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Analysis of Landslide Potential Based on Magnetic Susceptibility of Rocks Using Geomagnetic Methods in Suka Damai Village, Bulango Utara Subdistrict, Bone Bolango Regency

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Abstract

Landslides in Bone Bolango Regency have increasingly impacted the population, with data showing a rise in affected areas from 2020 to 2021. To mitigate these risks, mapping areas with potential landslides is crucial for providing early warnings, although such efforts remain incomplete. Therefore, this research aims to determine the potential for landslides in Bone Bolango Regency, especially in Suka Damai Village. The geophysical method used in this research is the geomagnetic method because it utilizes the magnetic properties of rocks below the surface and can interpret subsurface structures in areas with the potential for landslides. Based on the research results, it was identified that the research location is dominated by diorite and granodiorite igneous rocks, where diorite rocks dominate from the surface to a depth of 40 meters with a susceptibility contrast value of 3 – (2.5) SI. Meanwhile, granodiorite rocks are found at a 20 – 110 m depth with a susceptibility value of 1.5 – 3 SI. Based on 3D visualization, it was found that diorite rock acted as landslide material, and granodiorite rock acted as sliding rock. Besides that, material movement forms slopes caused by shear failure that occurs along one or more landslide planes. This research confirms that the research area is a potential landslide area with a level of stability in category D, which means it is less stable.

Keywords: *Landslide; Geomagnetic Method; Rock Susceptibility*

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INTRODUCTION

Landslides are the process of moving rock or soil masses due to gravity. This phenomenon is triggered by the disturbance of the balance of forces acting on the slope, namely the resisting and sliding forces [1]. Landslides are erosion accompanied by soil movement, which causes the movement of soil and rock material at a considerable intensity [2]. A landslide is a destructive earth disaster due to the movement of masses that make up the slope down or out of the slope [3]. One of the factors for landslides is very high rainfall, which results in water infiltration into the soil, increasing the load on a slope [4]. The stability of a slope is determined by the forces that attempt to loosen (driving forces) the soil or rock and the forces that attempt to maintain (resisting forces) the soil or rock remains in position [5]. Landslides occur due to two main factors: controlling factors and triggering factors. Controlling factors affect material conditions, such as geological conditions, slope, lithology, faults, and rock joints [6]. Meanwhile, triggering factors cause the movement of these materials, such as rainfall, earthquakes, erosion at the foot of the slopes, and human activities [7]. Data from the Regional Disaster Management Agency (BPBD) of Bone Bolango Regency in 2021, as listed in Table 1, shows an increase in the frequency of landslides in Bone Bolango Regency in the last four years.

Table 1. Frequency of Landslide Events in Bone Bolango District In 2017-2020 [8]

No	**Year**	**Total**	**Location**	**Affected Houses**	**Fatalities**	**Displaced Persons**
1	2017	2	1. Kabila Bone Bonepantai	2	0	0
2	2018	2	1. Bulango UluBulango Utara	3	0	0
3	2019	1	Bonepantai	14	0	704
4	2020	8	1. Suwawa Selatan 2. Suwawa Timur 3. Kabila Bone 4. Bulango Utara 5. Bonepantai 6. Bulango Utara 7. Bone Boneraya	163	4	1416
Total	14	182	8. 4	2.120		

Table 1 presents landslide disasters in the 2017-2020 period and shows the impact of landslides on property losses and casualties. The data suggest that landslides in Bone Bolango are causing more and more victims, which is indicated by the increasing area of landslides in 2020, such as in Suwawa Selatan, Suwawa Timur, Boneraya, and Bone Subdistricts. Therefore, mitigation is necessary to reduce the destructive impact of landslides, such as damage to buildings and public facilities and casualties. The results from Patuti show that the internal factors causing potential landslides in the Bone Bolango Regency area are the flow of 25 small rivers in the Bone and Bolango watersheds and also external factors, namely high rainfall (> 100 mm) and human activity around the slopes who tend to cut down trees and build houses on slopes [9]. This condition causes water to seep into the soil so that the soil becomes saturated. As the water level increases, the shear strength decreases.

Another study from Djakun identified landslide susceptibility using the Storie Index method in Bone Bolango [10]. The analysis shows a Storie Index value ranging from 0.0003 to 0.06 (attachment). If this value is converted into a level of vulnerability, the research location is categorized into three levels of landslide susceptibility: low, moderate, and high. Each of these categories represents an area covering 10.98% (low susceptibility), 84.41% (moderate susceptibility), and 4.61% (high susceptibility) of the entire study area [11]. Several studies have been conducted in the Bone Bolango Regency. However, they also have several shortcomings, including being unable to study the attitudes and opinions of the observed objects, taking much time, and the potential for subjective observer bias being very high [8, 9, 12].

Moreover, a notable weakness of the Storie Index method is that if any parameter category is assigned a value of zero, the resulting multiplication (Storie Index) will also be zero. The Storie Index is a semi-quantitative method for looking at soil characteristics to give a soil capacity rating [13]. Therefore, based on the description above from several studies that have been conducted in Bone Bolango Regency, there has been no research using geophysical methods, especially geomagnetic, so the author feels the need to research Landslide Potential Analysis Based on Rock Magnetic Susceptibility Using Geomagnetik Method In Suka Damai, Village, North Bulango Subdistrict, Bone Bolango Regency.

