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CHANGES IN MAGNETIC SUSCEPTIBILITY OF FOREST SOILS ALONG THE WEST AND SOUTH BORDER OF POLAND

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Keywords: Magnetic susceptibility, dust fall, heavy metal content, forest soil, boundary area.

Abstract: The aim of the present study was to estimate the magnetic susceptibility of the boundary area of western and southern Poland. The investigation was carried out in woodlands of chosen forest districts. Samples were collected selectively from the occurring genetic horizons of pit soils. The low-field magnetic susceptibility was obtained in the laboratory using the MS2B Bartington apparatus. Heavy metal content (Fe, Zn, Pb and Cu) was analyzed using AAS method, after the mineralization in the 70% $HClO_4$ + HNO_3 solution. The magnetic susceptibility results are very diverse and above 80% of them exceed $50 \cdot 10^{-8}$ m^3/kg, that is, a border value suggesting an occurrence of a magnetic anomaly. Heavy metal content varies in a wide range and the highest values are observed in mountainous areas, where the impact of geological structure is visible. Obviously, the input of dust emissions is significant, what is confirmed by well and positive values of correlation coefficients between magnetic susceptibility and heavy metal content (especially lead) in the area of cluster III.

INTRODUCTION

Anthropogenic dusts and fly ashes, especially those originating from processes of combustion, besides aluminosilicates contain ferrimagnetic iron oxide particles, mainly magnetite and maghemite [6]. These ferrimagnetic particles are produced from pyrite and other iron-containing minerals during combustion of fossil fuels [10]. Dependent on the wind speed and its direction, as well as the distance from an emission source, pollutants can be deposited far away from the emitters. In studies on soil pollution from combustion processes, soil magnetometry is based on the fact that these deposited dust particles can be easily detected by a measure of magnetic susceptibility, a parameter very sensitive to the presence of ferrimagnetic minerals, e.g. 0.01% of magnetite in soil contributes in about 85% to the total magnetic susceptibility [2, 12]. The ferrimagnetic particles are associated with other hazardous pollutants like heavy metals [9, 11, 21, 24, 27]. A positive relationship between magnetic susceptibility and content of some heavy metals in dusts and soils are observed by many researchers [1, 9, 11, 20, 21, 24]. Hansen *et al.* [4] showed that content of Cr, Mn, Co, Ni, Zn and Be are all significantly increased in the "magnetic" fraction of coal fly-ash. Hunt *et al.* [5] documented that some elements (V, Cr, Mn, Fe, Co, Ni, Cu and Zn) enriched the magnetic fraction, usually in the form of substituted spinels Fe_3-xM_yO_4, irrespective of variations in the type of coal used.

The enhanced value of magnetic susceptibility does not have to be only of technogenic origin. In many cases it could have a geological or a pedogenic background. The high values of magnetic susceptibility of natural origin are explained by the ferrimagnetic content in the bed rocks formed from, for example, basaltic or serpentinite rocks. Measurements of magnetic susceptibility along with the depth of soil profile enable distinguishing the atmospheric input from the natural background [12, 16].

The aim of the present study was to asses the dust fall impact on forest soils in the boundary area of west and south Poland using the magnetic susceptibility measurements as a tool. The important task was to distinguish between technogenic and natural character of increasing magnetic signal, as well as to estimate the level of soil contamination with heavy metals.

MATERIALS AND METHODS

Along the west and south border of Poland, on both sides of the border a lot of dust emission sources are located causing a deposition of many pollutants on soils. The emission sources in the west are mainly the power plants placed in the vicinity of coal (chiefly brown coal) mining industry, whereas in the south there is a large diversification of industry: e.g. the power, mining, metallurgical, cement industry, etc. The south-western part of Lower Silesia together with the area of Northern Bohemia (CZ) and the southern part of Saxony (DE), known as the "Black Triangle" is already well examined [3, 17, 21, 22, 23]. A detailed study performed in the Free State of Saxony resulted in the magnetic susceptibility map of soils from the network 4 × 4 km, which revealed the enhanced values of magnetic susceptibility around urban and industrial centers – around those bordering with Poland [15].

