Magnetic susceptibility of surface sediment in the Tallo tributary of Makassar city

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Abstract. Activities along the tributary of the Tallo river cause discoloration and unpleasant odors in the river water. This condition indicates that the river was polluted by anthropogenic waste. Therefore, a scientific study was conducted to determine the environmental conditions of the Tallo tributary through a preliminary study of the mineral characteristics of the surface sediments based on magnetic susceptibility data. The surface sediment was taken and its magnetic susceptibility measurements were carried out, followed by the interpretation of mineral types, element content, the presence of superparamagnetic minerals, and magnetic grains. The results showed that the minerals contained in the sediment samples were predominantly ferrimagnetic. The elemental content of the sediment samples indicated that Fe, Mn, and Cr were classified as heavy metals. Traces of the presence of superparamagnetic minerals show almost none. Meanwhile, the magnetic susceptibility values at low and high frequencies are identical, indicating that the grains contained in the sediment samples are multi-domain (MD), where the dominant magnetic minerals come from anthropogenic minerals.

1. Introduction

River surface sediments have been studied using environmental magnetization methods [1, 2]. Environmental sediments are included in the aquatic environment, apart from river sediments [3, 4], lakes [5, 6], and the sea as well [7, 8]. The environmental magnetism method is a method that is new and developing. This method is a development of the rock magnetism method which is associated with the mineral magnetic properties of a material with environmental processes that control it [9]. That is the identification of the dominant magnetic minerals associated with the source or mechanism of environmental change [10].

Magnetic minerals are influenced by elements such as iron (Fe) that are abundant in the earth’s crust [11-14]. Fe is easy to detect using the environmental magnetic method. One of the parameters used is magnetic susceptibility [15, 16]. The magnitude of the magnetic susceptibility value of material was controlled by the Fe content. Increasing the Fe concentration of a material has an impact on increasing the susceptibility value as well. Magnetic mineral properties depend on the type, concentration, shape, and magnetic mineral grains [17]. The advantages of the environmental magnetic method are that it is simple, fast in obtaining results, does not damage the sample, and is affordable [18].
This research was conducted on the surface sediments of the Tallo tributary. Along the river, there are residential areas, factories, and ponds. Several studies have shown that environmental changes were influenced by activities in river basins [19-23]. This study uses magnetic parameters to produce anthropogenic magnetic minerals. In addition to the types of minerals and features of surface sediments, studies related to the presence of superparamagnetic minerals and magnetic grain content were still underreported, so it is necessary to do so. In this study, measurements of magnetic susceptibility were carried out and analyzed for magnetic mineral properties. This paper is useful for knowing the types of minerals, elemental content, presence of superparamagnetic minerals, and magnetic grain content.

2. Method

2.1. Study area
Makassar City was located between 119°24'17"38" BT and 5°8'6"19" LS. Makassar City was influenced by alluvium deposits, camba formations, salo kalupang formations, and tonnage formations. Based on figure 1, especially in the Tallo tributary area, it is affected by alluvium deposits formed of gravel, sand, loam, and mud. The Camba Formation is the camba volcanic rock located in the western part, consisting of volcanic breccias and conglomerates, lava and tuff interbedded with marine sediments.

![Geological map and sediment sampling locations for the Tallo tributary.](image)

**Figure 1.** Geological map and sediment sampling locations for the Tallo tributary.

2.2. Sampling
Surface sediment samples were taken at 27 points randomly using a Van Veen grab samples. Each coordinate point is determined using GPS (Global Position System). The samples were put in nylon plastic and given a sample code name. Next, it was placed in a container and dried at room temperature. Samples were sieved using a 100 mesh sieve, weighed as much as 20 g, and tested for magnetic susceptibility.

2.3. Magnetic susceptibility measurement
The sample was put in a sample holder measuring 2.2 cm high and 2.54 cm in diameter. Then, the magnetic susceptibility was measured using the Bartington Susceptibility Meter MS2 type MS2B that worked at a low frequency of 470 Hz and a high frequency of 4700 Hz. Then, the measurement results were analysed using the Multisus application in order to obtain magnetic susceptibility values at low ($\chi_{\text{FD}}$) and high ($\chi_{\text{HF}}$) frequencies [15]. Based on $\chi_{\text{FD}}$ data, the type of minerals and contents were interpreted based on the magnetic susceptibility value according to [17] and [24]. Furthermore, $\chi_{\text{FD}}$ and $\chi_{\text{HF}}$ histograms was made to predict the presence of superparamagnetic minerals. Difference between magnetic susceptibility at low and high frequencies to obtain frequency-dependent magnetic susceptibility ($\chi_{\text{FD}}$) [25]. $\chi_{\text{FD}}$ analysis is used for the interpretation of mineral grain content, whether minerals contain multi-domain (MD), pseudo-single domain (PSD), single domain (SSD), and superparamagnetic (SP) [26]