The geomagnetic method is one of the geophysical methods that utilizes the magnetic properties of rocks [11]. The geomagnetic method is a potential data processing method to obtain an overview of the earth's subsurface based on its magnetic characteristics. This method utilizes the earth's magnetic properties to obtain contours to describe the distribution of subsurface rock susceptibility in the horizontal direction [14]. From this value, rocks that contain magnetic properties can be separated from those that do not so that we can determine the direction of distribution of the rock itself [15].

The research was conducted using the geomagnetic method because it has advantages in various ways, namely, the coverage area is quite wide, sensitive to susceptibility, modeling is related to distance and depth, data processing is more detailed, and this method is sensitive to changes in the value of the magnetic field strength vertically, making it suitable for preliminary surveys to determine the subsurface structure [16]. The geomagnetic method is used to interpret the underground structure based on the magnetic properties of the rock beneath the surface. Thus, this method is expected to interpret subsurface structures in areas experiencing landslides [17].

METHOD

The study was conducted in Suka Damai Village, North Bulango Subdistrict, Bone Bolango Regency, Gorontalo Province, with hilly topography. The main equipment for geomagnetic measurements is a magnetometer, especially the Proton Precision Magnetometer (PPM). The Proton Precession Magnetometer is a sensor for measuring total magnetic field induction whose working principle is based on the rotation of particle charges. The PPM specifications used are GSM-19T (Figure 1), which has sensitivity: 0.15 nT @ 1 Hz, resolution: 0.01 nT, cccuracy: 0.1 nT @ 1 Hz, Gradient Tolerance: more than 7000 nT / m, dimensions: 223 x 69 x 240 mm and integrated with GPS [18]. PPM Type GSM-19T can measure total magnetic field strength values. The Global Positioning System (GPS) is another equipment supported by magnetic surveys. This equipment is used to measure the position of measurement points, which include longitude, latitude, height, and time. This GPS determines the position of a location point using the help of satellites [19].

Potential landslides are mapped using the Geomagnetic Method based on the susceptibility value of the magnetized rock beneath the earth's surface. The total measurement is 31 points with a distance between points of 8 meters and five measurements at each point (Figure 2). This decision was influenced by the challenging field conditions, as expanding the survey area would have made data acquisition difficult due to the presence of residential buildings in the vicinity (Figure 3). The primary goal was to diminish interference caused by PPM readings, which are highly sensitive to ferrous materials. Iron can significantly affect the movement of electrons within the geomagnetic data acquisition instrument.

Figure 1. Proton Precession Magnetometer GSM-19T

GPS measures the position of the measurement point, including longitude, latitude, altitude, and time. In determining the position of a specific location, GPS utilizes satellite assistance to cover extensive areas not disturbed by mountains, hills, valleys, and ravines [119]. Another piece of equipment is a PC or laptop equipped with MS software: Word, MS Excel 2013, ArcGis 10.8, Oasis Montaj 8.4, and ZondGM3D.

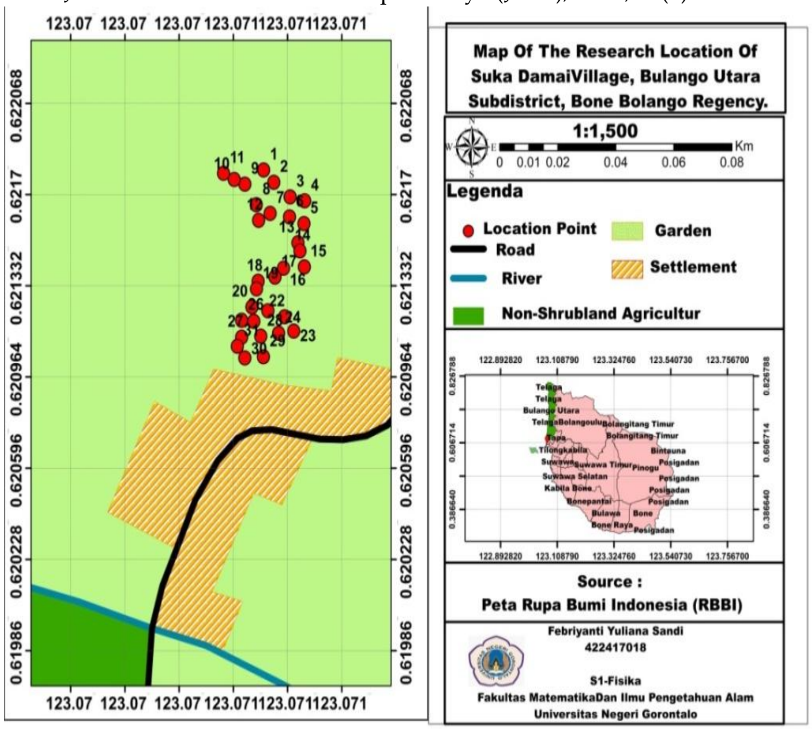

Figure 2. Research Site of Suka Damai Village, Bulango Utara Subdistrict, Bone Bolango Regency.

Figure 3. Data Acquisition Process in the Field

RESULTS AND DISCUSSION

Data obtained from field measurements are considered raw data or direct measurements that have not been processed. For this reason, the data is processed to obtain the desired magnetic field anomaly value by correcting the total magnetic field data measured at each location point or measurement station [20]. To obtain the magnitude of the magnetic field anomaly in the field, the external magnetic field and the main magnetic field need to be removed. The external magnetic field is removed by daily variation correction, and the magnetic field is removed by IGRF correction [21]. The corrected data is used to create maps using the Oasis Montaj 8.4 software. Some of the resulting maps are described as follows.

