Frequency Dependent Magnetic Susceptibility in Topsoil of Bandung City, Indonesia

K H Kirana¹², J Apriliawardani¹, D Ariza¹, D Fitriani¹², E Agustine¹², S Bijaksana¹, S J Fajar³, M G Nugraha⁴
¹Faculty of Mathematics and Natural Sciences, Universitas Padjadjaran, Jalan Raya Bandung-Sumedang Km. 21 Jatinangor, 45363
²Centre of Citarum Research, Universitas Padjadjaran, Jalan Raya Bandung-Sumedang Km. 21 Jatinangor, 45363
³Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Jalan Ganesa 10 Bandung 40132
⁴Faculty of Mathematics and Sciences Education, Universitas Pendidikan Indonesia, Jalan Dr. Setiabudhi 229, 40154

kartika@geophys.unpad.ac.id

Abstract. Soil contains lithogenic components as well as anthropogenic components including combustion residues from traffic activities. The high traffic activities in major cities such as Bandung have caused the air pollution level to increase significantly. These activities might also produce significant combustion residues that accumulate, among others, in the topsoils. Compared with lithogenic components in topsoil, the anthropogenic combustion residues might have different magnetic signatures that could be detected by magnetic measurements. In this study, 38 topsoil samples from 19 roadside sampling points in Bandung City were collected and magnetically analysed to map the magnetic signatures due to traffic activities. The samples were measured for magnetic susceptibility using Bartington MS2B Susceptibility Meter and hysteresis parameter analysed from Vibrating Sample Magnetometer (VSM). The results show that the values of mass-specific magnetic susceptibility $(\chi_{LF})$ vary from $391.20 \times 10^{-8}$ $m^3/kg$ with the average value of $1012.16 \times 10^{-8} m^3/kg$ while the values of frequency dependent susceptibility $(\chi_{FD})$% vary from 0.54% to 4.48% with the average value of 1.9%. The relatively high value of magnetic susceptibility indicates higher concentration of magnetic minerals compared to that of pristine topsoil around Bandung. This is in agreement with similar studies on roadside topsoil elsewhere. The poor correlation between mass-specific magnetic susceptibility and frequency dependent magnetic susceptibility infers that the magnetic minerals are predominantly non superparamagnetic. This finding is supported by magnetic hysteresis parameters showing that the predominant grains are likely to be pseudo-single domain (PSD) if magnetite is assumed to be the predominant magnetic mineral. Similar studies in Germany and China reported that the predominant magnetic mineral is mixture of single domain to multi domain magnetite.

1. Introduction
The increasing number of vehicles will produce abundant particulates, both as particulate matter that is present as air pollutants as well as those identified from the surface soil. Beckwith et al., (1986)
showed a relationship between the high abundance of magnetic minerals in the soil and particulate matter in air pollutants [1]. For decades, identification of magnetic mineral characterization of urban topsoil have been widely used for environmental monitoring.

Rocks, sediments and soil at least contains of natural ferri(o)magnetic minerals. However, anthropogenic sources containing ferri(o)magnetic minerals also but in different phase, that could be deposited and accumulated in soil and sediment [2]. Therefore, by relying on magnetic properties of soil, this study identifies the characterization of magnetic minerals in urban topsoil in Bandung city. Considering that Bandung is one of the big cities in Indonesia with a dense population and a large number of vehicles, which often causes traffic congestion, resulting in an increased abundance of particulates. Since most of the air quality monitoring system in Bandung City not working properly, then the information about particulate derive from anthropogenic activity need to assess. The use of magnetic properties on soil sample is one of the common methods.

Many studies that correlate the anthropogenic sources with the abundance of magnetic minerals from particulates derived from vehicle in urban topsoil have been conducted in German [2], China [3], Argentina [4], and other countries. Most of the studies show that the more polluted an area, the more anthropogenic contains on the soil will produce higher magnetic susceptibility value. Higher magnetic susceptibility detected in the urban topsoil in industrial and roadside area [3]. Moreover, the higher magnetic concentration-magnetic enhancement found also emitted by vehicle [4].

The magnetic mineral derived from vehicle usually has dominantly by coarse multidomain grains, its identified the multidomain particle on the urban dust aerosol [5]. The abundance of multidomain grain also showed from vehicle emission in Abuja, Nigeria [6]. Therefore, by identifying the characterization of magnetic minerals in urban topsoil, it is hoped that it can identify the presence of anthropogenic minerals caused by the presence of motorized vehicle particulates.

2. Material and Methods

This research uses urban topsoil from Bandung City. In total, there are 38 samples of topsoil that collected from 19 locations around Bandung City (Figure 1). Furthermore, all samples were conducted on preparation to do magnetic susceptibility and hysteresis parameter measurement. For magnetic susceptibility measurement, the sample is inserted into a 10 cm³ volume holder. Then, the sample is measured using a Bartington MS2B Magnetic Susceptibility meter. The results of these measurements will be obtained values of magnetic low-frequency susceptibility ($\chi_{LF}$) and high-frequency magnetic susceptibility ($\chi_{HF}$) which can then be calculated frequency-dependent susceptibility value using the equation ($\chi_{FD\%} = \frac{(\chi_{LF} - \chi_{HF})}{\chi_{LF}} \times 100\%$).