### 3. Result and Discussion

| Sample | $\chi_{\text{FD}}$ ($10^4 \text{m}^3/\text{kg}$) | $\chi_{\text{HF}}$ ($10^4 \text{m}^3/\text{kg}$) | $\chi_{\text{LH}}$ ($10^4 \text{m}^3/\text{kg}$) | $\chi_{\text{LH}}$ (%) |
|--------|---------------------------------|----------------------|-----------------------|-------------------------|
| M1     | 238.2                           | 234.8                | 3.4                   | 1.68                    |
| M2     | 259.6                           | 255                  | 4.6                   | 1.77                    |
| M3     | 374.6                           | 366.3                | 8.3                   | 2.22                    |
| M4     | 509.2                           | 502.9                | 6.3                   | 1.24                    |
| M5     | 216.5                           | 214.2                | 2.3                   | 1.06                    |
| M6     | 968.7                           | 957.4                | 11.3                  | 1.17                    |
| M7     | 521.5                           | 515.6                | 5.9                   | 1.13                    |
| M8     | 257.7                           | 254.1                | 3.6                   | 1.40                    |
| M9     | 343.4                           | 337.3                | 6.1                   | 1.78                    |
| M10    | 337.5                           | 331.7                | 5.8                   | 1.72                    |
| M11    | 463.4                           | 459.6                | 3.8                   | 0.82                    |
| M12    | 301.3                           | 298.3                | 3.0                   | 1                       |
| M13    | 249.6                           | 245.6                | 4.0                   | 1.6                     |
| M14    | 353.6                           | 349.3                | 4.3                   | 1.22                    |
| M15    | 246.8                           | 245.6                | 1.2                   | 0.49                    |
| M16    | 227.3                           | 224.5                | 2.8                   | 1.23                    |
| M17    | 204.3                           | 202.4                | 1.9                   | 0.93                    |
| M18    | 238.3                           | 236.7                | 1.6                   | 0.67                    |
| M19    | 183.1                           | 179.5                | 3.6                   | 1.97                    |
| M20    | 171.8                           | 167.9                | 3.9                   | 2.27                    |
| M21    | 107.5                           | 104.2                | 3.3                   | 3.07                    |
| M22    | 95.3                            | 92.6                 | 2.7                   | 2.83                    |
| M23    | 101.1                           | 99.7                 | 1.4                   | 1.38                    |
| M24    | 152.2                           | 149.8                | 2.4                   | 1.58                    |
| M25    | 47.7                            | 45.7                 | 2.0                   | 4.19                    |
| M26    | 136.1                           | 133                  | 3.1                   | 2.28                    |
| M27    | 124.2                           | 121.9                | 2.3                   | 1.85                    |

The mass-specific magnetic susceptibility values of the Tallo tributary sediments for 27 samples are shown in table 1. The values for magnetic susceptibility at low frequencies range from $47.7 \times 10^{-8}$ m$^3$/kg to $968.7 \times 10^{-8}$ m$^3$/kg. The histograms for samples 1 to 27 are shown in figure 2. The value of magnetic susceptibility in zone 1 (factory and residence) is high enough but in zone 2 (pond area) has decreased. This indicates that the sediment in zone 1 has a relatively high concentration of magnetic minerals compared to zone 2. This is shown on the contour map of the distribution of the magnetic susceptibility.
values (figure 3). This result is by following per under several studies which state that the increase in the magnetic susceptibility value of the sediment is in line with the increasing concentration of magnetic minerals contained in the sediment.

![Figure 2](image)

**Figure 2.** Histogram of magnetic susceptibility value at low frequency (\(\chi_{LF}\)) sediment samples of Tallo tributaries.

![Figure 3](image)

**Figure 3.** Distribution of magnetic susceptibility values at low frequency (\(\chi_{LF}\)) sediment samples of Tallo tributaries.