Elevation

Elevation data were obtained using the Oasis Montaj 8.8 software based on the magnetic anomaly data. In Figure 4, the elevation map shows that the altitude at the location ranges from 56.9 – 97.8 meters, with the highest elevation found in the northern part ranging from 85.3-96.8 meters and the lowest elevation in the southern part ranging from 56.9-66.8 meters. In Figure 5, the blue color indicates low anomaly values, while the red indicates a higher elevation anomaly value. Based on the anomaly map images with these contours, it can be analyzed whether high magnetic anomaly values always correspond to higher elevations or vice versa [22].

The type of rock can be determined through geophysical surveys. The presence of the earth's magnetic field in certain parts of the earth is called a magnetic anomaly, which is influenced by the rock's vulnerability and magnetic remanence [11]. Factors that affect the susceptibility value are lithology and minerals that make up the rock. Suppose a material with a magnetic susceptibility value is placed in an external magnetic field with a strong magnetic field. In that case, the external magnetic field will induce the material so that it has a magnetization intensity value indicated by Arwanda et al. [23]. The remanent magnetization in igneous rocks is the primary thermal remanent magnetization obtained in the cooling process during the formation of igneous rocks. Furthermore, subsequent secondary magnetization, such as viscous remanent magnetization, can be obtained since the rock was formed [24].

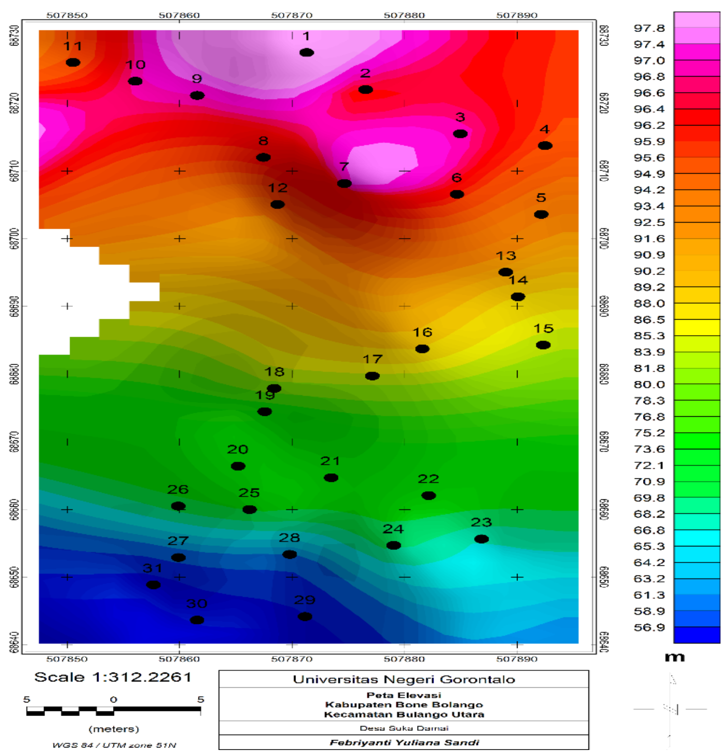

Figure 4. Elevation Map

Regional Anomaly

Regional anomalies originate from the earth's interior with low frequencies, such as the earth's crust. Regional filters can only be identified at sufficient depth [25]. The Regional Anomaly Map in Figure 6 shows that the high anomaly is in the southern part, with anomaly values ranging from -180.8 - (-129.3) nT, while the low anomaly presents in the northern part, ranging from

-290.4 - (-250.0) nT. Low anomalies are shown in dark blue and light blue, moderate anomalies in green and yellow, and high anomalies in orange, red, and purple. This condition occurred allegedly because there were sources of interference at the time of measurement, such as large trees, residential buildings, and cloudy weather conditions. According to Rumahorba et al., when cloudy, the magnetic intensity value usually becomes smaller [26]. Then, during a sun storm, the value of magnetic intensity is usually greater. In the morning, the weather is cloudy, and the sun is getting hotter; the trees at the measurement place can also affect the measurement time and close to the neighborhood homes.

Figure 5 displays the distribution of positive and negative magnetic field anomalies, indicating strong and weak magnetic anomaly values at the measurement location [27]. This finding is thought to be due to weather factors and the influence of solar storms. When it is cloudy, the magnetic intensity value is usually smaller. Then, during a solar storm, the magnetic intensity value is usually greater [26]. The black line in Figure 5 shows the lithological contact boundary.

