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Application of Rock Magnetic Methods to Landslide Disaster Vulnerability: a Case Study (Malalak, Agam Regency)

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ABSTRACT

Malalak is a landslide-prone area that has an undulating hilly topography with a height of more than 850 meters above sea level. Landslide potential can be determined by the value of magnetic susceptibility Percent Frequency-Dependent Susceptibility (χ_{fd}%). The study was conducted on slopes where landslides have occurred (A) and have not occurred (B) using the rock magnetism method to compare the potential for landslides on the slopes. Soil that has been taken and measured using a Bartington Magnetic Susceptibility Meter sensor type B (MS2B), the measured values are analyzed and interpreted to see a comparison between two different samples. The results showed that the value of low-frequency magnetic susceptibility (χ_{lf}) ranged from 447.5-698.8× $10^{-8}m^3kg^{-1}$ with an average of 580.6× $10^{-8}m^3kg^{-1}$, it is estimated that the magnetic mineral is ferrimagnetic with the type of mineral Hematite (Fe_2O_3). The graph of the relationship between the values of lf and fd% on slope A has a value of χ_{fd}% > 2% and a slope B of χ_{fd}% < 2%. Slope A contains superparamagnetic grains between 10%-75% which is a mixture of fine and coarse-sized superparamagnetic grains, while slope B does not exist or contains less than 10% superparamagnetic grains. The samples with high superparamagnetic grain content were almost all fine-grained soils which caused the level of soil mineral attachment by water to decrease. So that when the rainfall is high, the soil becomes saturated and accumulates on the slip plane, causing lateral movement on the slopes and landslides to occur.

Keywords : Malalak, Magnetic Susceptibility, Superparamagnetic Grain, Landslide.

I. INTRODUCTION

Indonesia is a country that has the most variations of disasters that occur in the world. Santoso research on floods and landslider, add references that discuss about earthquakes, landslides, floods, tsunami's, volcanoes, tornadoes, and flash floods [1], [2], [3], [4]. Among these disasters, which often occur in Indonesia are landslides which can result in property losses and even fatalities. This is because Indonesia has tectonic conditions that form high morphology, faults, and volcanic rocks that can weather and form soil. This condition is supported by the existence of a tropical climate that characterizes Indonesia.

The term landslide describes the movement of soil or rock on the lower slope due to the influence of gravity. While many landslides do occur through the process of rock or soil sliding on the actual surface there are different types of motion namely, fall, slide, and flow. The type of movement depends on the angle of inclination, the nature of the material, and the various stresses acting on the soil. Landslides occur on unstable slopes.

Slope instability can be caused by several things that function as slip planes. The slip plane is a boundary between moving and stationary material masses [3]. A slip plane is a plane where the material of an avalanche moves on it [4]. So, the slip plane is a plane where the material that experiences landslides moves. The movement of the material is caused by disturbances in the stability of the soil or rocks that make up the slopes as well as natural movements caused by geological processes such as earthquakes and high-intensity rain.

The potential for landslides can be determined using several geophysical methods such as the geoelectric method, the seismic method, and the microtremor method. The geoelectric method is used to determine the potential for landslides in predicting the position or location of a slip plane, usually, landslides move from above the slip plane [5]. Seismic methods are used for landslide investigations, with high accuracy and resolution in modeling geological structures below the earth's surface [6]. The microtremor method is used to solve the causes of landslides, where the microtremor method data is in the form of 3 component signals, namely: vertical (Up and Down), horizontal (North-South), and horizontal (East-West) components. Meanwhile, the parameters obtained are natural frequency and local area amplification value [7].

One method that can be used to determine the potential for landslides is the rock magnetism method which is a geophysical method based on measuring variations in the intensity of the magnetic field on the earth's surface. Magnetic methods are generally used to determine the magnetic properties of rocks. A susceptibility meter can be used to determine the concentration of magnetic minerals to get the susceptibility value in a material. Magnetic susceptibility is the amount of material that will be magnetized when subjected to a magnetic field [8], which will provide information about the magnetic minerals in a material. The value of magnetic susceptibility depends on the number of magnetic minerals contained in the sample so from this valuable information, it can be estimated about the magnetic minerals contained in the earth's material.

Factors that influence the occurrence of landslides include passive factors and active factors. Landslides can be triggered by soil characteristics formed in the area which are influenced by the size of the soil fraction, especially the finer soil fraction, namely the soil fraction of clay minerals [9].

The presence of superparamagnetic grains in the soil can be seen from the frequency-dependent susceptibility value, (χ_{fd}%). χ_{fd}% is the relative difference between low-frequency susceptibility (χ_{lf}) and high frequency (χ_{hf}). The higher the value of χfd%, the more the presence of superparamagnetic grains in the soil.

