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Analysis of Magnetic Susceptibility in Vertical Sediments in the Fish Pond Area of Limboto Lake

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Abstract: Limboto Lake is one of the lakes in Indonesia that has been degraded due to sedimentation and waste disposal, which will affect the lake ecosystem and its surroundings. This research aims to analyze the Magnetic Susceptibility in Vertical Sediments in the fish pond area of Limboto Lake. Efforts must be made to trace sediment's contribution, which is controlled by lithogenic and anthropogenic components. Vertical sediment samples from Fish Ponds in Limboto Lake were taken at one point with a depth of 15 meters using an XY-1A Spindle drilling machine. This type of research uses survey techniques and laboratory tests that use rock magnetism methods, especially susceptibility parameter analysis using the Bartington MS2 susceptibility meter instrument at a low frequency of 470 Hz and a high frequency of 4700 Hz to obtain information on the concentration of magnetic minerals. The sediment samples tested did not go through preparation, such as sieving and drying, but the unsifted samples were put into the plastic holder to analyze the susceptibility magnetic parameter. The measurement results show that the low-frequency magnetic susceptibility (X_{LF}) value ranges from 1.11 x 10^{-8} m^3/kg to 9.68 x 10^{-8} m^3/kg. The concentration of magnetic minerals in this sample contains paramagnetic minerals, and based on the X_{FD} % value, which ranges from 0.206% to 4.714% with an average value of 1.170%, the magnetic minerals in the samples tend to be dominated by coarse-grained non-superparamagnetic minerals (>0.03 μm) and tend to occupy stable single-domain (SSD) and multi-domain (MD) domains. Magnetic susceptibility parameters tested using sediment samples without going through a sieving process can be used to determine sediment characteristics in lake areas that tend to be controlled by anthropogenic components.

Keywords: Fish Pond; Limboto Lake; Magnetic Susceptibility; Vertical Sediment.

Introduction

Lakes are stagnant water sources originating from natural streams or freshwater sources. They have high biodiversity and potential for ecosystem function. However, lakes face many threats from anthropogenic activities [1]. Several priority lakes in Indonesia must be saved from environmental degradation. Limboto Lake is one of these lakes [2]. Limboto Lake is in Gorontalo province; 70% of the Limboto Lake area is in Gorontalo Regency, and 30% is in Gorontalo City [3]. In research conducted by previous researchers, the surface area of Limboto Lake is currently 26.09 km², has a maximum depth of 4 meters and maintains an average depth of 2.83 meters [4]. Compared with 2010 data regarding the area of Limboto Lake of 27 km², it can be seen that the current surface area of the lake has decreased by around 0.91 km², equivalent to around 91 hectares [5]. However, compared with 2019 data regarding the area of Limboto Lake, the lake area has increased by around 5.65 km² or 565 hectares [6]. This increase was due to government initiatives involving water hyacinth removal and dam construction during the measurement period. The main problems in Limboto Lake are extensive sedimentation and the reduction of the lake area [7].

Sediment is soil or parts of soil transported by water from a place that experiences erosion in a river basin and enters the water. Meanwhile, the deposition event is called the sedimentation process, based on the research results of previous researchers, explained that the problem with Limboto Lake was triggered by sedimentation from various main rivers, including the Alo Pohu River, with sediment supply reaching 63%, Marisa 10%, Rintega 8.9%, and Biyonga 8.1% [7, 8]. Besides that, one of the contributors to sediment is fish pond activity caused by settled feed residue, faeces and metabolic waste in fish [9]. Pond activities can cause colour changes in sediment; the visual characteristics of sedimentation change from brown to greyish brown with a soft texture like clay [10].

To determine the process of changing the water environment of rivers and lakes, the sediment must be analyzed using the rock magnetism method. The rock magnetism method is magnetically sensitive to minerals whose behaviour is controlled by environmental changes. Apart from that, the advantages of the magnetism method are that measurements can be carried out on all materials, the measurements are safe, simple, fast and non-destructive; measurements can be carried out in the laboratory, and measurements can complement many other types of environmental analysis [11]. One of the rock magnetism

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parameters most commonly used is the magnetic susceptibility parameter (X_{LF}), which is the ratio or ratio between the magnetization obtained by the sample and the weak magnetic field provided to see the magnetic moment response in the sediment. The magnetic susceptibility parameter is a good proxy indicator for determining the concentration and type of magnetic minerals, grain size, magnetic domain status, and shape, which are influenced by the environment in which they form [11].

