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Research Article

Relation Between Transport Distance with Frequency-Dependent Volume Magnetic Susceptibility in Surabaya River Sediments

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Abstract

Volume magnetic susceptibility measurements have been widely used in numerous studies related to river sediment characterization. A study of the transport distance effect toward the frequency-dependent volume magnetic susceptibility is needed to identify the superparamagnetic grain behavior in river sediments. The purpose of this study is to identify the presence of superparamagnetic grains and to obtain the relation between transport distances and frequency-dependent volume magnetic susceptibility in river sediments. The sediment samples were taken and measured by using the Bartington MS2B Susceptibilitymeter at two different frequencies of 470 Hz and 4700 Hz. The measurement results show that the sediment transport distance is directly proportional to the frequency-dependent volume magnetic susceptibility. Superparamagnetic grain content is identified to tend to be higher as the distance of sediment transport increases.

Keywords: *magnetic susceptibility, river sediments, transport distance, superparamagnetic grain*

Hubungan Antara Jarak Transportasi dengan Suseptibilitas Magnetik Volume Bergantung Frekuensi pada Sedimen Sungai Surabaya

Abstrak

Pengukuran suseptibilitas magnetik volume telah banyak digunakan dalam berbagai penelitian yang berhubungan dengan karakterisasi sedimen sungai. Penelitian mengenai pengaruh jarak transportasi *terhadap suseptibilitas magnetik volume bergantung frekuensi diperlukan untuk mengidentifikasi kelakuan bulir superparamagnetik di sedimen sungai. Tujuan penelitian ini adalah untuk mengidentifikasi keberadaan bulir superparamagnetik dan memperoleh hubungan antara jarak transportasi dengan suseptibilitas magnetik volume bergantung frekuensi pada sedimen sungai. Sampel sedimen diambil dan diukur dengan alat pengukur suseptibilitas magnetik Bartington MS2B pada dua frekuensi 470 Hz dan 4700 Hz. Hasil pengukuran menunjukkan bahwa jarak transportasi sedimen sebanding dengan suseptibilitas magnetik volume yang bergantung frekuensi. Kandungan butir superparamagnetik diidentifikasi cenderung semakin tinggi seiring bertambahnya jarak transportasi sedimen.*

Kata Kunci: *suseptibilitas magnetik, sedimen sungai, jarak transportasi, bulir superparamagnetik*

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I. INTRODUCTION

Geophysical survey on the earth's surface is an indirect measurement and an important stage to map the physical properties in the subsurface. Previous studies, such as surveys of magnetics [1,2], gravity [3,4], electrical resistivity [5,6], electromagnetics [7] and microearthquake [8] have successfully modeled the physical properties in the subsurface. On the other hand, direct measurement of the earth's material is also an important stage to characterize the subsurface conditions.

Magnetic susceptibility measurements have been widely used in various studies with various materials, including rocks [9,10], soils [11–13], sediments [14–16] and dusts [17,18]. In the aquatic environments, magnetic susceptibility measurements have been applied to river sediments [14,15,19], marine sediments [16,20] and lake sediments [15,21]. Measurements of magnetic susceptibility especially in riverine environments have been conducted in association with heavy metal pollution [19], storm event [22] and lithology [23].

Various studies of frequency-dependent magnetic susceptibility have been undertaken by several researchers related to magnetic viscosity [24], landmine clearance [25], systems containing nanometer-sized magnetic particles [26] and a proxy for fine-grained iron minerals and aggregate stability [27]. Measurements of frequency dependent magnetic susceptibility have been applied to characterize the properties of materials such as graphitic pottery [28], magnetite at low temperature [29], a colloidal suspension of manganese ferrite nanoparticle [30] and cobalt ferrite nanoparticles embedded in PAA Hydrogel [31].

Previous studies have never reported the effect of transport distance to the frequency-dependent volume magnetic susceptibility. Dearing [32] explains that the value of frequency-dependent volume magnetic susceptibility is influenced by the presence of superparamagnetic grain in the material. Superparamagnetic grain is associated to the grain size of magnetic minerals in the material. The hypothesis of this study is the transport distance of river sediments has a relation with superparamagnetic grain content so that it can affect the value of frequency-dependent volume magnetic susceptibility. The present study aims to identify the existence of superparamagnetic grains and to explain the relation between transport distances with frequency-dependent volume magnetic susceptibility in river sediments.