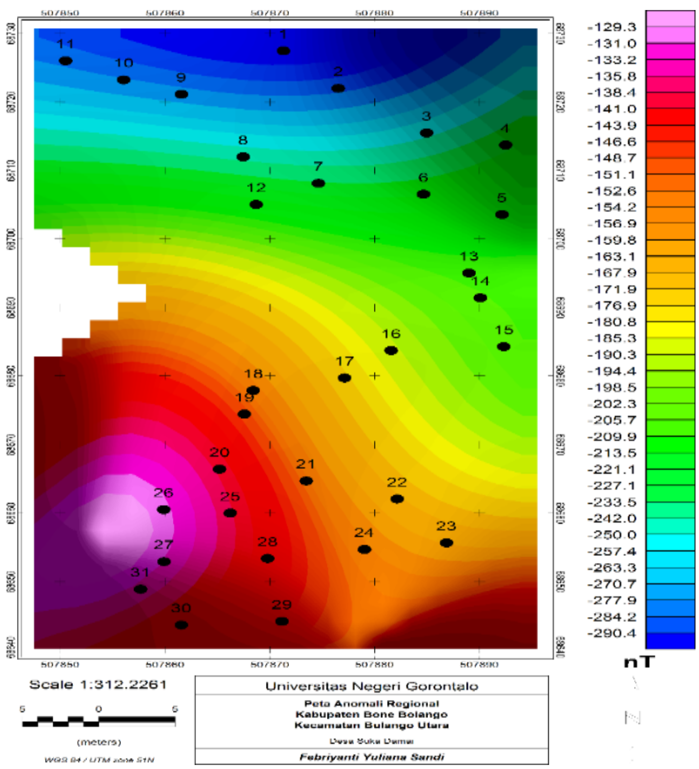

Figure 5. Regional Anomaly Map

Residual magnetic anomalies are anomalies formed due to the response of rocks in the shallow subsurface. The target of this research is subsurface conditions at a shallow depth, so it is necessary to know the distribution of residual magnetic anomalies at this research location [28]. Figure 6 residual anomaly results show a high residual anomaly with a value from the range of 0.5 - 58.2 nT, marked with red to light purple in the north and south. Then, low residual magnetic fields with a range of -72.1 - (-18.1) nT are marked with light blue to dark blue colors and located in the north and south. The residual filter only reads shallow magnetic anomalies.

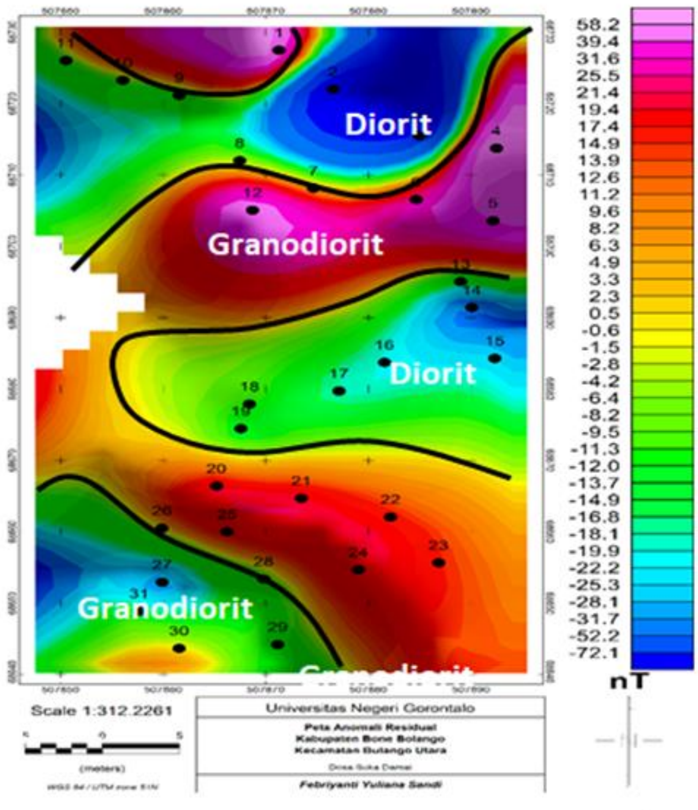

Figure 6. Residual Anomaly Map

The regional anomaly pattern results cannot describe or show the structural pattern of the study area in detail. To find out the shallower structural pattern, filtering is done to get the residual anomaly pattern. The residual anomaly obtained has a value range between -4 mGal to 4 mGal. The residual anomaly map shows a more complex anomaly pattern compared to the regional anomaly [29].

The Reduction to the Pole

Furthermore, a reduction to the pole is carried out on the residual anomaly map to eliminate the influence of one pole by bringing the residual anomaly as if to the pole reduction to the pole is done by changing the direction of the magnetic field, which is initially dipole to a monopole, to clarify the magnetic field anomaly. This analysis was done by making the inclination angle of the object 90° and the declination 0°. Thus, the resulting monopole anomaly comes from the same source [29]. Reduction to the poles is carried out by transforming the direction of the magnetic field from a dipole to a monopole to clarify the magnetic field anomaly. The reduction to the pole map displays the range of magnetic field variation values [30].

The middle and upper part of the slope section shows high magnetic anomalies. However, the lower slopes of the landslide area show significant low magnetic anomalies [24]. Factors that affect the susceptibility value are lithology and minerals that make up the rock. Suppose a material with a magnetic susceptibility value is placed in an external magnetic field with a strong magnetic field. In that case, the material will be induced by the external magnetic field so that it has a magnetization intensity value. The susceptibility value of a magnetic material can be positive or negative. Positive values indicate that the magnetization intensity has the same direction as the field, and negative magnetic susceptibility values indicate that it is in the opposite direction [31].

