Geoderma 277 (2016) 51–60

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

A methodology of integration of magnetometric and geochemical soil contamination measurements

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ARTICLE INFO

Article history:
Received 13 December 2015
Received in revised form 9 May 2016
Accepted 15 May 2016
Available online 25 May 2016

Keywords:
Soil magnetometry
Magnetic susceptibility
Heavy metals
Pollution Load Index
Cokriging
Data integration

ABSTRACT

There is still a high interest in the improvement of soil magnetometry procedures that could increase its accuracy. As it was often discussed in the literature, the depth of penetration of the magnetometric probe that is used to measure magnetic susceptibility on the soil surface (e.g. MS2D) can be insufficient to acquire the magnetic signal of pollutants accumulated in the deeper-located soil horizons. The goal of this study was to propose practical methods of the integration of surface and vertical measurements of soil magnetic susceptibility, and thus eliminate, or at least, minimize the number of geochemical measurements. It was assumed that these methods must be cost- and time-effective, and easy to implement, because it is of vital importance for fast screening method. Results obtained in this paper clearly showed that the method of the integration of magnetometric measurements should depend mainly on a thickness of organic soil horizon and on a thickness of this soil layer where the magnetic enhancement was observed. As soon as the thickness of an organic soil horizon falls in the interval between 15% and 30% of the effective penetration range of a Bartington MS2D magnetometer the assessment of the potentially polluted area becomes problematic. In such situation, the extent of the polluted area was determined using values of soil magnetic susceptibility measured with a MS2D device that were integrated with the values of a width of magnetic enhancement and the depth where it started to be observed in a soil profile. Values of Pearson's correlation coefficient between soil magnetic susceptibility and the Pollution Load Index ranged between 0.63 and 0.77.

In the case of a large area where the removal of soil horizon was problematic, it was sufficient to use cokriging in order to integrate the values of magnetic susceptibility measured on the soil surface with magnetometric parameters measured in the soil profile. However, it was observed that if the number of sample points is high, the extent of the potentially polluted area can be assessed using ordinary kriging and the values of magnetic susceptibility measured on the soil surface. Validation results showed that the values of Pearson's correlation coefficient between magnetic susceptibility that was estimated using kriging and the concentrations of Co, Ni, Cd, Pb were significant, and equaled to 0.77, 0.76, 0.65, and 0.74, respectively.

1. Introduction

Many authors reported statistically significant correlation between soil magnetic susceptibility (κ) and the concentration of pollutants that originates from a deposition of industrial dusts (Strzyszcz and Magiera, 1998; Bityukova et al., 1999; Petrovský et al., 2000; Hanesch and Scholger, 2002; Spiteri et al., 2005; D'Emilio et al., 2007; Blaha et al., 2008; Fürst et al. 2009; Zawadzki and Fabijańczyk, 2013; Naimi and Ayoubi, 2013; Łukasik et al., 2014). In particular, numerous studies confirmed that soil magnetic susceptibility was strongly correlated with a concentration of Potentially Toxic Elements (PTE) in soil (Dankoub et al., 2011; Karimi et al., 2011; Naimi and Ayoubi, 2013), and with Pollution Load Index (PLI) that was often used as an indicator of soil pollution (Rachwał et al., 2015). Soil magnetometry was also effectively used to identify landscape areas with different patterns of variability (Siqueira et al., 2015).

As it was previously reported high values of soil magnetic susceptibility were usually observed in the topsoil layers that indicated the influence of the industrial emission of heavy metals (Magiera et al., 2006; Ayoubi et al., 2014). The most of pollutants, including heavy metals, and Technogenic Magnetic Particles (TMPs), were usually accumulated in the soil horizons containing moderately decomposed organic material (Oe) and highly decomposed organic material (Oa). Accordingly, the maximum values of soil magnetic susceptibility, and the strongest magnetic enhancement were usually observed in the Oe

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http://dx.doi.org/10.1016/j.geoderma.2016.05.009
0016-7061/

and Oa horizons. The uppermost Oi subhorizon, which contains mostly fresh or only slightly decomposed organic material, revealed diamagnetic properties observed as slightly negative values of magnetic susceptibility (Magiera et al., 2006; Zawadzki et al., 2007).

Soil magnetometry is a method of screening of the potential soil pollution that is still dynamically developed in order to supplement the classical geochemical measurements. Usually field measurements are performed using sensors that allow to measure magnetic susceptibility on the soil surface. This type of measurements proved to be very cost- and time-effective in fast screening of potential soil pollution (Fürst et al., 2009; Petrovský et al., 2000; Sarris et al., 2009; El Baghdadi et al., 2012; D'Emilio et al., 2007; Gladysheva et al., 2007; D'Emilio et al., 2010; Vodyanitskii and Shoba, 2015). However, as it was previously analyzed such sensors have some limitations related to the limited depth of response or sensitivity to various measuring factors (Dearing, 1994; Lecoanet et al., 1999; D'Emilio et al., 2007; Zawadzki et al. 2010). Lecoanet et al. (1999) showed that the effective range of the popular MS2D Bartington sensor was equal to 6 cm. As it was reported in the literature, in the case when the thickness of the Oi horizon was higher than the penetration range of the magnetic sensor, the use of the MS2D sensor was insufficient for proper detection of magnetic signal from Oe and Oa horizons (Boyko et al., 2004; Zawadzki et al., 2007; Zawadzki et al., 2010). Strong influence of the thick organic horizon on the values of soil magnetic susceptibility measured on the soil surface was also investigated using other Bartington and other manufacturer's sensors (Zawadzki et al., 2010). These results suggested the advantage of removal of the Oi horizon before conducting the measurement of magnetic susceptibility on the soil surface. Unfortunately, the correct removal of Oi horizon only may be difficult, and may significantly increase the time period of the measurement campaign. In order to do it properly in the field, the operator has to possess the practical knowledge of soil sciences. As a result, the methodology of soil screening that assumes the removal of Oi horizon might be impractical.

