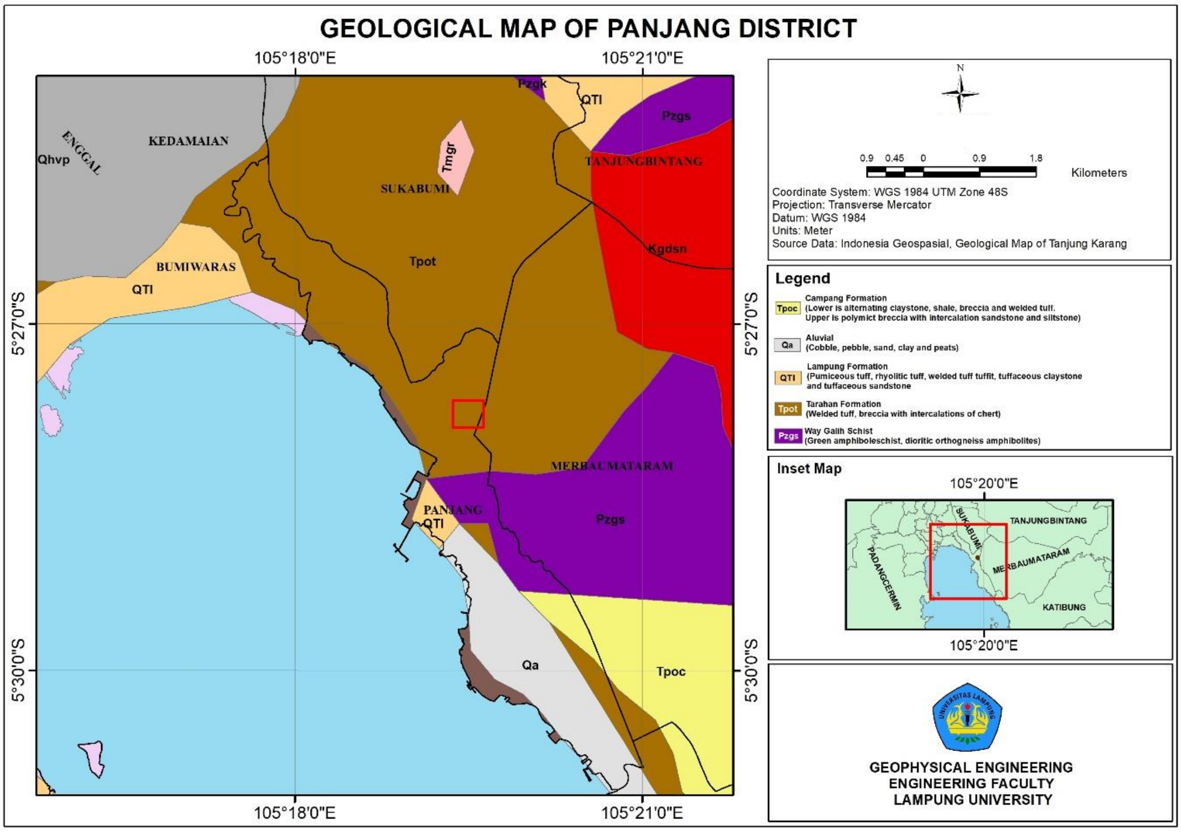

Figure 1. Geologic map of the study area (modification [1])

The research area is in Gang Sakal, Pidada Village, Panjang District, Bandar Lampung City. Geographically, the study area is located at coordinates on the first line 5°27'57.43" S, 105°19'26.97 E to 5°28'0.62" S, 105°19'25.12 E and the second line 5°28'1.56" S, 105°19'29.54 E to 5°28'1.66" S, 105°19'25.84 E. The electrode path length is 115 meters, with an electrode space of 5 meters.