Magnetic susceptibility is one of the important parameters to characterize the earth's material. Volume magnetic susceptibility is a quantity that states the ratio between the magnetization response of a material due to the presence of an external magnetic field acting on the material [33]. Dearing [32] states that magnetic susceptibility is influenced by the type, size and content of magnetic minerals in the material.

The grain size of the magnetic mineral is related to the magnetic domains of a magnetic material. An area within a crystal where all of its magnetic moments are aligned is called the magnetic domain. Each domain is separated by a domain wall [34]. Dunlop and Özdemir [35] classify the magnetic domains of magnetite mineral based on grain size from small to large including: single domain (<0.1 μm), pseudo single domain (0.1-10 μm) and multi domain (>10 μm). Single domain grain has only one domain whereas multi domain has more than one domain. Meanwhile, pseudo single domain is a grain with multiple domain but has properties like single domain grain.

Lowrie [33] explains that single domain grain is the more stable carrier of remanent magnetization than multi domain grain. There is a very fine magnetic grain <0.03 μm called superparamagnetic grain [32]. This grain cannot record remanent magnetization as a paramagnetic material but shows very high magnetization when the external magnetic field is applied.

II. RESEARCH METHOD

The study area is in Surabaya River, Province of East Java, Indonesia. Brantas River is the upstream part of the Surabaya River. This river flows from the Dam Mlirip in Mojokerto through the city of Gresik, Sidoarjo and ends in Surabaya. In Surabaya, this river branches into two parts namely the Mas River and Wonokromo River. The Mas River flows to northward while the Wonokromo River flows to eastward of Surabaya. Both rivers lead to the Madura strait. Mas River is an artificial river as a city drainage so that sediment sampling is not conducted in this river.

According to geological map that was published by the Geological Research and Development Center of Indonesia, rock formations around the Surabaya River consist of series of alluvial deposit and sedimentary rock. Sedimentary rock series is divided into the formation of Kabuh, Pucangan and Lidah. Alluvial deposit is estimated to be Holocene while the sedimentary rock series is estimated to be Pleistocene [36].

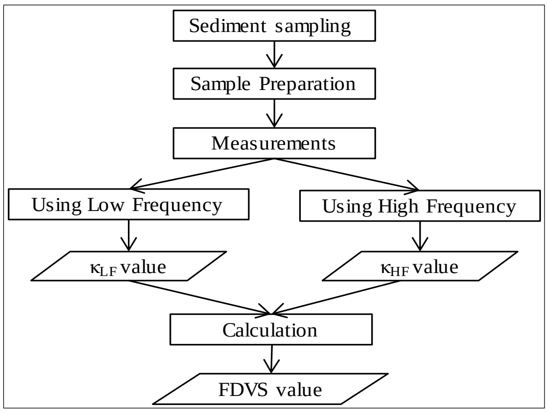

Figure 1. Data Collection Method

Figure 1 shows the flow chart of the data collection method consisting of sediment sampling, sample preparation and measurements. Sediment sampling was conducted in eight different locations along the Surabaya River with spaces between sampling points 4-8 km (Figure 2). Sample preparation consists of cleaning the sample, drying the sample and the treatment before the measurement. The dried samples were inserted into plastic cylinders and measured using the Bartington MS2B Susceptibilitymeter. Mathematically, the volume magnetic susceptibility can be expressed by the Equation (1) [32]:

$$\kappa = \frac{M}{H} \tag{1}$$

in which:

$\kappa =$ volume magnetic susceptibility (dimensionless)

$M =$ magnetization (Am^{-1})

$H =$ magnetizing field (Am^{-1})