Vertical sediment sampling is one method for obtaining sediment in a lake to determine the concentration and type of magnetic minerals. Vertical sediment sampling occurs on the surface at different depths [12]. The degradation of Limboto Lake caused by sedimentation, especially in fish pond areas, requires analyzing sediment characteristics so that the sedimentation process can be identified and strategies for conserving this area from anthropogenic activities. Therefore, this research aims to investigate the characteristics of magnetic minerals based on the susceptibility parameters in the vertical sediments in the Fish Pond area of Limboto Lake. This research is essential to know the magnetic mineral characteristics of sediments, which are controlled by lithogenic and anthropogenic components.

Research Methods

Based on rock magnetism, studies reported by previous researchers show that the sediments of Limboto Lake tend to be dominated by magnetic minerals originating from anthropogenic components [13]. However, this study reports magnetic mineral sources in the upstream and downstream areas of the Biyonga River, Alopohu River and Talumelito River and uses horizontal sediments. However, comparing mineral sources at each lake depth is also necessary to track environmental changes. Therefore, in this study, one point was taken vertically with a depth of 15 meters in the Limboto Lake Fish Pond Area with the point location presented in Figure 1.

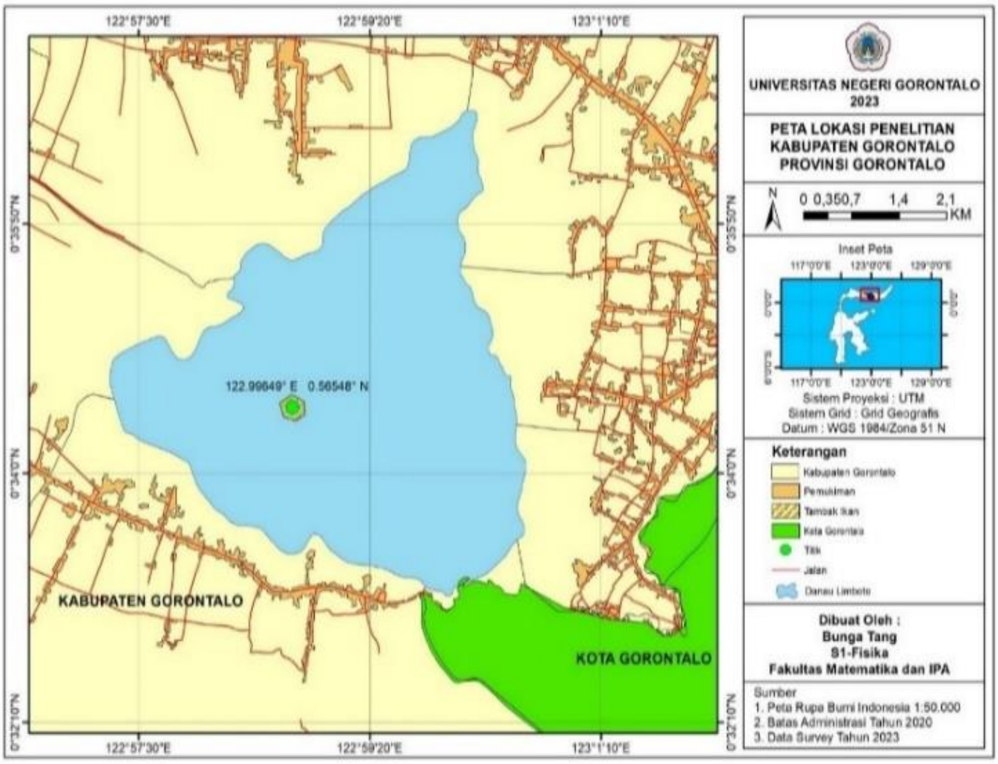

Figure 1. Sediment Sampling Locations

Sediment sampling in the fish ponds of Limboto Lake was carried out in 2023. At that time, the lake was shallow, with an average depth of 3 meters. The fish ponds in Limboto Lake use floating net cages made from wood, bamboo and nets. Samples were taken using an XY-1A Spindle drilling machine, separated at each depth to produce 15 samples. Sample preparation for the magnetic susceptibility test was different from that carried out by previous researchers, namely that preparations such as filtering, drying and grinding were not carried out [13-14]. The sediment samples tested in this study were placed in a cylindrical plastic holder with a diameter of 25.4 mm and a height of 22 mm for the magnetic mineral susceptibility test. The magnetic susceptibility parameter measured is mass-based magnetic susceptibility in units of m^3/kg measured using the Bartington MS2 