Table 1. Interpretation of χ_fd% value

Score χ_{fd}%	Information
0,0-2,0	No or less than 10% superparamagnetic grains
2,0-10,0	Contains superparamagnetic grains between 10% to 75% which is a mixture of fine and coarse superparamagnetic grains
10,0-14,0	Whole or contain more than 75% superparamagnetic grains

(Source: Ref [9])

Table 1 shows that the higher the value of χ_{fd}%, the higher the content of superparamagnetic grains, but values greater than 14% are very rare and are often considered errors in measurement [10]. The size of the magnetic grains of a material will affect the stability of the magnetic moment [11]. The properties of magnetic minerals are greatly influenced by the size of their grains and consist of a large number of small, cooperative magnetic units known as magnetic domains. The magnetization is uniform but in different directions from each other. Magnetic domains are regions in the crystal structure of magnetic minerals consisting of magnetic minerals whose magnetization is directed in a certain direction. The crystal structure of a magnetic mineral can have more than one domain. Each domain consists of millions of dipoles [12].

II. METHOD

Sampling was carried out in the Malalak area, Agam Regency, Indonesia, and magnetic susceptibility measurements were carried out at the Geophysics Laboratory, Department of Physics, FMIPA UNP. The sampling process is carried out in several stages such as; seeing and measuring the topography of the slopes that have or have not occurred, determining the sampling location, making a sampling grid, and taking samples on the ground surface.

Before sampling, a survey was conducted in areas prone to landslides to see the topographical conditions of the slopes that would be used as sampling points. The topographic criteria for sampling are having almost the same slope characteristics. The slope of the slope shows the amount of angle formed from the difference in height in a landscape which is usually expressed in percentage units or degrees. The slope angle on landslide slopes usually has an angle of >40^∘ to make the slope critical to landslides [13]. The sampling position was determined using the Global Positioning System (GPS). GPS is a navigation and positioning satellite system owned and managed by the United States. GPS geographic coordinates can be set as needed. In this study, UTM (Universal Transverse Mercator) coordinates were used.

Grid sampling was carried out in a stratified manner (stratified sampling), which is soil sampling that was representative of other soils (Figure 1).

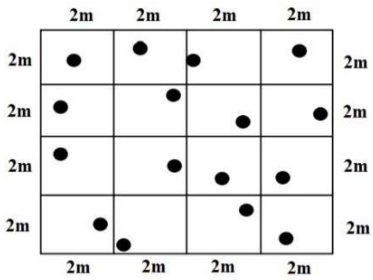


Fig. 1. Sampling position grid

Soil sampling using the stratified sampling method was carried out in a survey area sequentially moving from highlands to lowlands (soil with a slope) assuming different soil properties based on changes in altitude. Stratified random sampling is a sampling process through the process of dividing the soil into strata, then selecting a simple random sample from each stratum, and combining it into a sample to estimate the soil parameter in the form of magnetic susceptibility.

Fig. 2. Creation of a sampling grid in Malalak, Agam Regency

Fig 2 explains about sampling was carried out using the disturbed soil sampling technique. Determination of the sampling method is determined based on the purpose of the analysis of soil properties. The condition of disturbed soil samples was not the same as the situation in the field, because when transferring samples to Ziplock plastic, they did not pay attention to the above and below the soil so when they were brought to the laboratory, the samples had changed (disturbed).

Next, the existing sample was prepared and the magnetic susceptibility value of the sample was measured. Measurements were carried out three times for each sample in a low field state (χ_{lf}) and three times in a high field state (χ_{hf}) so that an average magnetic susceptibility value ($\bar{\chi}$) was obtained. The ratio of measurements at both frequencies is expressed as a frequency-dependent susceptibility which is written as:

$$\chi_{fd}\% = \frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}} \times 100\% \qquad (1)$$

From the results of sample measurements, the magnetic susceptibility value was hypothesis analyzed using the Statistical Package for Social Sciences (SPSS) ver 22 programs. This hypothesis analysis was used to determine the difference in susceptibility values on slopes where landslides had occurred and had not occurred accordingly. Before carrying out the similarity test of the two averages, a prerequisite test was carried out, namely the normality test and the homogeneity of variance test.