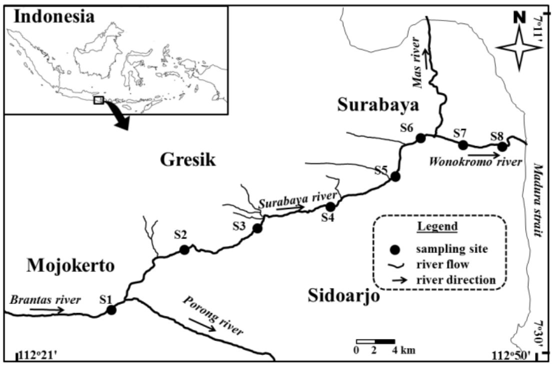

Figure 2. Map of the Location of Sediment Sampling in Surabaya River

The measurements are performed in two stages using two different frequencies. The first measurement was performed using low frequency (470 Hz) resulting value of volume magnetic susceptibility at low frequency. The second measurement was performed using high frequency (4700 Hz) resulting value of volume magnetic susceptibility at high frequency. Both measurements will produce value of frequency-dependent volume magnetic susceptibility. Mathematically, frequency-dependent volume magnetic susceptibility can be given by equation (2) [32]:

$$\mathrm{FDVS} = \frac{\kappa_{LF} - \kappa_{HF}}{\kappa_{LF}} \tag{2}$$

in which,

FDV=frequency-dependent volume magnetic susceptibility (dimensionless)

κ_{LF} =frequency-dependent volume magnetic susceptibility at low frequency (dimensionless)

κ_{HF} =frequency-dependent volume magnetic susceptibility at high frequency (dimensionless)

The analysis was conducted to find out the relation between frequency-dependent volume magnetic susceptibility with river sediment transport distance. The reference of transport distance is determined from upstream to downstream of the river (from sample S1 to S8). In addition, frequency-dependent volume magnetic susceptibility is also used to determine the extent of superparamagnetic grain influence on sediment samples.

III. RESULTS AND DISCUSSION

Magnetic measurements using Bartington MS2B Susceptibilitymeter produce two values of volume magnetic susceptibility in different frequencies by each sediment sample. By calculation using equation (2), we can obtain the frequency-dependent volume magnetic susceptibility value (Table 1). The value of frequency-dependent volume magnetic susceptibility ranges from 0.01146 to 0.02386 (on average 0.01839).

Based on the interpretation of frequency-dependent magnetic susceptibility values proposed by Dearing [32], we can identify the presence of superparamagnetic grains in sediment samples. Samples of S1, S2, S3 and S4 are in area closer to the upstream of the river having value of frequency-dependent volume magnetic susceptibility less than 0.02. The value less than 0.02 is interpreted to be included in the low category. The condition indicates that four samples closer to the upstream contain lower superparamagnetic grain (<10%). Meanwhile, Samples of S5, S6, S7 and S8 are in area closer to the downstream of the river having value of frequency-dependent volume magnetic susceptibility greater than 0.02. The value between 0.02-0.10 are interpreted to be included in the medium category. This condition indicates that four samples closer to the downstream contain higher superparamagnetic grain (>10%) or admixture of superparamagnetic and coarser non-superparamagnetic grains, or superparamagnetic grains <0.005 μm.

Table 1. The Results of Magnetic Susceptibility Measurement and Transport Distance of River Sediment

Sample	Transport Distance (km)	κ_{LF} (x 10^{-5} SI)	κ_{HF} (x 10^{-5} SI)	FDVS
S1	0	930	920	0.01146
S2	8	547	539	0.01465
S3	16	423	416	0.01596
S4	24	433	425	0.01786
S5	32	240	235	0.02043
S6	37	282	276	0.02121
S7	41	239	234	0.02168
S8	45	270	264	0.02386

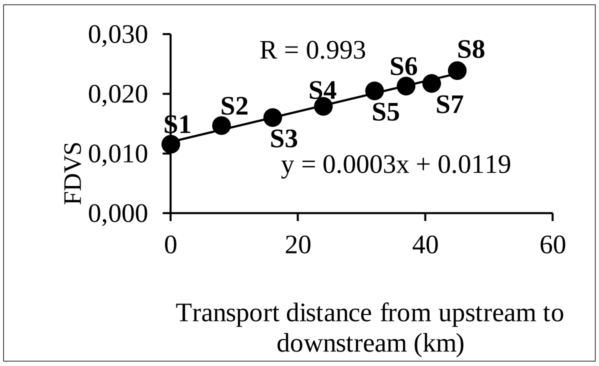

Figure 3. Plot Between Transport Distances with Frequency-Dependent Volume Magnetic Susceptibility in Surabaya River Sediments, Indonesia.