susceptibility meter instrument. This tool works at a low frequency of 470 Hz and a high frequency of 4700 Hz to obtain information on magnetic mineral concentrations. In addition, the comparison of magnetic susceptibility at low frequencies (X_{LF}) and high-frequency magnetic susceptibility (X_{HF}) produces frequency-dependent magnetic susceptibility values (X_{FD}%) using equation 1 [11].

$$\chi_{FD}(\%) = \frac{\chi_{LF} - \chi_{HF}}{\chi_{LF}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

The parameter X_{FD} % is an indicator of the concentration of ultrafine grains (ultrafine grains) superparamagnetic (SP), namely magnetic grains, by the classification [11, 15].

Results and Discussion

The results of measuring magnetic susceptibility values in the vertical sediments in the fish ponds of Limboto Lake can be seen in Table 1. In Table 1, the magnetic mineral susceptibility values at low frequency (X_{LF}) and high frequency (X_{HF}) are presented, as well as the percentage of frequency-dependent magnetic susceptibility (X_{FD}%) measured on 15 vertical sediment samples from fish ponds in Limboto Lake. The X_{LF} value ranges from 1.11 x 10^{-8} m^3/kg to 9.68 x 10^{-8} m^3/kg. Meanwhile, the X_{HF} value ranges from 1.10 x 10^{-8} m^3/kg to 9.66 x 10^{-8} m^3/kg. The average values of X_{LF} and X_{HF} are around 4.464 x 10^{-8} m^3/kg and 4.421 x 10^{-8} m^3/kg, respectively. Meanwhile, the X_{FD}% value ranges from 0.206% to 4.714%, with an average value of 1.170%.

Table 1. Magnetic susceptibility values in vertical sediments in the fish ponds area of Limboto Lake

Sample Code	X_{LF} ($10^{-8}m^3$/kg)	X_{HF} ($10^{-8}m^3$/kg)	X_{FD} (%)
S1	7.68	7.64	0.521
S2	3.97	3.81	4.031
S3	2.97	2.83	4.714
S4	4.65	4.59	1.291
S5	4.34	4.32	0.461
S6	1.41	1.39	1.418
S7	4.95	4.91	0.808
S8	3.08	3.07	0.325
S9	2.56	2.55	0.391
S10	1.11	1.10	0.901
S11	9.68	9.66	0.206
S12	6.34	6.32	0.315
S13	8.31	8.25	0.722
S14	1.26	1.25	0.794
S15	4.65	4.62	0.645
Average	4.464	4.421	1.170
Min	1.11	1.10	0.206
Max	9.68	9.66	4.714

The magnetic mineral susceptibility value (X_{LF}) of vertical sediments in the fish ponds of Limboto Lake is lower than 10 x 10^{-8} m^3/kg in Figure 2. This shows that all measured sediment samples contain magnetic minerals dominated by the paramagnetic mineral group [11]. Paramagnetic are minerals with a small magnetic susceptibility value (< 10^{-6} m^3/kg) but have a positive value [16].

