Spatial distribution of topsoil magnetic susceptibility in Sawahlunto City, West Sumatera

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Abstract. A research to determine the spatial distribution of top soil magnetic susceptibility at Sawahlunto City, West Sumatra has been conducted. The top soil samples were taken at four locations; ie the downtown area, the steam power plant area, the agricultural area, and coal mine area. At each location, the soil samples were taken at 10 points at a depth of 20 cm. Magnetic susceptibility were measured using Bartington MS2B Magnetic Susceptibility Meter. The topsoil samples from Sawahlunto city have relatively low average value of the magnetic susceptibility that is $6.7 \times 10^{-8}$ m$^3$/kg. The magnetic susceptibility of topsoil samples from downtown area have the average and the highest value of magnetic susceptibility $(100.6 \times 10^{-8}$ and $259.9 \times 10^{-8}$ m$^3$/kg), and followed by sample from the steam power plant area $(98.4 \times 10^{-8}$ and $258.0 \times 10^{-8}$ m$^3$/kg), the agricultural area $(56.2 \times 10^{-8}$ and $83.7 \times 10^{-8}$ m$^3$/kg), and coal mine area $(12.9 \times 10^{-8}$ and $26.8 \times 10^{-8}$ m$^3$/kg). Soil samples from the steam power plant area have the widest range of magnetic susceptibility value range from $0.3 \times 10^{-8}$ to $258.0 \times 10^{-8}$ m$^3$/kg.

1. Introduction
Mining and industrial activity is involved in the drastic disruption of regional ecosystems and soil properties [1]. Industrial and mining activities has produced a significant release of heavy metals to the environment from processes such as energy production, mining, metal processing, manufacturing, burning of waste, and burning of fossil fuels [2]. Heavy metals can accumulate in the soil around the industrial area through atmospheric deposition, waterlogging of waste piles, and this causes serious pollution and degradation of soil quality [3]. The soil is the accumulation of toxic materials such as heavy metals. This non-biodegradable material deposited on surface soil can affect its environment for decades which has a strong negative impact on the environment [4]. The surface layer is the recipient of various pollutants, especially heavy metals and can be used as an indicator to determine the quality of the environment. The topsoil is the part that is most affected by industrial deposition and not depend on the type of industry [5].

Sawahlunto is one of the cities that has significant mineral resources. The city has a coal mining that has been operating since 1891, initially operated by the Dutch East Indies government. After Indonesia became independent, it was managed by the state through Ombilin Coal Mining Company. The company was then liquidated as a subsidiary of PTBA located in Tanjung Enim, South Sumatera. Coal from Sawahlunto is used to meet the needs of coal of PT Semen Padang and Ombilin power plant in the city of Sawahlunto. This mining site has not been operating since 2002. In addition, in the city of Sawahlunto also there are many traditional gold mines. Sawahlunto also has a coal fired power
A plant with coal consumption of 2000 tons per day. This activity is a source of soil contamination in the city of Sawahlunto besides from transportation and agricultural activities. There are many studies about the influence of mining on air and water quality, but few that focus on land quality issues by pollution of mines. So, it needs to know the contamination level of topsoil in city of Sawahlunto through the mapping its magnetic susceptibility value.

To estimate the concentration of heavy metals in the soil is usually used geochemical methods, but this method is expensive and time consuming, so it needs a time-efficient and cost-effective, non-destructive method. Magnetic methods have been successfully applied in several European countries [6]. The magnetic method has also conducted to determine the heavy metal distribution in Bucharest [7]. From these studies it is known that magnetic susceptibility can be used as an indicator of high concentrations of heavy metals in topsoil. Magnetic susceptibility is a measurable and concentration-dependent geophysical parameter that describes a material's ability to obtain magnetization when given an external magnetic field [8].

The application of magnetic susceptibility measurement for characterization and pollution checking is possible due to the presence of technogenic magnetic particles (TMP) in soils and sediments that are influenced by industrial deposition and urban dust derived from high-temperature engineering processes [9]. Areas which are closer to industrial areas have higher magnetic susceptibility values. The magnetic concentration parameters show significantly different magnetic responses to different sources of pollution. Magnetic proxies provide a fast way of detecting heavy metal contamination caused by anthropogenic pollution sources in large areas, although their sensitivity is controlled by pollution sources [10].

