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Micro-scale spatial correlation of magnetic susceptibility in soil profile in forest located in an industrial area

Jarosław Zawadzki [a], Piotr Fabijańczyk [a,*], Tadeusz Magiera [b], Marzena Rachwał [b]

[a] Warsaw University of Technology, Environmental Engineering Faculty, Nowowiejska 20, 00-653 Warsaw, Poland
[b] Institute Of Environmental Engineering Polish Academy Of Sciences, M. Skłodowskiej-Curie 34, 41-819 Zabrze, Poland

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ABSTRACT

So far, studies concerning the analyses of the soil magnetic susceptibility in the soil profile have been usually making use of classic statistics. The number of papers where spatial correlations of magnetic susceptibility were analyzed is still limited. In particular, the micro-scale spatial correlations have been rarely analyzed.
The goal of this study was to analyze microscale spatial correlations of magnetic susceptibility in the soil profiles collected in an old park, located in the Upper Silesian Industrial Region. In particular, the micro-correlations of κ were investigated by using measurements of soil κ values made with a SM400 device. The use of this device was necessary because the spatial resolution of other devices like Bartington MS2C or MS2H was too low. The spatial correlations of soil κ were investigated by calculating directional variograms along the soil profile and then modeling them. Analyses of spatial correlations were calculated separately for the topsoil and subsoil layers.
The spatial correlations of the soil magnetic susceptibility in soil profiles collected in the forested study area were characterized by the Gaussian model with no nugget effect. The linear regression showed clear dependence between the thickness of the topsoil and the range of correlation of the soil magnetic susceptibility in the soil profile.
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1. Introduction

A combination of in situ soil magnetometry with limited number of chemical analyses is a method that was developed as a cost-effective alternative to the “classic” geochemical soil survey that aims to detect and assess the level of soil contamination caused by anthropogenic pollution (Magiera et al., 2007; Boyko et al., 2004; Desenfant et al., 2004; Hanesch and Scholger, 2002; Kapicka and Petrovsky, 1997; Petrovsky et al., 2000; Strzyszcz et al., 1996). Soil magnetic susceptibility (κ) was found to be strongly correlated with the concentration of industrial dusts deposited on the soil surface. These dusts usually contain significant amounts of technogenic magnetic particles (TMPs), which are mostly composed of ferrimagnetic iron oxides that are known as carriers of many trace elements, including heavy metals. This property leads to an assumption of strong correlation between κ and heavy metal concentration in soil, which was also confirmed by numerous studies conducted mostly on forest areas, due to the fact that forest soil profiles (in contrast to arable soil) preserve their natural structure with well-developed uppermost organic soil horizon (Schibler et al., 2002; Spiteri et al., 2005; Wang and Qin, 2005). Most of the pollutants are usually accumulated in the organic horizon, especially at the bottom of this soil layer. However, the explanation of the mechanisms of correlation between TMP concentration measured as a κ enhancement and content of heavy metals is not easy as it depends on numerous physical, geochemical, and pedological properties of the forest topsoil.

So far, there are plenty of available studies that concern the development of the field and laboratory measurements of κ, the analyses of soil pollution using field magnetometry, and so on. The detailed analysis of the distribution of κ values, concentration of selected metals, and selected physical properties of soil in soil profiles can be found in Blaha et al. (2008) and Fürst et al. (2010a, 2010b). There are also studies (Magiera and Zawadzki, 2006; Zawadzki and Fabijańczyk, 2007) where κ was analyzed using geostatistics, including the investigation of spatial correlations characterizing the κ measured with a MS2D Bartington sensor on the soil surface (Dearing, 1994). Some studies, where three-dimensional spatial correlations were analyzed, have been also conducted. Three-dimensional variograms were also calculated, but the anisotropic spatial variability, along the soil profile was not investigated (Zawadzki et al., 2012). The advantages of 3-dimensional screening over the 2-dimensional one were also analyzed and demonstrated in studies concerning applications different from soil pollution (Dalan, 2009).

The distribution of the κ values in soil profile has many informative properties. The peak value of κ and the highest concentration of heavy metals are usually observed at the same depth (Spiteri et al., 2005). The width of the peak of the distribution of κ is strongly related to the thickness of the organic horizons. These properties have been so far

* Corresponding author.
E-mail addresses: j.j.zawadzki@gmail.com (J. Zawadzki), piotr.fabijanczyk@is.pw.edu.pl (P. Fabijańczyk), tadeusz.magiera@ipis.zabrze.pl (T. Magiera), marzena.rachwal@ipis.zabrze.pl (M. Rachwał).

