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Spatial variation of soil magnetic susceptibility in relation to different emission sources in southern Poland

Tadeusz Magiera [a,*], Henryk Parzentny [a], Leokadia Róg [b], Ryszard Chybiorz [c], Małgorzata Wawer [d]

[a] Department of Land Protection University of Opole, Oleska 22, 45-052 Opole, Poland
[b] Central Mining Institute, Plac Gwarków 1, 40-166 Katowice, Poland
[c] Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland
[d] Institute of Environmental Engineering, PAS, M. Skłodowskiej-Curie 34, 41-819 Zabrze, Poland

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ABSTRACT

The study in the area surrounding the Rybnik urban agglomeration (southern Poland) was conducted to determine the influence of various emission sources on the occurrence of local magnetic anomalies observed in the forest topsoils. For this reason field measurement of volume-specific magnetic susceptibility (κ) was conducted in forest topsoil on the area of study. The measurements were performed twice: directly on the surface and after removal of forest litter to see the influence of the litter on the magnetic signal measured on the soil surface. The maps of surface distribution of κ value revealed that magnetic anomalies were observed 2.0 km around the residential areas dominated by low emission sources, 2.1 km around the coke plant, 2.8 km around the old steelworks, 1.4 km around the coal-mining waste heaps, and 4.0 km around the combined heat and power plant and coal mines. On the 43% of the study area, the topsoil magnetic susceptibility was between 50 and 100×10^{-5} SI units; on the 5.2% of the area, κ value was between 100 and 200×10^{-5} SI units; and on the 1.2% of the research area, the κ value was over 200×10^{-5} SI units. Also the vertical distribution of technogenic magnetic particles (TMPs) along the topsoil profile was analysed using topsoil 30 cm cores. Two κ value maxima were observed in the soil profile. The upper one ($\kappa_{average} = 333.9 \times 10^{-5}$ SI units) was found in either the Oa or Ah subhorizons at the depth of 3 cm to 8 cm dependently of thickness of organic horizon. The lower one ($\kappa_{average} = 53.4 \times 10^{-5}$ SI units) was observed in the B or C horizon at the depth of 19 cm to 23 cm. The upper maxima was of anthropogenic origin with large content of the magnetic fraction (magnetic spherules), whereas the lower maxima containing isometric crystals of iron oxides was of pedogenic or geogenic origin. The soil magnetometry seems to be a useful tool in identification of anthropogenic "hot spots" caused by industrial and urban dust deposition from different emission sources.

1. Introduction

Soil magnetic susceptibility maps show clearly and exactly both the present and the predicted state of the environmental pollution and soil quality affected by industrial and urban dust deposition. The first maps of soil magnetic susceptibility, on both the national and regional scales, were prepared in England (Hay et al., 1997), Poland (Magiera et al., 2002), and Austria (Hanesch et al., 2007). Many studies have examined local variations in magnetic susceptibility (Bityukova et al., 1999; Petrovský et al., 2000; Hanesch and Scholger, 2002; Boyko et al., 2004; Goddu et al., 2004; Chianese et al., 2006; Lu and Bai, 2006; Shi and Cioppa, 2006; Hu et al., 2007; Rothwell and Lindsay, 2007; Magiera et al., 2007, 2011b; Matýsek et al., 2008; D'Emilio et al., 2010; Aguilar-Reyes et al., 2011, 2013).

In Poland, researchers have identified several dozen areas where magnetic susceptibility anomalies occur. They are mainly caused by the presence of technogenic magnetic particles (TMPs) in the topsoil. The origin of TMP's deposition was not fully recognized. The different pollution sources have different dynamics of the magnetic particle emission into the soil environment, affecting the size and shape of magnetic "hot spots". The further understanding of the emission sources and products is crucial because many toxic heavy metals co-occur with the dusts (Petrovský et al., 2000; Schmidt et al., 2005; Spiteri et al., 2005; Lu and Bai, 2006; Jordanova et al., 2008; Magiera and Zawadzki, 2007).