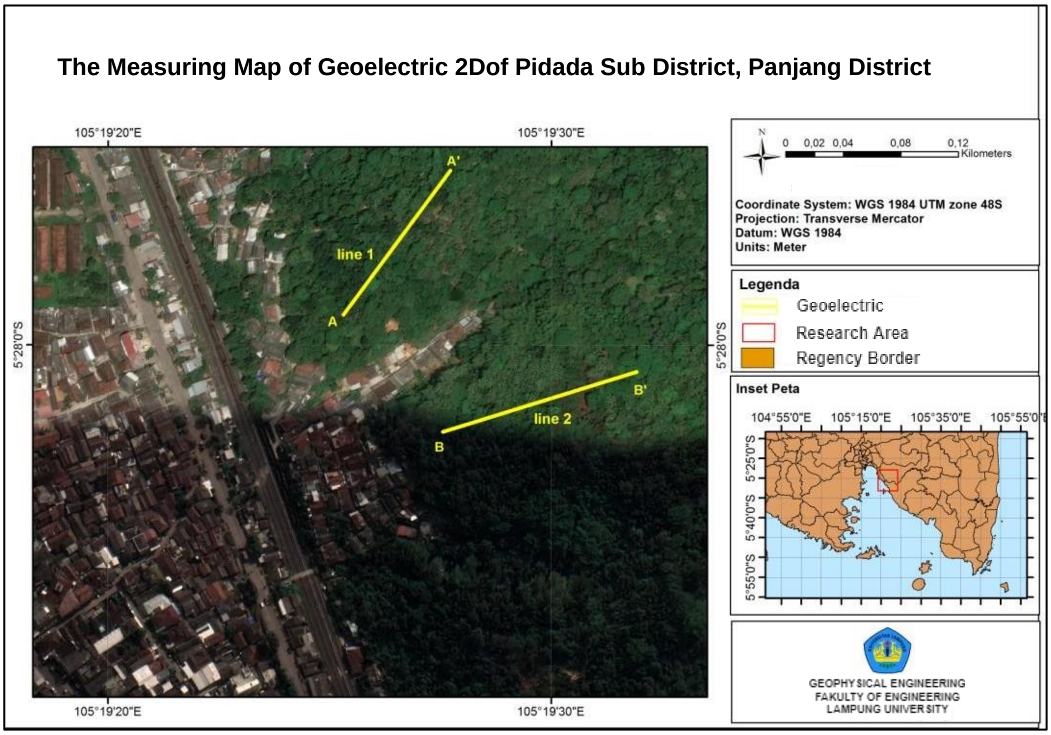

Figure 2. Map of research areas

This study also used 74 aerial photography (drone) images, regional geological maps of the Tanjung Karang area, and annual rainfall data from 2019–2021. Aerial photos taken using the DJI Phantom 4 Drone include several pieces of aerial photo data with image format (.jpeg), Orthomosaic, Digital Elevation Model (DEM), Digital Surface Model (DSM), and X, Y, and Elevation coordinates with a flight altitude of 125 meters from the surface or starting point of flight (85 masl). The measurement results use drones (with file name DJI_0036) and are the results of aerial photos taken at a height of 125 meters above the surface using the Pix4D Capture application version 4.11.0.

Moreover, the acquired aerial photographs' outcomes undergo data processing to ensure alignment among the captured images. The initial step in this process involves employing the "align photos" sub-menu, which serves as a tool for synchronizing aerial photos with JPEG formats that are already geographically referenced or possess coordinates. During the align photos phase, each image is adjusted to correspond with its specific coordinates. In this investigation, high-resolution quality is opted for to achieve enhanced image detail. Subsequently, following the compilation of multiple images during the align photos phase, the next stage involves creating a dense point cloud. This phase incorporates the camera's location points and depth information from each image. Upon the completion of the dense point cloud phase, the subsequent step entails mesh generation, resulting in the creation of a 3D polygonal network that faithfully represents the object's surface, based on the data from the dense point cloud.