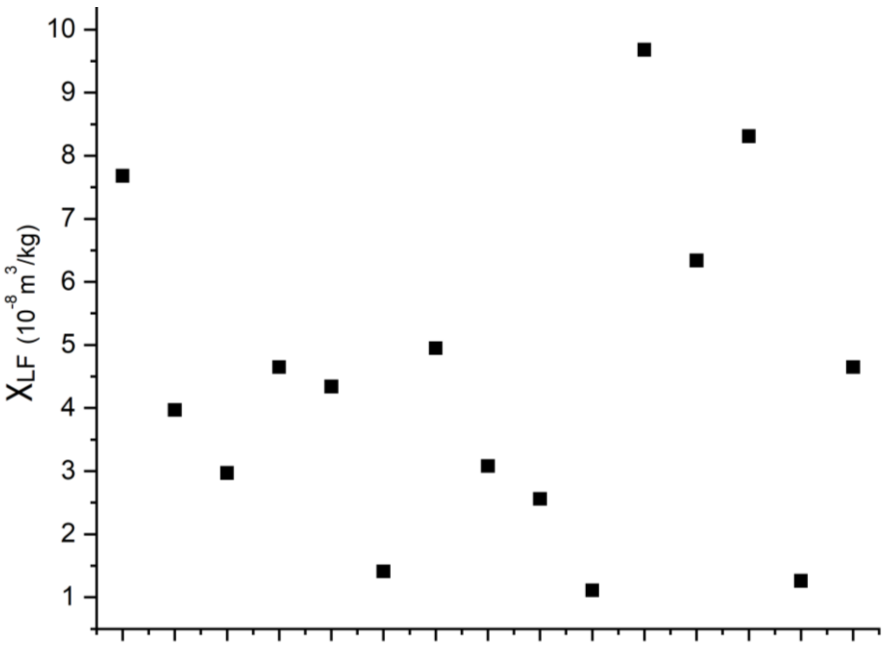

Figure 2. Graph of X_{LF} susceptibility to depth

In Graphic Figure 2, changes in the X_{LF} value for each depth are caused by magnetic minerals with different concentrations at each depth. Interestingly, the highest X_{LF} value was at a depth of 11 m (S11), namely 9.68 x 10^{-8}

m^3/kg. High and low X_{LF} values in magnetic susceptibility values can be caused by differences in the distribution of magnetic minerals in the samples [17].