Furthermore, the hysteresis parameter was measured using the Oxford type 1.2H Vibrating Sample Magnetometer (VSM). The plot result of this measurement will obtain a hysteresis curve, which is the plot between the magnetization value M (Am²/kg) to the applied field H (T). Before measuring hysteresis parameters, preparation was carried out by sieving the sample using a 325-mesh size in order to obtain a more uniform and smoother grain [7]. Through this measurement, a Day plot can also be obtained to determine the type of magnetic domain in the sample. The Day plot is a plot between the ratio of remanent saturation magnetization and saturation magnetization (Mrs/Ms) to the comparison of coercivity remanent field and coercivity field (Hcr/Hc).

3. Results and Discussions

The results of $\chi_{LF}$ mapping are shown in Figure 1. The value of low-frequency magnetic susceptibility ($\chi_{LF}$) of topsoil samples in Bandung City shows that the samples have a range of $391.20 – 1835.20 \times 10^{-8}$ m³/kg with an average of $1012.16 \times 10^{-8}$ m³/kg. Based on the mapping in Figure 1, the North, East and South part of Bandung regions appear to have a larger and abundance distribution of magnetic susceptibility values, compared to the West and North Bandung areas which have small to large magnetic susceptibility values.
The magnetic susceptibility value with mean of $1012.16 \times 10^{-6} \text{ m}^3/\text{kg}$ indicates that the urban topsoil sample is highly magnetic and dominated by ferrimagnetic minerals. This high value of magnetic susceptibility indicates higher concentration of magnetic minerals [8]. Soil that has a magnetic susceptibility value above $100 \times 10^{-6} \text{ m}^3/\text{kg}$ is a very magnetic soil and may have magnetic enrichment [9]. This result is supported by the hysteresis parameter measurement where the hysteresis curve shows the shape of the curve for magnetite minerals, which is experiencing magnetization saturation before 0.3 T. Figure 2 and Figure 3 are the hysteresis curves of two representative samples, namely the BBS1 and MTH1 samples.

The value of frequency-dependent susceptibility mapping represents in Figure 4. The figure shows that the North Bandung area is an area that has the highest value of $(\chi_{FD})\%$ compared to other areas in
Bandung City. The results of measuring ($\chi_{FD}$\%) of urban topsoil samples in Bandung City show that the samples have a range of ($\chi_{FD}$\%) 0.38% - 4.52% with an average of 1.89%. The ($\chi_{FD}$\%) value below 2% indicates a small amount of the superparamagnetic grain content in the sample (<10%) or almost no superparamagnetic grains, while the ($\chi_{FD}$\%) value in the range 2% - 10% indicates a mixture of superparamagnetic and non-superparamagnetic coarse grains [10].

Based on the mapping results of $\chi_{LF}$ and ($\chi_{FD}$\%), it can be said that the areas of East and South Bandung have a high $\chi_{LF}$ and an average ($\chi_{FD}$\%) was less than 2%, the North Bandung area has a value of $\chi_{LF}$ and an average ($\chi_{FD}$\%) was more than 2%, while the West Bandung area had $\chi_{LF}$ and the average ($\chi_{FD}$\%) was less than 2%. Several studies suggest that the high value of urban topsoil magnetic susceptibility is derived from fuel combustion pollutants and vehicle emissions [2] However, the value of $\chi_{LF}$ topsoil in Bandung City has a greater value than some areas, for example in Tubingen Germany has a magnetic susceptibility value range of 200 - 300 $\times 10^{-5}$ SI [2], in Lanzhou China with the average magnetic susceptibility value is 449.88 $\times 10^{-8}$ m$^3$/kg [3], and Luoyang China with an average magnetic susceptibility value less than 1000 $\times 10^{-8}$ m$^3$/kg [5]. The high value of $\chi_{LF}$ topsoil in Bandung City is due to the type of soil in Bandung City is volcanic. Natural volcanic soil (away from roadside vehicle activity) has a susceptibility value range of 339.8 – 806.7 ($\times 10^{-8}$ m$^3$/kg) [11].

In addition, high magnetic susceptibility values can also be caused by the presence of fine particles (superparamagnetic grains) that come from anthropogenic materials. The samples that has ($\chi_{FD}$\%) values ranging from 1 - 4% indicate the presence of anthropogenic minerals [12]. Most of the minerals that contain anthropogenic sources have multi-domain (MD) coarse grain types [5]. This is in line with the results of the Day plot (Mr/Ms to Hc/Hcr) in Figure 5 which shows that the urban topsoil BBS1 sample has a mixed SD-MD type with a larger MD grain composition, while the MTH1 sample is dominated by SP grains. Magnetic minerals that have a tendency to have a mixture of more MD grains are spherule-shaped magnetite minerals [13]. The magnetic mineral that has spherule magnetite derived from anthropogenic sources [14].

Figure 4. Map of frequency dependent susceptibility value of topsoil samples in Bandung City
4. Conclusion

The urban topsoil samples have a high magnetic mineral content indicated by a high $\chi_{LF}$ value dominated by magnetite. This high magnetic mineral content is due to the presence of magnetic enrichment by anthropogenic sources as evidenced by the small value ($\chi_{FD}$%) and the abundance of coarse magnetic grains which have SD-MD domains.

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