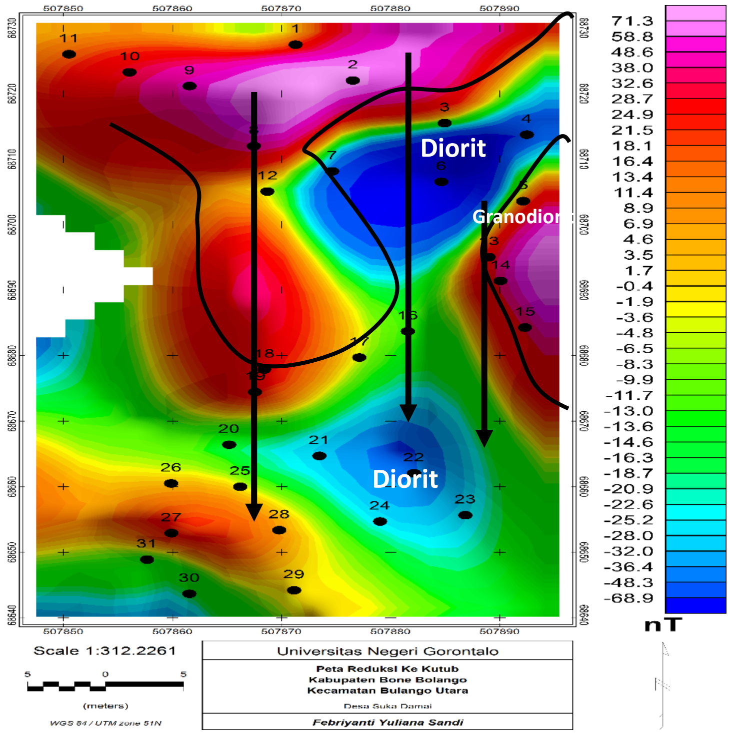

Figure 7. Reduction to the Pole Map

Derivative Analysis

Derivative analysis aims to determine the distribution of geological structures at the study site. The analysis was carried out through two processes which are described as follows.

<u>First Horizontal Derivative (FHD)</u>

First Horizontal Derivative (FHD) is a type of derivative analysis that identifies the position and direction of geological structures with a maximum FHD value (very high anomaly). This analysis is carried out by slicing the residual anomaly contour map to clarify the presence of fault geological structures. The black line in the black line in figure 8 shows the fault/joint line. The principle of the FHD method lies in the indication of faults seen from its minimum or maximum peak. The FHD map displays the distribution of magnetic field anomalies at locations ranging from 0.72 – 13.91 nT. The maximum anomaly is in the northern part, with values ranging from 12.38 – 13.91 nT.

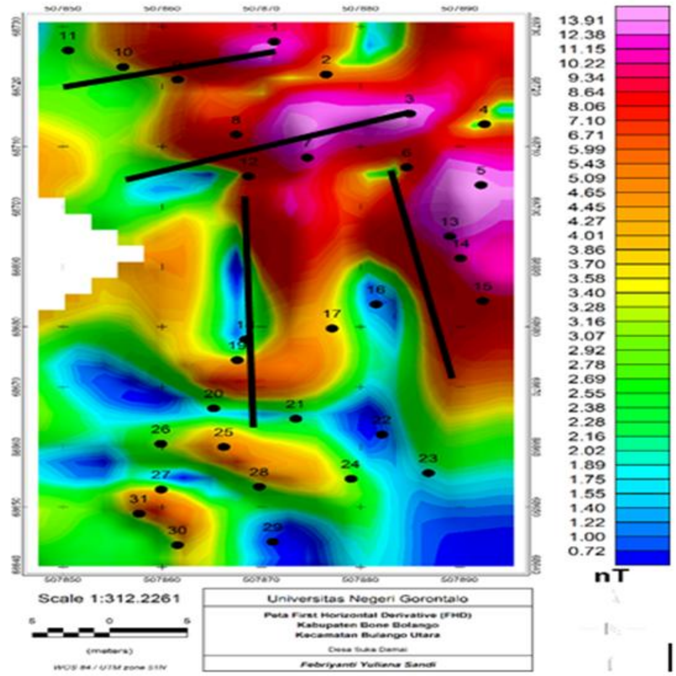

Figure 8. First Horizontal Derivative (FHD) Map

<u>Second Vertical Derivative (SVD)</u>

The Second Vertical Derivative (SVD) identifies the position, direction, and type of geological structure with a characteristic SVD value of 0 which acts as a high pass filter. The SVD map displays the distribution of magnetic field anomalies at locations ranging from -3.4150 – 3.0622 nT. The dominance of anomaly 0 is located in the northern part, which ranges from 12.38 –13.91 nT. The color scale to the right of the magnetic field anomaly map indicates the magnitude of the magnetic field anomaly. Red represents a higher magnetic intensity value, while blue indicates a lower one, and the black line in the black line in Figure 9 shows the fault/joint line.