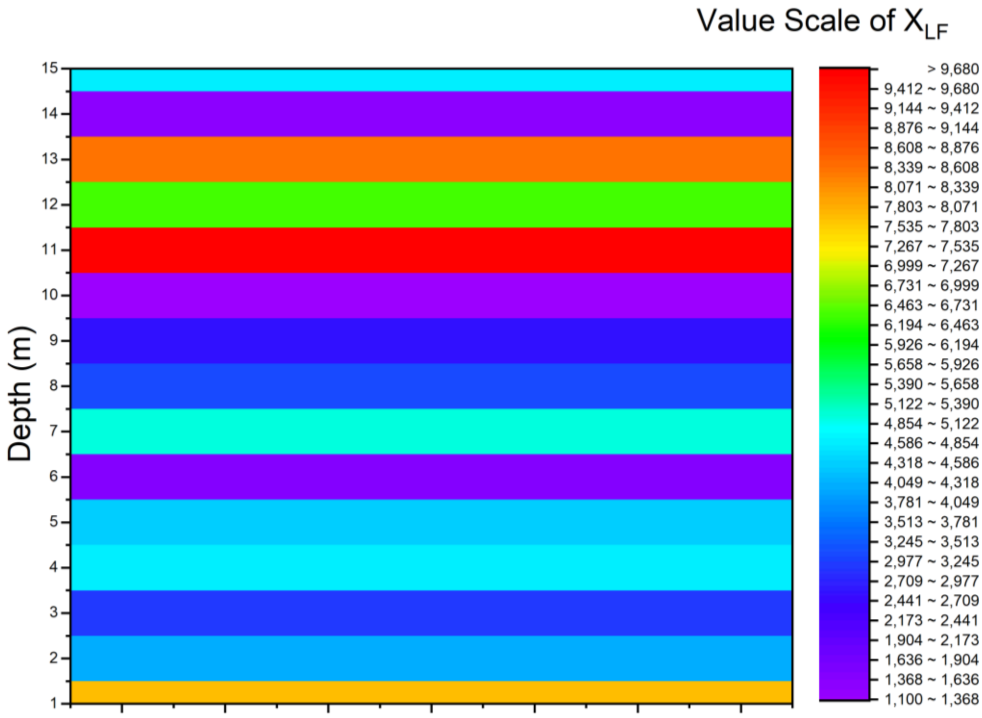

Figure 3. The contour of magnetic susceptibility values (X_{LF}) based on depth

Figure 3 shows the magnetic susceptibility value (X_{LF}) contour based on depth. The X_{LF} value scale is displayed with color gradations; red represents the highest X_{LF} value, while purple represents the lowest value. The X_{LF} value found in the vertical sediment samples from fish ponds in Limboto Lake at a depth of 1 m tends to be lower, namely 7.68 x10^{-8} m^3/kg, compared to the horizontal sediment in Limboto Lake at point 15 around the fish pond, namely 67.40x10^{-8} m^3/kg [13]. The low X_{LF} susceptibility value in fish ponds is thought to be due to anthropogenic activities, especially ponds that use fish feed, which contain chemicals such as heavy metals, which can affect the susceptibility value. Apart from that, the weathering of bamboo and wood used as floating net cages by fish farmers is also thought to contribute to sediment. In research conducted by previous researchers, excessive fish feeding every day resulted in deposition at the bottom of the lake, and the metal levels of Fe, Cu, Pb and Cd originating from fish food in the sediment of Lake Meninjau had exceeded the threshold set by Roseau National d Observation [18]. The high X_{LF} value in horizontal sediments is because horizontal sediments are usually newer than vertical sediments. New sediment tends to contain more magnetic material because it has not undergone a weathering process that can reduce the magnetic mineral content [13, 19].

In addition, the sediment samples tested did not go through a sieving process, so the impurities contained in the samples, such as organic matter, were still combined with the sediment samples. The condition of this sample is thought to have influenced the magnetic mineral concentration value to be minor, as indicated by the low X_{LF} value. The sediment preparation process for testing rock magnetism, which uses an extraction process of impurities, can provide test results for the characteristics of magnetic minerals [20]. The mineral composition can be distorted without proper preparation, affecting the measured susceptibility values [21].

However, this research shows that sediment samples without a separation or sieving process can still provide information on magnetic characteristics appropriate to the natural conditions studied. Sediment X_{LF} data in the fish pond area of Limboto Lake, which tends to be low, apparently has a trend similar to that found by [13, 14, 22], shows that X_{LF} in residential areas tends to be lower compared to locations far from settlements or far from anthropogenic activities. This finding further confirms that the low susceptibility value in this study is more caused by anthropogenic activities, especially fish pond activities that use organic and chemical materials.

The presence of the mineral magnetite in sediments originates from natural or lithogenic rock weathering processes and from human or anthropogenic activities [11, 23]. To find the source of this magnetite mineral, it is necessary to look at the concentration, grain size and type of magnetic domain, which are presented from the results of measuring magnetic parameters, namely magnetic susceptibility because the concentration value is influenced by the grain size, composition and shape of the magnetic minerals that make up it [24]. The size of magnetic mineral grains can be identified from the X_{FD} % value, which indicates the presence of excellent superparamagnetic (SP) grains (>0.03 µm) originating from natural bedrock weathering processes or lithogenic components.

The data in Table 1 shows that the average X_{FD} % value in the sample is around 1.170%, which is included in the low X_{FD} % category. This means that the magnetic minerals in the samples tend to be dominated by non-SP magnetic minerals with coarse grain size (>0.03 µm) [11, 15]. This finding can be strengthened by the plot diagram between X_{LF} and X_{FD} % in Figure 4, which shows the grain size and magnetic mineral domain status, indicating the source of the magnetic minerals in the sample.