The goal of this study was to analyze practical methods of the integration of surface and vertical measurements of soil magnetic susceptibility, in order to increase the precision of the assessment of potential soil pollution. Both types of measurements were integrated using regression method, kriging and cokriging. The results were verified using chemical measurements of concentrations of heavy metals and Pollution Load Indexes.

2. Materials and methods

2.1. Description of study sites

Study sites were located in the Upper Silesian Industrial Area (Fig. 1), in forested areas that were subjected to the anthropogenic pressure of large agglomeration and numerous sources of emission of industrial dusts. The study sites were selected as representative types of areas that are usually used to investigate the soil pollution using soil magnetometry. Major pollution source that was located in the vicinity of the study areas was Katowice Ironworks (Fig. 1). The sources that were located about 10 to 15 km to the east from the study area B were Ząbkowice dolomite mine, and coke plant Przyjaźń.

The site A (as denoted in the Fig. 1) had a small area of about 0.01 km^2 and was specially selected to analyze the methods of the integration of magnetometric measurements in small scale. It was located in a young pine forest, where the predominated forest stand was pine with some sparse admixture of birch-trees. The forest floor was overgrown with ferns and high grass, and the soil surface was covered with a layer of pine needles and leaves. There were no major industrial sources of pollution located in the direct vicinity of the study site A. This site was subjected mostly to the anthropogenic pressure of the Katowice Agglomeration that was located about 30 km to the north. Due to the fact that it was a relatively small area, it was possible to perform more detailed preparation of the soil surface before conducting the measurements of soil magnetic susceptibility.

The site B (as denoted in the Fig. 1) had an area of about 10 km^2, and was located north of Dąbrowa Górnicza. The majority of the area was occupied by a large park, with one extensive reservoir (0.75 km^2) that was located in the center of the park. The study site B was located in the direct vicinity to industrial objects that can exert a significant anthropogenic pressure on the soil. The largest industrial factory was Katowice Ironworks, located south-east of the study site. Less important, but still significant sources of pollution that were neighboring the study site B were an old railway depot that is currently used as a scrap

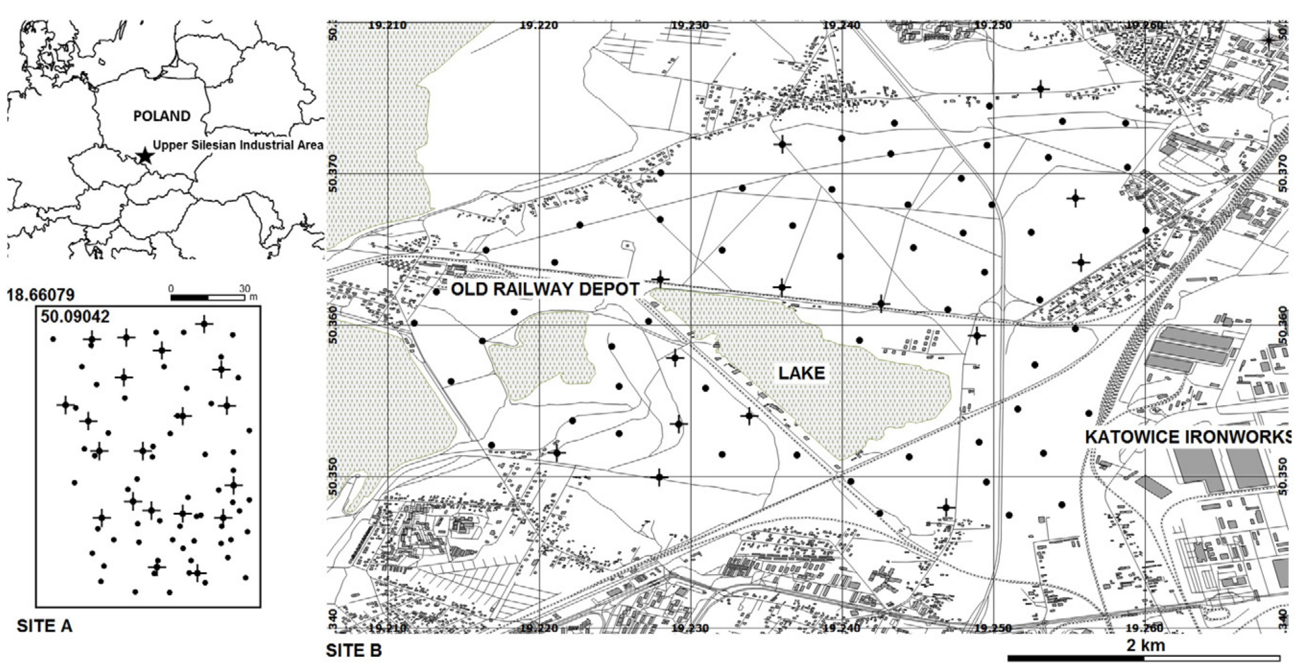

Fig. 1. Location of the study sites A and B; sample points of surface soil magnetic susceptibility were denoted by points, and locations where soil cores were collected were denoted by crosses; coordinates were marked in the WGS84 system.