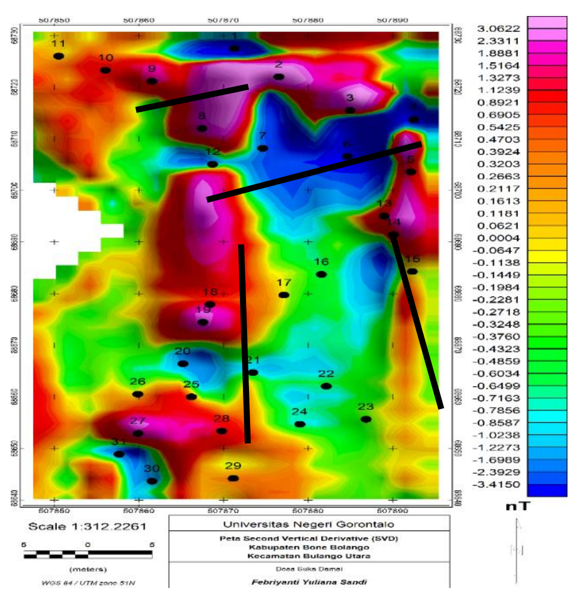

Figure 9. Second Vertical Derivative (SVD) Map

<u>3D Inversion Models</u>

After analyzing the fault and the slide level, 3D modeling was carried out to see the subsurface structure of the landslide area using ZondGM3D software. The data used include the inclination and declination angle values to determine the rock or mineral susceptibility value consistent with the research site's geological conditions. 3D inversion modeling was carried out three times at locations with potential landslides. The parameter is changed to get a picture of the structure of the model. Modeling depth and susceptibility value. Changing these parameters is carried out continuously until the test anomaly value approaches the anomaly value measured at the research location (trial and error method). The s indicated by the increasing overlap f the trial anomaly graph (solid line) with the research anomaly graph at the research location. In the 3D model of section A-A' oriented from north to south, two types of rocks are observed to be distributed beneath the surface: granodiorite and diorite. The rock types identified at the research site are dominated by diorite and granodiorite igneous rocks. This fact can be explained by geomagnetic data, especially the reduction anomaly to the pole, as in Figure 8. Figure 8 shows the low magnetic anomaly data (Blue-Green), which shows diorite rocks, while the high anomaly (yellow-pink) identified granodiorite rocks. This figure shows that the high and low magnetic anomalies reflect the type of rock found in the study area. These results are based on the geological map issued by Apandi and Bachri [32], which is by the type of rock in the research location. The type of subsurface rock in Suka Damai Village, North Bulango Subdistrict, Bone Bolango Regency, consists of diorite and granodiorite rocks.

Diorite dominates with a susceptibility contrast value of -3 – (-2.5) SI, while granodiorite has a susceptibility contrast value of 1.5 – 3 SI. In section B-B', diorite dominates with a susceptibility contrast value of -3 – (-2.5) SI, and granodiorite predominates with a susceptibility value of 1.5 – 3 SI. Meanwhile, the C-C section has a susceptibility contrast value of -3 – (-2.5) SI, whereas granodiorite predominates with a susceptibility contrast value of 1.5 – 3 SI (see Figure 10, Figure 11, and Figure 12).

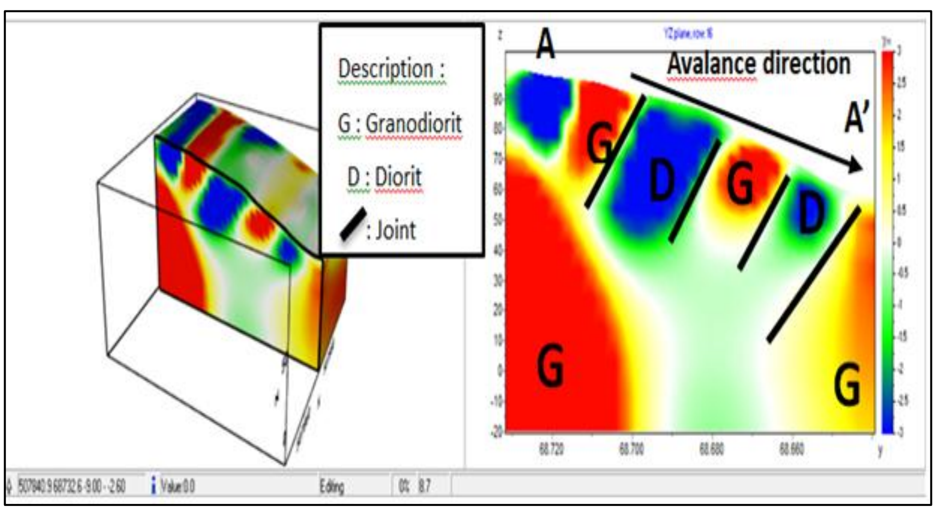

Figure 10. 2D and 3D Modeling (Section A – A')

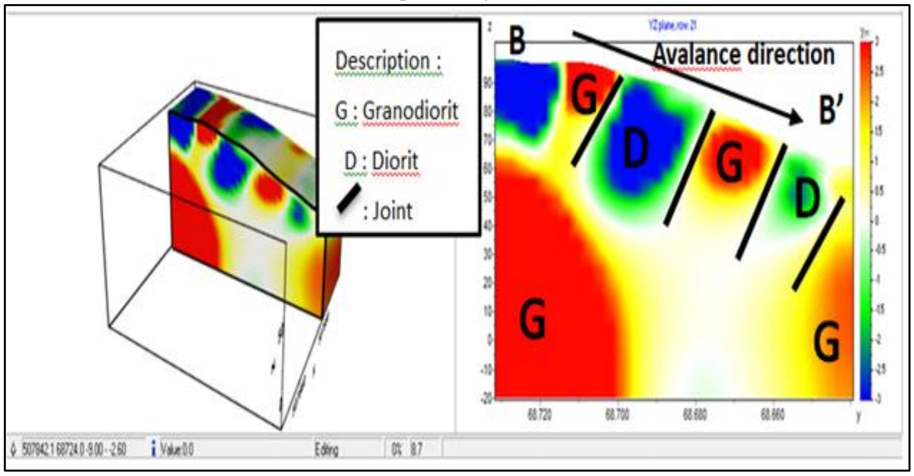

Figure 11. 2D and 3D Modeling (Section B – B')