2. Methodology
The research was conducted at the Earth Physics Laboratory, the Physics Department of Andalas University. Sampling was conducted at four locations is in the Sawahlunto city, ie at the coal mine area, power plant area, agricultural area, and downtown (see Figure 1). At each of the locations, topsoil samples were collected at 10 points. The position of the sampling points in the locations are presented in Figure 2 to 5. At each of the 40 points, 50 g topsoil samples were collected at a depth of 20 cm. The distance between the sample points was 500 m.

![Figure 1](image-url). Location of the research area in Sawahlunto City.
Equipments that were used in the research are MS2B magnetic susceptibility meter (to measure the magnetic susceptibility of the sample), core drill, and other supporting equipment such as balance, hammer, meter, and sample container. Measurement of the magnetic susceptibility of the samples were conducted in the laboratory. Each of the topsoil samples was mixed, air dried for 5 days to reduce the effect of water, and then sieved with 100-mesh sieve. Then a 12 g of each samples was stored into plastic container (sample holder), and their mass magnetic susceptibility was measured in the laboratory using MS2 magnetic susceptibility meter with MS2B sensor. The measurements were conducted in 15 directions and then its average was calculated.

Figure 2. Sampling points in the coal mine area.

Figure 3. Sampling points near coal fired power plant area.

Figure 4. Sampling points in the downtown area.
3. Results and Discussion
The value of the magnetic susceptibility of topsoil samples at four locations in the research area and their statistics are presented in Table 1. The topsoil samples from Sawahlunto city have relatively low (<150×10⁻⁸ m³/kg) average value of the magnetic susceptibility that is 67.0×10⁻⁸ m³/kg. The value is ranging from 0.3 to 259.9×10⁻⁸ m³/kg with only 3 samples have the value of magnetic susceptibility larger than 150×10⁻⁸ m³/kg. For comparison with mean value (74.34×10⁻⁸ m³/kg) found in urban topsoil of Ishafan in Central Iran [11] and median value (107×10⁻⁸ m³/kg) found in urban topsoil of Xuzhou in China [12], the mean value in Sawahlunto city topsoil is lower. The mean value of the topsoil magnetic susceptibility in the research area is also lower than that in three mining cities in China those are Jinchang (327.55×10⁻⁸ m³/kg), Baiyin (191.89×10⁻⁸ m³/kg), and Jiayuguan (930.92×10⁻⁸ m³/kg) [10].

Topsoil samples from the downtown area have the average and the highest value of magnetic susceptibility (100.6×10⁻⁸ and 259.9×10⁻⁸ m³/kg), and followed by the sample from around the steam power plant (98.4×10⁻⁸ and 258.0×10⁻⁸ m³/kg), the agricultural area (56.2×10⁻⁸ and 83.7×10⁻⁸ m³/kg), and the coal mine area (12.9×10⁻⁸ and 26.8×10⁻⁸ m³/kg). The relatively higher value of the magnetic susceptibility of the downtown area suggest that vehicle exhaust emissions is probably a dominant factor in increasing the magnetic susceptibility value of topsoil in the Sawahlunto city. The similar result found in agricultural soil of Tadla plain near Beni Mellal (Marocc) that area near to the road had higher value of magnetic susceptibility (121×10⁻⁸ SI) than in area away from the road (53×10⁻⁸ SI) which was concluded as a consequence of road gasoline emissions [13]. Soil samples from the steam power plant area have the widest range of magnetic susceptibility from 0.3×10⁻⁸ to 258.0×10⁻⁸ m³/kg.