2.2. Geoelectric Method

A significant catalyst for avalanche occurrences is the existence of a slip plane or slip surface. Typically, avalanche-prone terrain moves along this slip plane. An effective approach to investigating or identifying these slip zones involves employing the resistivity geoelectric method, also known as the resistance method [15].

The resistivity geoelectric method is a geoelectric technique that assesses the resistivity characteristics of subsurface soil layers. This method involves injecting an electrical current into the earth's surface using two current electrodes, followed by the measurement of potential differences across two potential electrodes [16]. Current on the surface by using one electrode. Suppose that the current electrode C1 is located on a surface of a homogeneous medium and connected to the current electrode C2, which is located infinitely far away, so that the influence of C2.

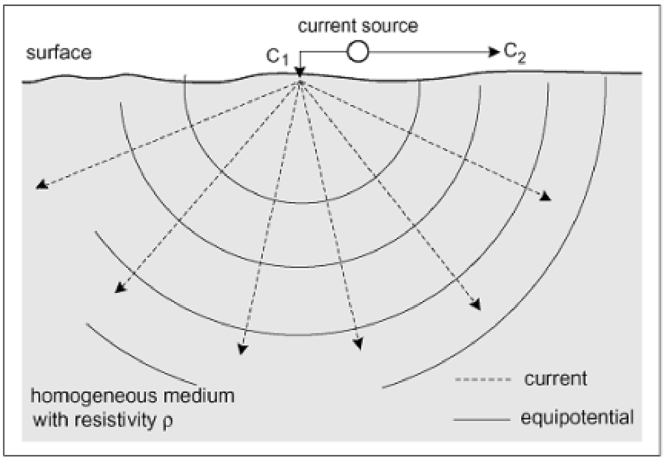

Figure 3. The point of current source on the surface of the medium is homogeneous [17].

The Wenner-Schlumberger configuration represents a blend of the Wenner and Schlumberger configurations, aiming to ensure measurements maintain their continuity within a single cross-section, ultimately yielding a pseudosection. This configuration finds application in various techniques, including 2D resistivity mapping. Resistivity mapping involves detecting horizontal variations in subsurface resistivity by adjusting the positions of current and potential electrodes while keeping their separation distance constant. The measurement method of this configuration entails modifying the placement of both current (C1, C2) and potential (P1, P2) electrodes [16]. The Wenner-Schlumberger configuration adheres to a consistent spacing rule system, where the "n" factor represents the ratio of the distance between C1-P1 or C2-P2 electrodes to the spaces between P1-P2. When the potential electrodes (P1 and P2) are separated by a distance "a," the current electrodes (C1 and C2) are positioned at a distance of 2na + a. The resistivity calculation is accomplished through the deployment of four electrodes arranged linearly [18].

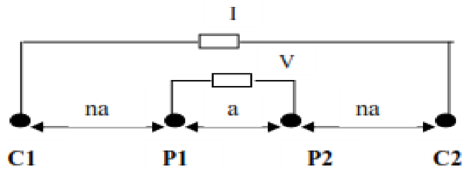

Figure 4. Wenner Schlumberger configuration electrode arrangement [19].

The data that has been obtained is then analyzed and interpreted to obtain appropriate results. The interpretation of resistivity geoelectric processing data is correlated with topographic maps, geological maps, and rock resistivity value tables (Table 1).

Table 1. Resistivity Value of Rocks and Minerals [17]

Materials	**Resistivity (Ωm)**
air	0
Pyrite	0,01 - 100
Quartz	500 - 800000
Calcite	$1x10^{12}$ - $1x10^{13}$
Rock Salt	30 - $1x10^{13}$

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Granite	200 - 10000
Andesite	$1{,}7\times10^2$ - 45×10^4
Basalt	200 - 100000
Limestone	500 - 10000
Sandstones	200 - 8000
Shales	20 - 2000
Sand	1 - 1000
Clay	1 - 100
Ground Water	0,5 - 300
Sea Water	0,2
Magnetite	0,01 - 1000
Dry Gravel	600 - 10000
Aluvium	10 - 800
Gravel	100 - 600
Consolidated Shales	20 - 2×10^3