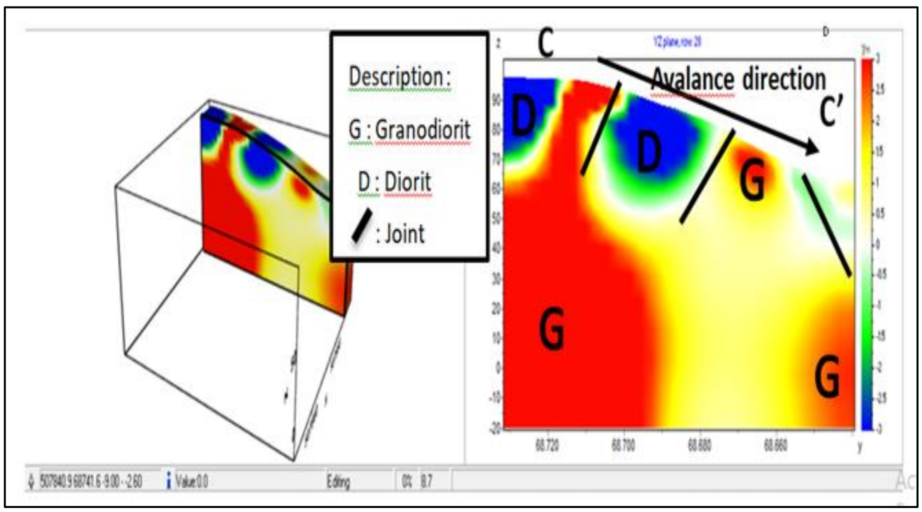

Figure 12. 2D and 3D Modeling (Section C – C')

The study aims to determine the analysis of potential landslides using the geomagnetic method. Based on data from the Regional Disaster Management Agency (BPBD) of Bone Bolango Regency in 2021, there has been an increase in the frequency of landslides that have caused victims in the last four years. Therefore, it is necessary to research landslide potential mapping using geophysical methods such as the geomagnetic method.

Geological factors that influence the occurrence of landslides are geological structure, rock properties, loss of soil adhesive due to natural processes (dissolving), and earthquakes. The geological structures that trigger ground motion are bedrock contacts with weathered rocks, cracks, rock layers, and faults. The dominant rock types identified at the study site are igneous rocks such as diorite and granodiorite. This phenomenon can be explained by using geomagnetic data, especially the reduction of the poles map, as shown in Figure 7. In Figure 7, the low magnetic anomaly data (Blue-Green) indicates Diorite rock, while the high anomaly (red-pink) is identified as Granodiorite rock. This finding agrees with the geological map issued by Apandi and Bactiar [32]. The results of calculating the magnetic anomaly value from the total field data at the research location are obtained by Equation 1 [33].

$$HA = H_{total} - I_{IGRF} \pm \Delta H_{daily} \tag{1}$$

Magnetic anomalies depend on magnetic rocks' magnetic susceptibility and natural remanent magnetization (NRM). Magnetic susceptibility is the ratio of the induced magnetization that appears in response to an external magnetic field. Remanent magnetization in igneous rocks is the primary thermal remanent magnetization obtained in the cooling process during rock formation. Meanwhile, secondary magnetization, such as thick remanent magnetization, can be obtained since the rock was formed [31]. The magnetic susceptibility value at the measurement point can be obtained through the following equation [35].

$$IA(X) = k\,(H0) \qquad k = I\_(A(X))/H\_0 \tag{2}$$

In Figure 2, the altitude ranges from 56.9 – 97.8 meters, where the highest altitude is located in the north, ranging from 85.3 – 96.8 m. The diorite rock type is found at this elevation when correlated with the total magnetic anomaly map. The total magnetic anomaly map is shown in Figure 5; high anomalies are in the south with anomaly values ranging from -172.1 - (-126.8) nT, and low anomalies in the north ranging from -344.8 - (-258.8) nT, which are thought to be associated with diorite rocks. In contrast, the lowest elevation is located in the southern part, ranging from 56.9 to 66.8 meters. Geological structures are one of the factors influencing landslides, as they can affect the stability of slopes [36]. These hard rocks will become even more vulnerable if they ride on wrinkled soft rocks. Areas with thick soil and located on high topography are also prone to landslides due to the high potential to experience additional mass loads since soil generally has a relatively higher capacity to absorb rainwater than fresh rocks [34].

3D modeling was carried out to see the subsurface structure of the landslide area in three sections: section 1 (A - A'), section 2 (B - B'), and section 3 (C - C'). Table 2 displays two types of rock: diorite and granodiorite. In all three sections, diorite rocks act as landslide material. Meanwhile, granodiorite rocks act as slip rocks since they are located below the diorite rocks and are dense in nature. In addition, it is suspected that four faults also trigger landslides.

Table 2. Rock Susceptibility Value in 3 sections

Section	**Types of Rock**	**Susceptibility (SI)**
(A - A')	Diorite	-3 – (-2.5)
	Granodiorite	1.5 – 3
(B - B')	Diorite	-3 – (-2.5)
	Granodiorite	1.5 – 3
(C - C')	Diorite	-3 – (-2.5)
	Granodiorite	1.5 – 3

Source: Researcher's Analysis Data

The 3D modeling found two rock types at the study site: diorite with a susceptibility value of -3 – (-2.5) SI and granodiorite with a susceptibility value of 1.5 – 3 SI. These findings are identical to those in Sections A-A', B-B', and C-C', which show the distribution of the two rock types in the study site. According to Telford et al., the value of the susceptibility of a magnetic material can be positive or negative [31]. A positive value indicates that the magnetization intensity (M) has the same direction as the magnetic field (H), while a negative magnetic susceptibility value indicates the opposite. The received magnetization, whether induced or remanent, depends on the direction of the applied magnetic field. Based on the susceptibility value, the types of rock materials in the research site fall into two categories: diagmentic materials with a susceptibility value of k < 0 and paramagnetic materials with a susceptibility value of 10-6 < k < 1. Magnetic susceptibility is the ability of a material to be magnetized, as described by the value of magnetic susceptibility (k). Magnetic susceptibility (k) is a physical parameter of the rock that is sought in geomagnetic measurements [31].