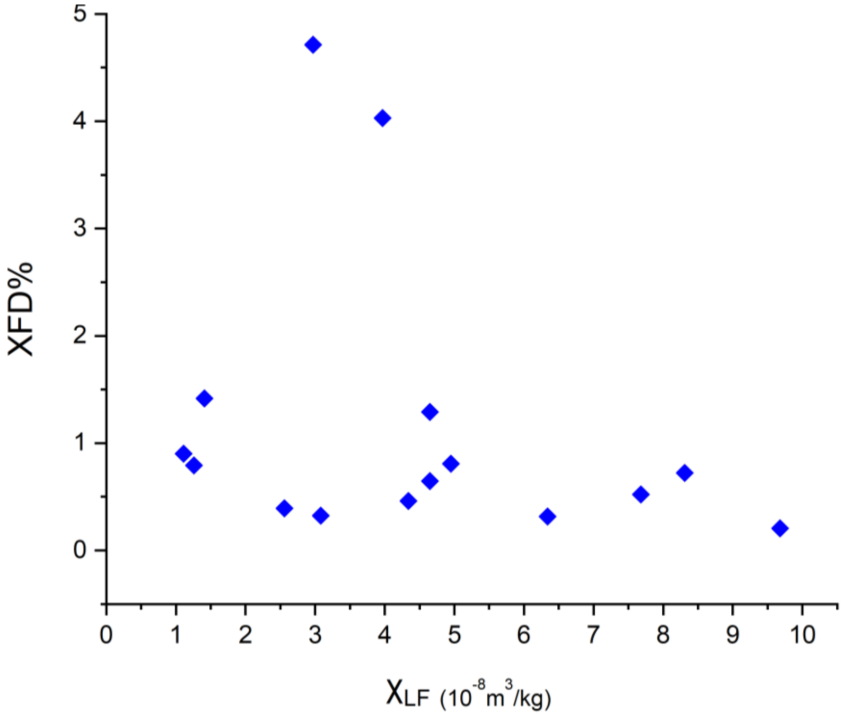

Figure 4. Bivariate scatter diagram between X_{LF} and X_{FD} %

Figure 4 shows a bivariate scatter diagram between X_{LF} and X_{FD} %, which shows the typical grain size and magnetic mineral domains in the vertical sediment samples of Fish Ponds in Limboto Lake. Paramagnetic minerals more influence the X_{LF} value, and the highest X_{FD} % value was obtained in samples (S2 and S3) with two depths, namely (2 m and 3 m), with values of 4.031% and 4.714%. This shows that the sediment samples contain superparamagnetic grains of ultrafine grain (< 0.03 µm) [11]. The nature of the superparamagnetic minerals in this sediment indicates that the magnetic minerals do not have residual magnetization (remanence) after removing the external magnetic field. Consequently, superparamagnetic minerals deposited in lake sediments may reflect sources of particulates in environments controlled by human activities.

From this research, it is suspected that at depths of 2 and 3 m, there are events in the same season which cause high X_{FD} % values. According to [25], in palaeoclimatology studies, high X_{FD} % values in lake sediments have often been associated with wet climate conditions. This could indicate historical climate change, where fluctuations in X_{FD} % values indicate variations between dry and wet periods that influence depositional patterns and the composition of magnetic minerals in lake sediments. This means that at a depth of 2 and 3 meters, damp climate conditions occur, which have a more dominant influence on the sediment deposition process in Limboto Lake. While the other 12 depths have low X_{FD} % values of less than 2%, this indicates that the type of magnetic mineral in the sample is dominated by non-SP magnetite minerals, which are coarse-grained (>0.03 µm) and tend to occupy stable single-domain (SSD) domains and multi-domain (MD). This finding is similar to research results by [13, 14], which have found that magnetic mineral properties originate from anthropogenic components, mainly from agricultural activities and residential waste, which tend to be dominated by coarse-sized non-SP minerals (> 0.03 µm) and have SSD and MD domains.

Interestingly, this research found that sediment samples used to test the susceptibility of magnetic minerals without going through the sieving process still provided information on the characteristics of magnetic minerals, which tended to be the same as wet sediments that went through the sieving process. Apart from that, it was also found that the trend of sediment characteristics in fish pond areas has a deficient concentration of magnetic minerals and is included in the paramagnetic category. However, the properties of these magnetic minerals tend to be influenced by human activities in fish ponds, except for areas 2 and 3, which are strongly influenced by the sedimentation process, which is transported by water to the lake. Based on the results of this research, it is recommended that a study of sediment utilization be carried out in fish pond areas to reduce high sediment deposits in the area.

Conclusion

The magnetic susceptibility parameter analysis results have proved that the Fish Pond sediments of Limboto Lake, without preparation, tend to come from anthropogenic components, especially from fish pond activities, agriculture and residential waste. The measurement results show that the magnetic susceptibility value X_{LF} ranges from 1.11 x 10^{-8} m^3/kg to 9.68 x 10^{-8} m^3/kg. The concentration of magnetic minerals in this sample contains paramagnetic minerals, and based on the X_{FD} % value, which ranges from 0.206% to 4.714% with an average value of 1.170%, the magnetic minerals in the sample tend to be dominated by non-superparamagnetic coarse-grained minerals (>0.03 µm) and tend to occupy

SSD and MD. These findings can recommend efforts to save Limboto Lake from anthropogenic components by reducing fish feed organic materials, which increase the sedimentation process in fish pond areas. There is also a need for studies on the potential utilization of sediment in fish pond areas to reduce high sediment deposits. Besides that, this research has proven that magnetic susceptibility parameters can differentiate the magnetic mineral characteristics of sediments, which are controlled by lithogenic and anthropogenic components, even though the sediment samples have not undergone a sieving process.

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