3. Results and Discussion

3.1. Track Layer 1 Lithology Wenner-Schlumberger Configuration

Interpreting the Wenner-Schlumberger configuration results involves multiple iterations to attain an interpretation that closely aligns with real field conditions. This process continues until the third iteration, resulting in a root mean square error value of 8.6%. According to the inversion outcomes, the maximum measured depth reaches 19.8 meters. Below is a 2D representation of the inversion data, both without considering topography and incorporating topography within the Res2DInv software.

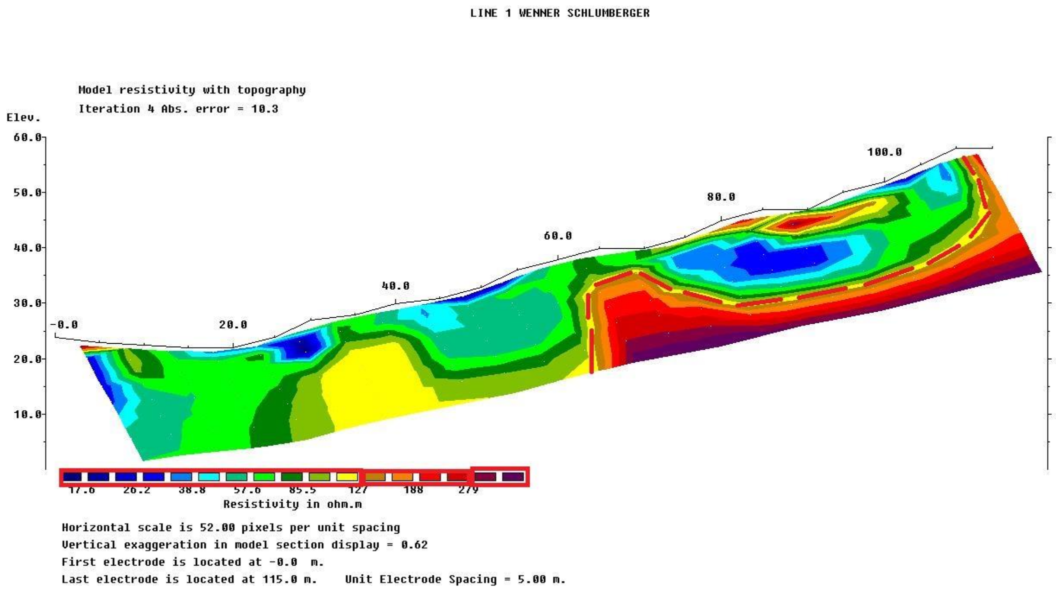

Figure 5. 2D cross-section of Wenner-Schlumberger configuration inverted with trajectory topography 1.

The resistivity values ranging from 1 to 127 Ωm, represented by the dark blue-yellow indicator, are indicative of weathered rock or areas prone to landslides. These zones may contain water-saturated material with low resistivity, likely linked to rocks mainly composed of clay tuff and sand tuff (tuff sediment) originating from volcanic products of the Tarahan Formation. This type of material is prone to landslides and is found at depths ranging from 0.94 to 15 meters. Within the depth range of 7.5 to 115 meters, the thickness of this layer varies from 1 to 15 meters. Materials displaying resistivity values between 127 and 279 Ωm, found at depths of 0.94 to 15 meters, are also observed within the 62 to 115-meter depth range. These materials are indicated by the brown-dark red indicator and are presumed to be clay sand originating from the Campang Formation. They are located at depths of 15 to 20 meters, with a thickness ranging from 2 to 5 meters and spanning the depth range of 65 to 115 meters. In geoelectrics, the presence of slip planes is characterized by a resistivity contrast between adjacent rock layers. Impermeable layers exhibit high resistance values compared to more permeable layers. Clay sand can become slippery and transform into a slip plane, causing material above it to shift, leading to avalanches and subsidence. The slip plane within the measurement track is believed to be situated between the sedimentary layers of tuff and clay sand at a depth of 4.6 to 15 meters from the ground level. This is indicated by the dark purple-purple indicator along this trajectory. Additionally, resistivity values exceeding 279 Ωm are observed and signify a hard layer with low porosity, making it unable to store water within rock pores. This layer is estimated to be a combination of breccia and igneous rocks derived from the Tarahan Formation. It is found at depths ranging from 15 to 21.5 meters and has a thickness of up to 5 meters, spanning the depth range of 65 to 115 meters.