The relation between transport distances with frequency-dependent volume magnetic susceptibility is shown in Figure 3. The value of frequency-dependent volume magnetic susceptibility tends to increase downstream of the river. The relation model between these two parameters is approximated by a linear equation. The linear regression shows that the transport distance has a significant linear relation with frequency-dependent volume magnetic susceptibility.

The value of frequency-dependent volume magnetic susceptibility tends to increase by 0.0003/km additional transport distance. This value is represented by the gradient in the linear equation in Figure 3. Pearson correlation coefficient (R) states how significant the relation between the both parameters. In this case, R=0.993 indicates that frequency-dependent volume magnetic susceptibility is very significantly correlated to the sediment transport distance. The increasing value trend indicates that the sediment transport distance is allegedly to affect the content of superparamagnetic grain of the sediment. Sediments transport over longer distances are allegedly to have higher superparamagnetic grain content. This study provides information on the possible location of the presence of river sediments containing high superparamagnetic grain in the downstream area.

We compare the result of the present study with measurement result of frequency-dependent volume magnetic susceptibility in two rivers in India. [37]. Figure 4 and Figure 5 respectively show plot between transport distance with frequency-dependent volume magnetic susceptibility of selected sediments in Cauvery and Palaru River. Transport distance is not in actual distance value (not in km) and only in order of sample number from upstream to downstream of the river. Despite ignoring the actual transport distance, both plots show a similar trend to the conditions in Surabaya river sediments. The value of frequency-dependent volume magnetic susceptibility of Cauvery and Palaru river sediments tends to increase downstream. In addition, the sediments from both rivers are dominated by the value of frequency-dependent volume magnetic susceptibility in low-medium categories similar with Surabaya river sediments.

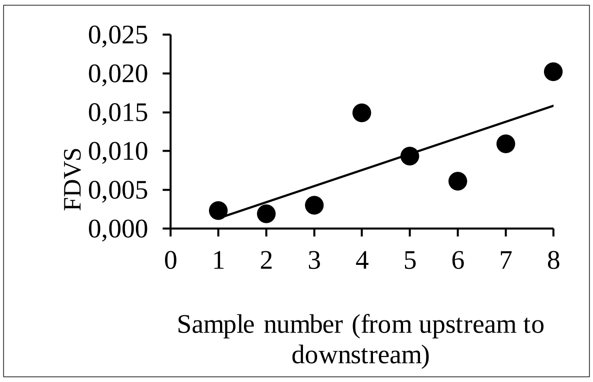

Figure 4. Plot Between Transport Distance with Frequency-Dependent Volume Magnetic in Cauvery River Sediments, India [37]

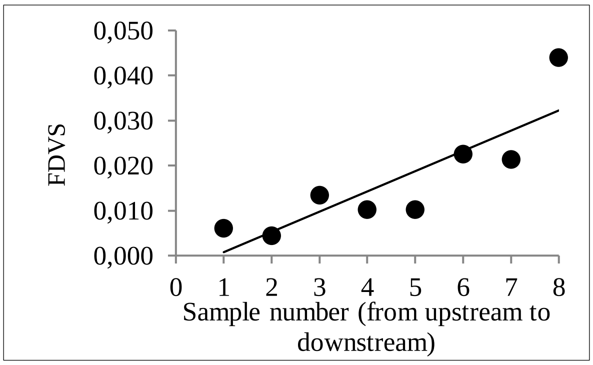

Figure 5. Plot between transport distance with frequency-dependent volume magnetic in Palaru river sediments, India [37]

IV. CONCLUSION

The Surabaya river sediments have frequency-dependent volume magnetic susceptibility in low-medium category with value varying from 0.01146 to 0.02386 (on average 0.01839). The relation between transport distance and frequency-dependent volume magnetic susceptibility shows a very high positive correlation. The increase in transport distance is identified as the cause of the increase in superparamagnetic grain content in the river sediments.

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