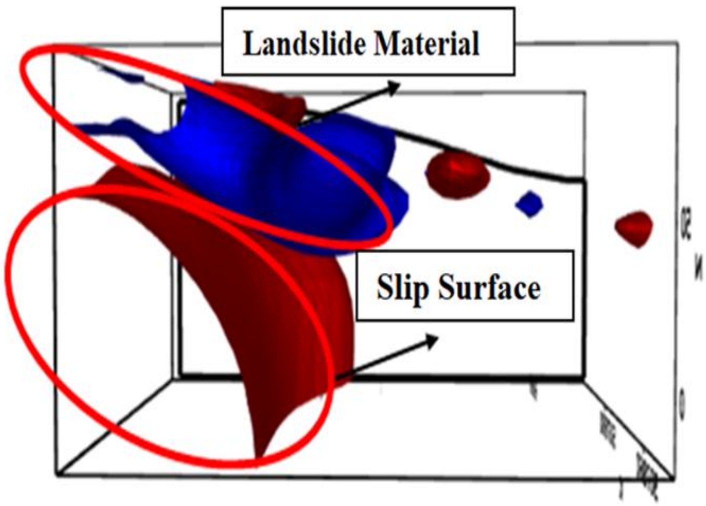

Figure 13. Model 3D Isosurface

After analyzing the 3 models 3D inversion model above, a 3D isosurface model was created which functions to see the shape of the rock that acts as landslide material, namely diorite rock, and the rock that acts as a sliding plane, namely granodiorite rock, also according to field data the slope angel is 70^{o}, where if the slope is > 45° then this area has a high potential for landslides (Figure 13).

Table 3. Landslides Threat Parameters [37]

Parameters	Class	Abillity Value	Weight	Score	Results
Slope	0-8%	1	30%	18	18
	8-15 %	2			
	15-25%	3			
	25-45%	4			
Rock Type	Andesit, Basalt, Diroit,Batuan Tefra	1	20%	4	4
	Batu Karang, Aluvium, Endapan Laut Muda	2			
	Batu Gamping, BatuKarang, Batupasir	3			
Land Cover	Forests / Dense Vegetation	1	20%	4	28
	Shrubs / Mixed	2		8	

Parameters	Class	Abillity Value	Weight	Score	Results
	Gardens Plantations / Irrigated Rice Fields	3			
	Residential / Industrial Areas	4		16	
	Empty Land	5			

Table 4. Suspension Assessment In Determining The Typology Of Disaster-Prone Areas [36]

Classification Of Stability	Score Range	Regional Typology
Stable	30 – 40	A B
Less Stable	41 – 50	C D
Unstable	50 – 60	E F

Thus, based on the research results, it shows that the potential for a landslide at the research location is included in the type D area where there are factors that cause landslide susceptibility so that the presence of these factors gives the research location a score range of 41-50 which is interpreted as an area that is less stable against the potential for landslides. Caused by trigger factors based on Guidelines for Spatial Planning in Landslide-Prone Areas [36] in Table 4. The findings of this research are relevant to the results of the study by Patuti and Indriati [9], which shows that the research location has a slope of 30-40 degrees, and this zone is even a zone prone to landslides. Besides that, according to the research results of Djakun et al. [10], who used the story index method, it was shown that the research location had landslide vulnerability in the categories of low, medium, and high vulnerability levels. The potential vulnerability to landslides in the research area is also supported by a study [12] that the research area's lithology consists of granodiorite and alluvial units. The lithology that makes up the alluvial unit is composed of loose material ranging in size from sand to gravel. Thus, the analysis of landslide potential using geomagnetic methods in this research area further strengthens that this research area has the potential for landslides so that these findings become a reference for the community and consideration for stakeholders in mitigating landslides.

CONCLUSION

The rock susceptibility values obtained using the geomagnetic method show that two types of rock act as landslide material, namely diorite and granodiorite. The diorite rock has a depth of up to 40 meters, which acts as a slip plane. Meanwhile, granodiorite rock has a depth of up to 110 meters, which acts as a sliding rock because of its position at the bottom of the diorite and is dense. The type of landslide found at the research location is translational slide landslide, namely the movement of slope-forming material caused by shear failure that occurs along one or more landslide planes. This landslide occurs due to the movement of soil and rock masses on a sliding surface that can be flat or gently wavy. The potential for landslides at this research location is type D, where this area is less stable due to lithology, elevation, and geological factors that trigger landslide susceptibility. This research is the basis for development research in designing solutions to minimize the impact of potential landslides at the research location.

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AUTHOR CONTRIBUTIONS

Raghel Yunginger, and Febriyanti Yuliana Sandi: Conceptualization, Methodology, Original Draft, Writing-Review & Editing; Dewa Gede Eka Setiawan: Methodology and Formal Analysis; Maman Hermana Husen: Methodology and Supervision; M. Zulkifli: Data and Resource Curation; Kamal Ardiyanto: Data Curation and Resources.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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