3.2. Track Layer 2 Lithology Wenner-Schlumberger Configuration

The interpretation of the Wenner-Schlumberger configuration results involves multiple iterations to align with actual field conditions. In the second path, these iterations extend to the third cycle, achieving a root mean square error value of 5.5%. The maximum depth determined through inversion results is 19.8 meters.

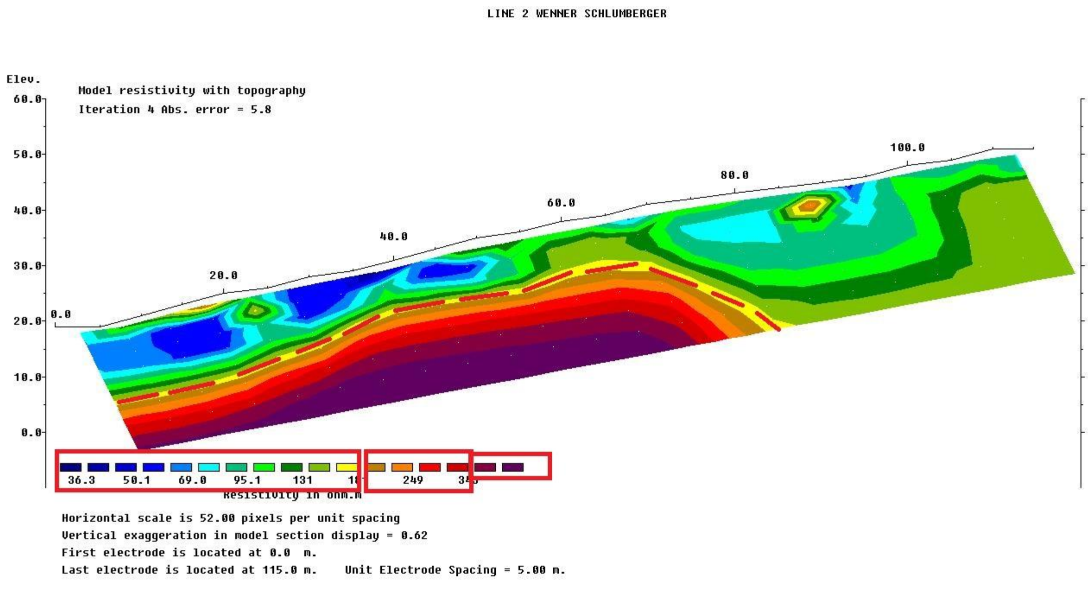

Figure 6. The 2D cross-section of the Wenner-Schlumberger configuration is inverted with topography.