III. RESULTS AND DISCUSSION

Soil Magnetic Susceptibility Value

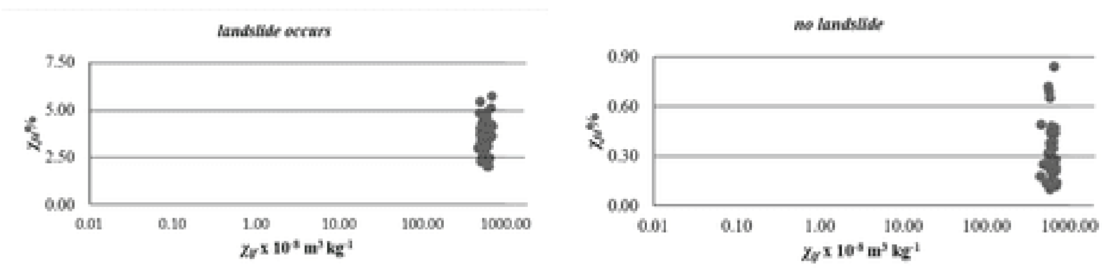
The magnetic susceptibility value of landslide-prone areas in Malalak, Agam Regency is divided into two points where the first point is on a slope where landslides have occurred (point *A*) while the second point is on a slope where landslides have not occurred (point *B*). The sample at this point is 32 samples, each sample is divided into 3 holders and has an average value per sample (Table 2).

Table 2. The soil magnetic susceptibility value

No	Sample Name	Magnetic Susceptibility Average ($\times\ \mathbf{10^{-8} m^3 kg^{-1}}$)							
		A				B			
		$\bar{\chi}_{lf}$	$\bar{\chi}_{hf}$	$\bar{\chi}_{fd}$	$\bar{\chi}_{fd}\%$	$\bar{\chi}_{lf}$	$\bar{\chi}_{hf}$	$\bar{\chi}_{fd}$	$\bar{\chi}_{fd}\%$
1	ML01	497.2	481.4	0.0318	3.18	642.9	640.0	0.0045	0.45
2	ML02	564.7	547.9	0.0295	2.95	609.6	607.8	0.0029	0.29
3	ML03	641.4	621.6	0.0307	3.07	462.6	461.2	0.0031	0.31
4	ML04	642.2	618.6	0.0368	3.68	553.1	551.5	0.0028	0.28
5	ML05	503.6	484.8	0.0376	3.76	600.8	598.9	0.0031	0.31
6	ML06	651.1	627.7	0.0357	3.57	630.7	628.9	0.0029	0.29
7	ML07	500.6	483.0	0.0355	3.55	598.4	615.8	0.0019	0.19
8	ML08	586.6	562.4	0.0418	4.18	572.3	570.4	0.0032	0.32
9	ML09	555.4	539.2	0.0293	2.93	663.1	660.5	0.0038	0.38
10	ML10	602.9	584.4	0.0307	3.07	562.3	560.6	0.0032	0.32
11	ML11	508.1	488.9	0.0379	3.79	532.5	531.1	0.0025	0.25
12	ML12	678.0	645.4	0.0481	4.81	600.1	597.3	0.0045	0.45
13	ML13	579.3	562.0	0.0301	3.01	557.5	556.3	0.0023	0.23
14	ML14	502.8	482.9	0.0392	3.92	625.3	623.3	0.0033	0.33
15	ML15	584.7	559.2	0.0436	4.36	612.8	611.6	0.0019	0.19
16	ML16	589.0	566.6	0.0381	3.81	550.2	548.3	0.0035	0.35
Min		497.2	481.4	0.0293	2.93	462.6	461.2	0.0019	0.19
Max		678.0	654.4	0.0481	4.81	663.1	660.5	0.0045	0.45
Average		574.2	553.5	0.0360	3.60	585.89	585.22	0.0031	0.31

Based on Table 2, it can be seen that all samples have a susceptibility value at χ_{lf} greater than the value of χ_{hf}. The larger χ_{lf} value is due to the dipole moments of magnetic minerals in the material, ranging from a single domain (SD), multi-domain (MD), pseudo domain (PSD), and superparamagnetic grains. This is because the magnetic field changes very quickly at χ_{hf} so it is not possible for the superparamagnetic grains to interact with the external magnetic field used and the superparamagnetic grains cannot follow the alternating field changes it can also be said that the relaxation time of superparamagnetic grains is longer and takes fast time to follow. alternating field changes from high-frequency χ_{hf} [14].

Table 2, it can be plots of the relationship between the value of Low field susceptibility (χ_{lf}) and frequency-dependent susceptibility ($\chi_{fd}\%$) in samples found on slopes that have experienced landslides (Figure 3).