Based on the magnetic susceptibility values of [17] and [24], it is indicated that the sediments of the Tallo river contain magnetic minerals such as hematite (\(\alpha\)-Fe\(_2\)O\(_3\)), ilmenite (FeTiO\(_3\)), goethite (\(\alpha\)-FeOOH), pyrrhotites (Fe\(_{1-x}\)S), jacobsite (MnFe\(_2\)O\(_4\)), and chromite (FeCr\(_2\)O\(_4\)) (table 2). These minerals
are predominantly included in antiferromagnetic minerals. This becomes interesting, when generally river sedimentary minerals are ferrimagnetic. This means that the magnetic minerals in the sediments dominantly do not come from rock weathering (lithogenic), but indicated to come from human activities (anthropogenic).

| No. | Mineral   | Formula         | Magnetic order         |
|-----|-----------|-----------------|------------------------|
| 1   | Hematite  | α-Fe₂O₃         | Canted antiferromagnetic|
| 2   | Ilmenite  | FeTiO₃          | Antiferromagnetic       |
| 3   | Goethite  | α-FeOOH         | Antiferromagnetic       |
| 4   | Pyrrhotites | Fe₁₋ₓS     | Ferrimagnetic           |
| 5   | Jacobsite | MnFe₂O₄         | Ferrimagnetic           |
| 6   | Chromite  | FeCr₂O₄         | Ferrimagnetic           |

Table 2. Mineral content in the surface sediments of the Tallo tributary.

From the alleged content of magnetic minerals, it can be seen that the content of elements such as iron (Fe), oxygen (O), titanium (Ti), hydrogen (H), sulfur (S), manganese (Mn), and chromium (Cr). Three elements are included in heavy metals, namely Fe, Mn, and Cr because they have a density of more than 5 g/cm³ [27]. All magnetic minerals contain the element Fe [28]. Fe is a ferromagnetic metal with the highest magnetic susceptibility value [17]. As previous studies [22] suggest that Fe is a ferromagnetic element that greatly affects the value of magnetic susceptibility in sediment samples. Increasing the concentration of the element Fe causes an increase in the concentration of magnetic minerals and has an impact on increasing the value of magnetic susceptibility.

Higher frequency measurements do not allow the superparamagnetic grain to react with the magnetic field used, because it changes faster than the relaxation time required for superparamagnetic grains. As a result, in higher frequencies, lower magnetic susceptibility values are encountered [26]. In this study, the measurement results show that there is no significant difference between the magnetic susceptibility values at high and low frequencies (figure 4). This means that the river sediment samples contain almost no superparamagnetic minerals. If there is no superparamagnetic mineral (SP), the two measurements are identical. This can be seen in the frequency-dependent magnetic susceptibility values ranging from 0.49 to 4.19%. Based on [17], the frequency-dependent susceptibility value for simple single domain (SSD) grains ~30 x 10⁻⁶ m³/kg and for superparamagnetic grains (SP) 75-160 x 10⁻⁶ m³/kg. The identical magnetic susceptibility values at low and high frequencies also indicate that the grains contained in the iron sand sample are multi-domain (MD). This result is by following per under the theory which states that multi-domain magnetic grains (MD) are frequency-independent because they show the same magnetic susceptibility values at low and high frequencies [26, 29].

The frequency-dependent percentage of magnetic susceptibility is used to estimate the total concentration of superparamagnetic grains. Based on table 1, it shows that the percentage of magnetic susceptibility depends on the frequency of more than 2% in samples M3, M20, M21, M22, M25, and M26. This means that the sample contains a coarse mixture of SP and non-SP grains or SP <0.005 μm granules. For samples other than this code, the percentage is less than 2%. According to [17], the percentage value of less than 2% is included in the low percentage group and indicates that there are almost no superparamagnetic grains in the river sediment samples. These results are consistent with the χLF-χFD scattering diagram in figure 5 which shows that most of the sediment samples contain multi-domain (MD) grains with grain diameter ~110 μm and more than 2% contain superparamagnetic grains and single domain (SP-SSD) [17, 29].
Figure 4. Histogram of magnetic susceptibility values at high ($\chi_{HF}$) and low ($\chi_{LF}$) frequencies sediment samples of Tallo tributaries.

Figure 5. $\chi_{LF}$-$\chi_{FD}$ scattering diagram showing the type of domain in the Tallo tributary sediment sample.

4. Conclusion
The results indicated that the minerals contained in the sediment samples were hematite (α-Fe$_2$O$_3$), ilmenite (FeTiO$_3$), goethite (α-FeOOH), pyrrhotites (Fe$_{1-x}$S), jacobsite (MnFe$_2$O$_4$), and chromite (FeCr$_2$O$_4$). These results obtained elemental content which is classified as heavy metals such as Fe, Mn, and Cr. Meanwhile, the magnetic susceptibility values at low and high frequencies that are identical indicate that the grains contained in the sediment samples are multi-domain (MD), where the dominant magnetic minerals were derived from anthropogenic minerals.
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