The range of resistivity values from 1 to 131 Ωm, identified by the dark blue-yellow color indicator, suggests the presence of low-resistivity rock, such as weathered rock or a zone prone to landslides. This zone may contain water-saturated areas associated with the lithology of clay tuff and sand tuff (tuff sediment) derived from volcanic products of the Tarahan Formation, known for its susceptibility to landslides. These materials are found at depths ranging from 5 to 98.7 meters and vary in thickness from 2 to 17 meters. In contrast, resistivity values in the range of 181 to 343 Ωm, indicated by the dark brown-red color, are believed to represent clay sand material originating from the Campang Formation. This material is situated at depths of 12 to 16 meters and exhibits a thickness between 2 and 5 meters within the depth range of 2 to 80 meters. Geoelectric observations reveal that slip planes exhibit a resistivity contrast between adjacent rock layers, where impermeable layers demonstrate higher resistance values in comparison to layers with lower resistances. In the case of clay sand, its resistivity can change depending on moisture content, potentially becoming a slippery slip plane capable of triggering avalanches and subsidence. The observed slip plane in the measurement path is identified to exist between the sedimentary layers of tuff and clay sand at depths ranging from 12 to 16 meters. Additionally, the presence of a resistivity value exceeding 343 Ωm, marked by a dark purple-purple indicator in this context, is indicative of a hard layer with poor porosity, making it unable to retain water between rock pores. This layer is believed to be a combination of breccia and igneous rocks originating from the Tarahan Formation, with depths ranging from 15 to 20 meters, extending across 1 to 68 meters.

3.3. Peta DSM (Digital Surface Model)

The DSM (Digital Surface Model) is one example of an elevation map, but it depicts the height from sea level to the top of objects on the surface (buildings, trees, etc.). The result of the mesh build process does not yet have a smooth appearance that really depicts the surface of the object, therefore, the texture build process and tiled model build process are carried out so that the model obtained is DSM.

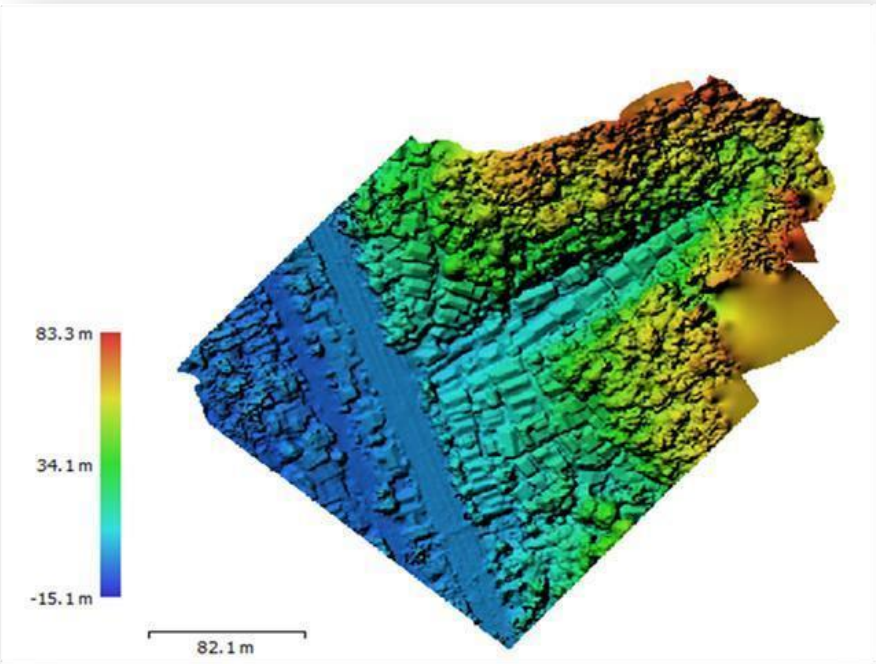

Figure 7. DSM map with aerial photo area boundaries around Sakal alley.

Based on the DSM map, the magnitude of the slope at the study site >70° and is included in the steep category in the Van Zuidam classification [20]. While the *net volume* in the area with the potential for landslides (0.4 hectares) is 4.718 m^3, assuming the potential area is only the area represented by aerial photographs and geoelectric data. Clay rocks have a fine and compact granular mineral arrangement, if this layer is exposed to liquid substances it will tend to become soft and slippery.