The aim of this study was to determine the influence of various emission sources on the occurrence of local magnetic anomalies observed in the forest soils. This study was also carried out to understand the TMP's location in the soil profile. An important task was to determine the levels in the topsoil in which the percentage of the magnetic particles was the highest. Additionally, the influence of the forest litter on the surface κ measurement values was analysed.

* Corresponding author.
E-mail address: tadeusz.magiera@interia.pl (T. Magiera).

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2. Site characteristics and methodology

2.1. Site characteristic

The researchers investigated the topsoil (up to the 25 cm depth) present in the areas covered with trees (forests, parks) in the Rybnik urban agglomeration and its northern forest belt (Fig. 1). The research area (303.8 km^2 with population ca. 185,000) was defined with the following coordinates: 18°23′19″E–18°40′08″E and 50°10′21″N–50°02′01″N. The first primitive charcoal-fired ironworks in Rybnik and surrounding villages were established before the 15th century. The first large blast furnace that operated on the base of local limonite ores was built in 1753. In the end of the 19th century 18 ironworks were active in the area of study. The first coal mine in this area was open in 1792. The first foundry in Rybnik was established in 1888. In 1911, in Radlin (south from Rybnik) the coke plant was built and it operates up to now. In 1972 a large hard coal power plant was built on the NW outskirts of the city of Rybnik. Its actual power generation capacity is 1775 MW with annual consumption amounting to 4–4.5 million mg of hard coal. Two flue gas stocks of this plant are 260 and 300 m high. The concentration of many industrial sources and thousands of households using coal for heating caused the annual total dust emission in the end of 1980s in Rybnik to be 35 g m^{-2} and in 1999 it was even 45 g m^{-2}. After closing some old plants and modernization of others including the application of high efficient precipitators the annual dust emission was reduced to the amount of 3.2 g m^{-2} in 2013 (Stan Środowiska, 2014).

The volume magnetic susceptibility κ was measured at 515 points located in the research area. The measurement point grid was created (Fig. 1). The points were placed at the distance of 300 m to 500 m from each other (average distance: 350 m). Their location was similar to that used by other authors (Fialova et al., 2006; Magiera et al., 2007). The volume-specific magnetic susceptibility (κ) was measured on the soil surface with the Bartington MS2D sensor according to the procedure described by Schibler et al. (2002). The sensor data was integrated with the GPS coordinates. Two series of the soil magnetic susceptibility measurements were performed, that is, with and without the forest litter. Each measurement result is the arithmetic mean obtained from approximately 10 to 20 individual measurements performed in the circle (radius = 1.0 m).

The most commonly used statistical parameters describing the mean value, dispersion of results and consistency of results with respect to the normal distribution, were calculated for sets of all topsoil magnetic susceptibility measurements. The average content of the magnetic fraction in the soil was calculated in the whole research area and in the vicinity of the main emitters of solid pollutants. The contour lines of the topsoil κ value were determined, both for the series with and without the forest litter (Figs. 2 and 3, respectively). The main wind directions in the research area (Fig. 2) were defined with the results available from the air quality measurements (SAM, 2010–2014).

In the research area, 25 cm long soil cores were collected with the Humax soil probe at 43 points with the enhanced magnetic susceptibility. The Bartington MS2C sensor was used to measure the magnetic susceptibility (κ) of each soil core along its whole length with a resolution of 1 cm. The genetic soil horizons were characterized according to the WRB standards (IUSS, 2007). From each soil layer that represented horizons and subhorizons in the cores, the separation of magnetic fraction by hand magnet was performed. The percentage (weight %) of both (magnetic and nonmagnetic) fraction was determined. Moreover, the fraction percentages were determined. The results from the soil core investigations helped to characterize the soil pollution level in the six regions of the research area (Figs. 4–7):