(a) (b)

Fig. 3. The relationship between Low Field Susceptibility (χ_{lf}) and Percent Frequency Dependence Susceptibility ($\chi_{fd}\%$) in Malalak, Agam Regency, a) landslide occurs, b) no landslide

Based on Figure 3, *A* it is obtained that the relationship plot of χ_{lf} with $\chi_{fd}\%$ varies in the range of 2.93-4.81%, the highest is in the sample, the highest is in the ML12A sample, while the lowest value is in the ML09A sample. Meanwhile, Figure 3 on *B* can be seen plotting the relationship between Low Field Susceptibility (χ_{lf}) and Percent Frequency Dependence Susceptibility ($\chi_{fd}\%$) on slopes that do not occur landslides in Malalak, Agam Regency has a data interval of Percent Frequency Dependence Susceptibility ($\chi_{fd}\%$) between 0.19 -0.45%. The highest values on this slope were obtained in samples ML01B and ML12B, while the lowest values were found in samples ML07B and ML15B.

Magnetic Susceptibility $\chi_{fd}\%$ with Magnetic Domain

Graph of the relationship between the sample susceptibility value to $\chi_{fd}\%$ it can be seen that the point where landslides occur has a value of $\chi_{fd}\%$ above 2%, while the point where there is no landslide has a value of $\chi_{fd}\%$ below 2%. If referring to Table 1, the point that experienced landslides (*A*) contains between 10% and 75% superparamagnetic grains which are a mixture of fine and coarse superparamagnetic grains based on the range of $\chi_{fd}\%$ values between 2%-10%, and for points that are not a landslide, occurs (*B*) is absent or contains less than 10% superparamagnetic grains. According to [9], the value range of $\chi_{fd}\%$ 0-2% does not have superparamagnetic grains and is usually dominated by the Multidomain (MD) grain type and the value of $\chi_{fd}\%$ 2-10% has Singledomain (SD) and Superparamagnetic (SP) grain sizes.

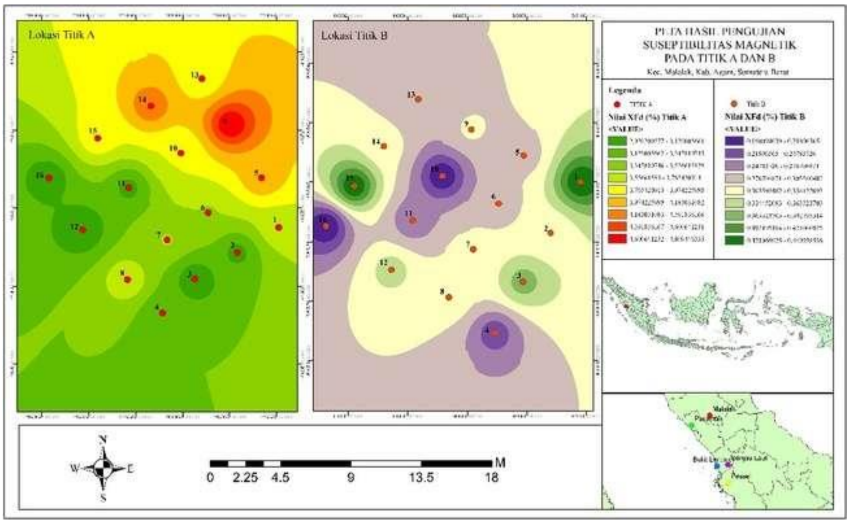


Fig. 4. Map of the results of testing the magnetic susceptibility value on slopes that have occurred landslides (A) and slopes that have not occurred landslides (B)

Figure 4 is the result of measuring the magnetic susceptibility value measured on the Bartington Magnetic Susceptibility Meter sensor type B (MS2B) where the χ_{lf} value is used for strong magnetic iron oxide (Fe) concentrations (magnetite, maghemite, titanomagnetite) [15], slope *A* and slope *B* the average with normally distributed data so that the susceptibility value of the two samples is different with an average value of $580.6 \times 10^{-8} m^3 kg^{-1}$ which has ferrimagnetic magnetic properties and the type of mineral Magnetite. χ_{hf} for the magnetic susceptibility of paramagnetic minerals (for example, clay) and iron oxide (Fe) high coe magnetic minerals or similar populations. Furthermore, the calculated values of χ_{fd} and $\chi_{fd}\%$ for the concentration of magnetic particles and the relative proportion of the superparamagnetic fraction in the magnetic field total magnetic susceptibility [15] with values on slope *A* varying from 2.93-4.81% and slope *B* 0.19-0.45%. Based on the hypothesis test, it was found that the difference between the two sample averages had an insignificant difference or H=0.

IV. CONCLUSION

The existence of superparamagnetic grains has a relationship with the value of magnetic susceptibility, some points have soil with high superparamagnetic grains, namely at point *A*, while at point *B* the soil has low superparamagnetic grains so that at that point landslides are not easy to occur. From the analysis of superparamagnetic grains with landslides, the high susceptibility values at points *A* and *B* (red color) with superparamagnetic grains indicate a high level of landslide susceptibility that occurs at that point.

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