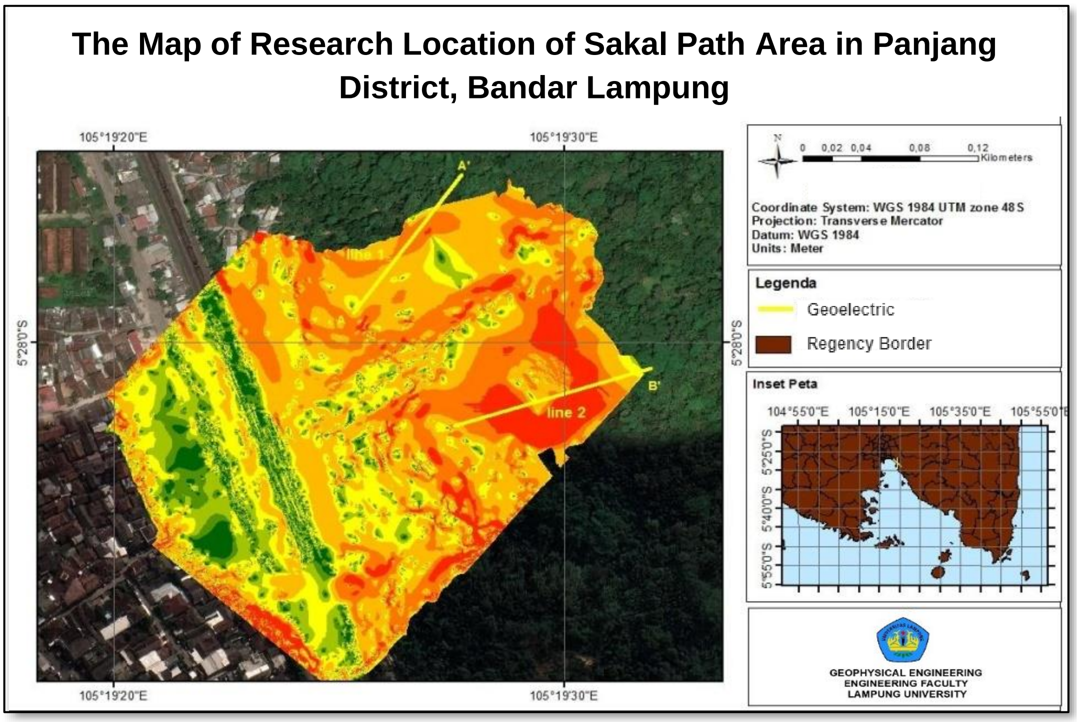

Figure 8. Map of slope from dem data generated by drones in the Panjang sub-district.

5. Conclusions

The analysis of data processing in the research area reveals several key findings. In the cliffs of Gang Sakal, one constituent material appears to consist of weathered rocks characterized by clay tuff and sand tuff, showing resistivity values within the range of 1–127 Ωm. The second layer is identified as clay sand originating from the Campang Formation, exhibiting a resistivity range of 127–279 Ωm. The third layer is believed to be a combination of breccia and igneous rocks derived from the Tarahan Formation, with resistivity values exceeding 279 Ωm. For the second track, it consists of weathered rock associated with clay tuff and sand tuff, having resistivity values between 1 and 181 Ωm. The second layer is interpreted as clay sand from the Campang Formation, with resistivity values ranging from 181 to 343 Ωm. The third layer in this track is considered to be a fusion of breccia and igneous rocks originating from the Tarahan Formation, indicating resistivity values higher than 343 Ωm. Moreover, in Track 1, the clay sand layer is identified as a slip plane within the electrode position located between 62.5 and 115 meters from the starting point. This slip field is situated at a depth range of 5–20 meters. In Track 2, the clay sand layer serves as a slip plane at depths of 2–80 meters, with the average depth ranging from 15 to 20 meters from the ground level. Additionally, data obtained from UAV-photogrammetry provides a visualization of the topographic slope in the study area, indicating an angle of approximately 70 degrees.

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