A. Region at the biggest distance from the pollution emitters (background); it is represented by the sample no. 227.
B. Regions that were mainly affected by urban emission sources dominated by thousands of scattered individual emission sources (so-

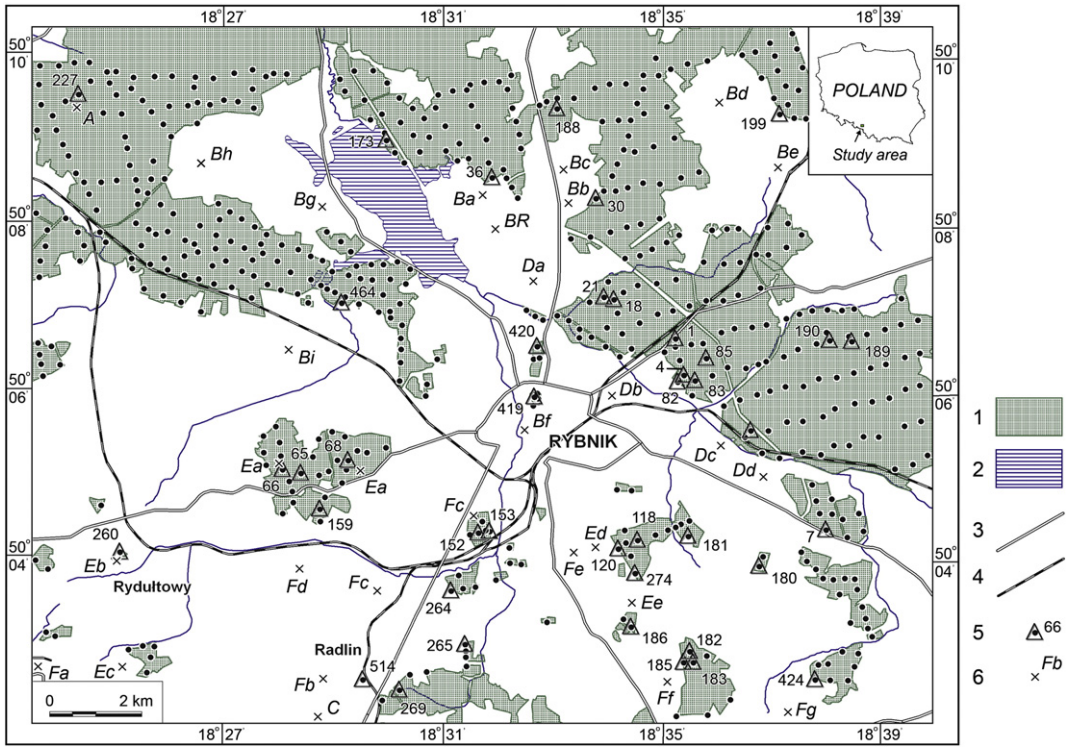

Fig. 1. Location of studied area and sampling point. 1 — areas covered with trees; 2 — Rybnik Lake; 3 — main roads; 4 — main railway lines; 5 — sampling points for soil cores; 6 — main pollution emitters; A — background; B — urban quarters (Ba — Rybnik Grabownia, Bb — Rybnik Górka, Bc — Rybnik Golejów, Bd — Książenice, Be — Rybnik Lasoki, Bf — Rybnik Centrum, Bg — Rybnik Chwałęcice, Bh — Lyski Zwonowice, Bi — Jejkowice); BR — Rybnik Power Plant; C — Radlin Coking Plant; D — former steel works (Da — Rybnicka Kuźnia, Db — Silesia, Dc — Ligocka Kuźnia, Dd — Huta Gotartowska); E — coal mining waste heaps (Ea — Beatensglück, Eb — Karol, Ec — Anna, Ed — Chwałowice, Ee — Jankowice); F — combined heat and power plant and coal mines (Fa — Anna, Fb — Marcel, Fc — Rymer, Fd — Hyom, Fe — Chwałowice, Ff — Jankowice, Fg — Żory).