Table 1. The value of magnetic susceptibility of topsoil samples at four locations in the research area.

| Points | Magnetic Susceptibility (×10⁻⁸ m³/kg) |
|--------|--------------------------------------|
|        | Downtown Area | Agricultural Area | Power Plant | Coal Mine |
| 1      | 44.3          | 36.5              | 123.0       | 13.7      |
| 2      | 138.1         | 20.1              | 66.7        | 14.7      |
| 3      | 36.5          | 82.7              | 13.7        | 5.8       |
| 4      | 259.9         | 77.3              | 11.3        | 6.6       |
| 5      | 94.3          | 69.3              | 22.5        | 14.5      |
| 6      | 96.6          | 51.9              | 174.9       | 24.2      |
| 7      | 64.4          | 39.8              | 126.9       | 11.9      |
| 8      | 58.3          | 52.2              | 258.0       | 26.8      |
| 9      | 86.5          | 83.7              | 186.9       | 8.0       |
| 10     | 126.8         | 48.9              | 0.3         | 2.9       |
| Average | 100.6        | 56.2              | 98.4        | 12.9      |
| Maximum| 259.9         | 83.7              | 258.0       | 26.8      |
Figure 6 represents a comparison of the magnetic susceptibility value of samples for four locations in the Sawahlunto city. The topsoil samples from the coal mine area have the lowest value of magnetic susceptibility, then followed by samples from the agricultural and downtown area. Samples from the power plant area have the widest range of magnetic susceptibility value. Four samples from this area have higher value than samples from other locations, while the rest samples are not.

4. Conclusions
The topsoil samples from Sawahlunto city have relatively low (<150×10^{-8} m^3/kg) average value of the magnetic susceptibility that is 67.0×10^{-8} m^3/kg. The magnetic susceptibility of the topsoil samples from downtown area have the average and the highest value of magnetic susceptibility (100.6×10^{-8} and 259.9×10^{-8} m^3/kg), and followed by the sample from around the steam power plant (98.4×10^{-8} and 258.0×10^{-8} m^3/kg), the agricultural area (56.2×10^{-8} and 83.7×10^{-8} m^3/kg), and surrounding coal mine sites (12.9×10^{-8} and 26.8×10^{-8} m^3/kg). The topsoil samples from the coal mine area have the lowest value of magnetic susceptibility, then followed by samples from the agricultural and downtown area. Samples from the power plant area have the widest range of magnetic susceptibility value. Four samples from this area have higher value than samples from other locations, while the rest samples are not.

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References
[1] Liu X, Baia Z, Zhoua W, Cao Y and Zhang G 2017 J. Ecol. Eng. 98 228
[2] El Khalil H, El Hamiani O, Bitton G, Ouazzani N and Boularbah A 2008 Environ. Monit. Assess. 136
[3] Li Z Y, Ma ZW, Kuijp TJ, Yuan ZW and Huang L 2014 J. Sci. Total Environ. 468 843
[4] Adamczyk Z and Nowińska K 2016 J. Environ. Earth Sci. 75 956
[5] Jordanova D, Goddu S R, Kotsev T and Jordanova N 2013 J. Geoderma 192 237
[6] Klčiarová D and Gregorová D 2007 J. Geochem.: Explor. Environ. Anal. 66 313
[7] Panaiotu C G, Necula C, Panaiotu C E and Axente V 2005 *A Magnetic Investigation of Heavy Metals Pollution In Bucharest* (South Eastern Europe: Editura Politehnica-Timisoara)

[8] Evans M E and Heller F 2003 *Environmental Magnetism: Principles and Applications of Enviromagnetics* (California: Academic Press)

[9] Magiera T, Jabłońska M, Strzyszcz Z and Rachwał M 2011 *J. Atmos. Environ* 45

[10] Wang B, Xia D, Yu Y, Jia J, Nie Y and Wang X 2015 *J. Environ. Pollut.* 207 288

[11] Karimi R, Ayoubi S, Jalalian A, Sheikh-Hosseini A R and Afyuni M *J. Appl. Geophys.* 74 1

[12] Wang XS and Xin Y 2005 *J. Environ. Geol.* 49 10

[13] El Baghdadi M, Jakani K, Barakat A and Bay Y 2011 *J. Mater. Environ. Sci.* 2 (S1) 513