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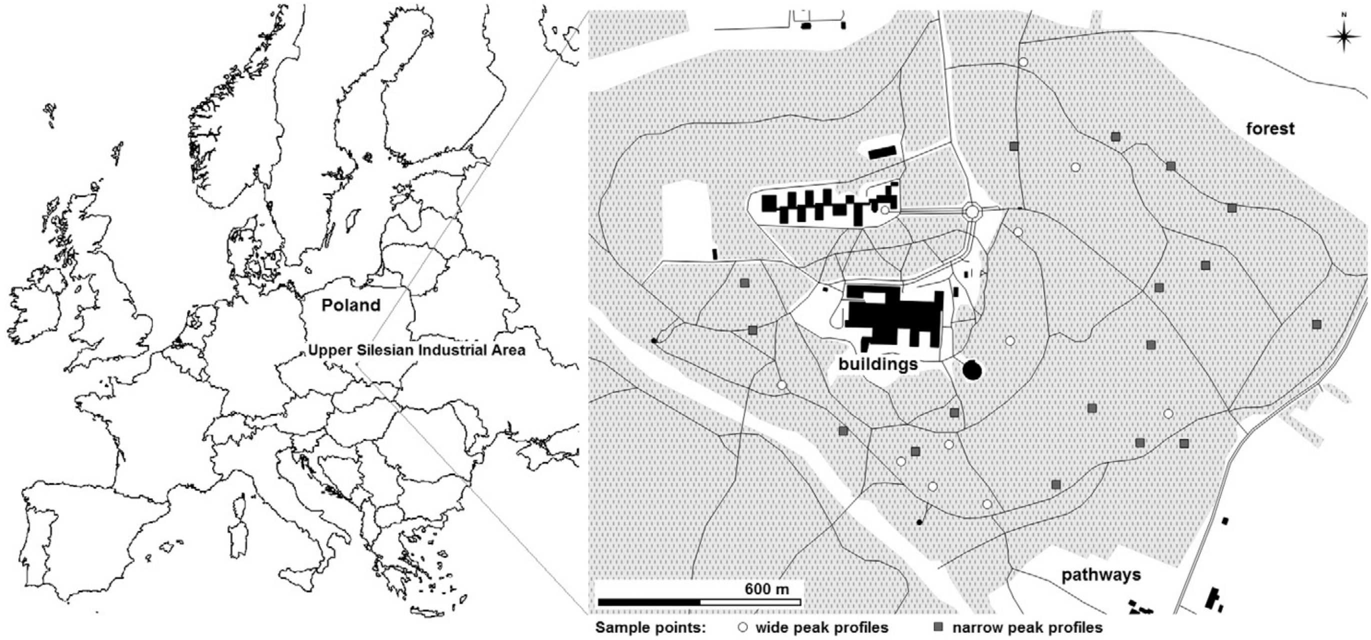

Fig. 1. Location of the study area, and sample points of SM-400 measurements of soil magnetic susceptibility.

successfully used to differentiate between the magnetic enhancement caused by anthropogenic pollution or by lithogenic soil properties (Magiera et al., 2006) or to investigate in which soil horizons most heavy metals are accumulated (Fialova et al., 2006).

In order to investigate the κ in the soil profile it is possible to use various devices like MS2H Bartington, MS2C Bartington (Dearing, 1994) or SM400 (Petrovsky et al., 2004). In field magnetometry, the crucial parameter of such device is a spatial resolution. Previous studies showed that most of the anthropogenic, ferrimagnetic particles are usually accumulated in very thin topsoil layer, whose thickness is usually about 6 cm. Using MS2H or MS2C devices it is possible to make only about 6 readings of κ in this layer because their spatial resolution is equal to about 1 cm. Such number of readings may be too low to investigate the spatial correlations of κ in detail. The SM400 device can be more suitable for this type of analyses because the spatial resolution of the SM400 device is equal to about 1 mm. As a result, it is possible to get ten times more readings of κ from the topsoil layer, using the SM400 device than using MS2H or MS2C devices.

In study areas with a complex structure of the soil profile, the use of vertical measurements can be very valuable. It can make it possible to enhance the interpretation of magnetic anomalies caused by anthropogenic pollution. It can also provide information on the spatial limits of magnetic anomalies in the third dimension that is related to the development of soil profile and vertical spatial distribution of ferrimagnetic particles.

The goal of this study was to analyze the spatial correlations of κ in the soil profiles collected in an old park, located in the Upper Silesian Industrial Region. Parks and urban forests are commonly used in field magnetometry for the determination of potential soil pollution in densely populated areas. In particular, the micro-correlations of κ were investigated which were possible owing to high spatial resolution of a SM400 device. The spatial correlations of soil κ were investigated by calculating directional variograms along the soil profile and then modeling them. Analyses of spatial correlations were calculated separately for the topsoil and subsoil layers. Such division of the soil profile was based on the previous studies suggesting that most of the pollutants are accumulated in the O and A horizons (Magiera et al., 2006; Fialova et al., 2006).

Additionally, the relationship between calculated parameters of variograms of κ and topsoil thickness was analyzed using classic statistics, in particular regression methods.

Fig. 2. Photography of the field measurement performed with SM-400 device, and an example of soil core collected in the study area.

2. Material and methods

2.1. Study area

The study area was located in the Upper Silesian Industrial Region, in an old, wild park closed for traffic. The study area was located in the direct vicinity of the Katowice agglomeration. The most significant pollution sources were related to the extraction and further use of hard coal. Within the Katowice agglomeration there were numerous power plants and coal mines, and steelworks. Significant amounts of air pollutants were also emitted due to burning the hard coal for heating purposes, and by traffic. At present, the emission of air dust is decreasing, and has been reduced significantly during the last 25 years. In the region where the study area was located the average dust deposition on the soil surface is below 70 g/m^2/year (Leśniok, 2011).

According to the physical–geographical division, the study area belonged to the mesoregion of Katowice Upland, which is the central

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