The present study encompasses larger area – almost the whole border line of the west and south Poland (Fig. 1). Based on a cooperation with the Department of Forest Soil Science of the Agricultural University of Kraków over 50 forest soil profiles from

Fig. 1. Sample localizations (rhombuses)

a Polish side of the border and 5 profiles from Germany and Czech Republic were investigated in respect of the volume and mass magnetic susceptibility. Dried samples taken from different soil horizons were placed in 10 cm^3 boxes. Then volume (κ) and mass (χ) magnetic susceptibility was obtained using the MS2 Bartington apparatus equipped with the MS2B sensor. Both, volume and mass magnetic susceptibility are proportional, but the mass magnetic susceptibility takes into account the mass density of a sample, so only the mass magnetic susceptibility will be discussed in this paper.

The selected soil samples were subjected to an analysis of heavy metal content (Fe, Zn, Pb and Cu) using AAS method after the mineralization in the 70% $HClO_4$ + HNO_3 solution, assuming these elements content as near-total content [14].

The data concerning a dust fall was worked out on the basis of the results of the Research Institute of Forestry [8].

RESULTS AND DISCUSSIONS

A surface (organic horizon) distribution of the magnetic susceptibility (χ) as well as the dust fall values along the border lines: N-S and W-E are shown in Figure 2. The χ values range from about 20 to almost $700 \cdot 10^{-8}$ m^3/kg. Only about 15% of obtained results are below $50 \cdot 10^{-8}$ m^3/kg, that is, a border value suggesting an occurrence of magnetic anomaly, which is often accompanied by a geochemical anomaly (a situation when the permissible content of at least one heavy metal is exceeded) [18, 19, 25, 26].

The magnetic susceptibility distribution in the study area is very diverse. In the area of Wolin and Świnoujście the χ values keep at a level of $50 \cdot 10^{-8}$ m^3/kg and then constantly rise to $500 \cdot 10^{-8}$ m^3/kg in the environs of Olszyna. The increase could be caused by dusts produced by the Dolna Odra Power Plant as well as the Schwedt Refinery located on a German side of the border, but the main source of magnetic particles, especially in soils from Słubice and Gubin seems to be a steelworks in Eisenhüttenstadt. In Łęknica area influenced by the contaminations from the Schwarze Pumpe power and coking plant, the χ value is still very high ($277 \cdot 10^{-8}$ m^3/kg), but in the next study points decreases to under $50 \cdot 10^{-8}$ m^3/kg. In the area of Węgliniec and Bolesławiec (being under the influence of the "Black Triangle" industry) there is observed another enhancement of χ, probably caused by the emissions from Turów, Hirschwelde, Hagenwerden, Boxberg, Počerady and Melnik power plants. Samples taken in the area of the Giant Mountains are characterized by lower values of magnetic susceptibility, yet over $50 \cdot 10^{-8}$ m^3/kg. The χ of forest soils in the southern border line systematically rises from the Giant Mountains to the region of Kędzierzyn-Koźle achieving $561 \cdot 10^{-8}$ m^3/kg. The reason for this could be the pollutants emitted by the native chemical industry. The samples from Rudy Raciborskie are characterized by high χ values, but lower than these of previous samples. The maximum of χ ($669 \cdot 10^{-8}$ m^3/kg) is accomplished in the area of Rybnik and caused mainly by emissions from a Power Plant Rybnik (with a 1775 MW capacity), Power Plant Dětmarovice (with an 800 MW capacity) and probably a coking plant in Rydułtowy. The next extreme value of χ occurs in the area of Wisła where the impact of a power plant and iron works in neighboring Czech town Třinec is visible. Further along the border line there is observed a big drop in χ up to $25 \cdot 10^{-8}$ m^3/kg in samples from Bieszczady National Park. The χ values of German and Czech soils are the highest in the whole study area, in Schleife and Třinec they exceed $1000 \cdot 10^{-8}$ m^3/kg. The χ is two times higher for these sites. Therefore, it

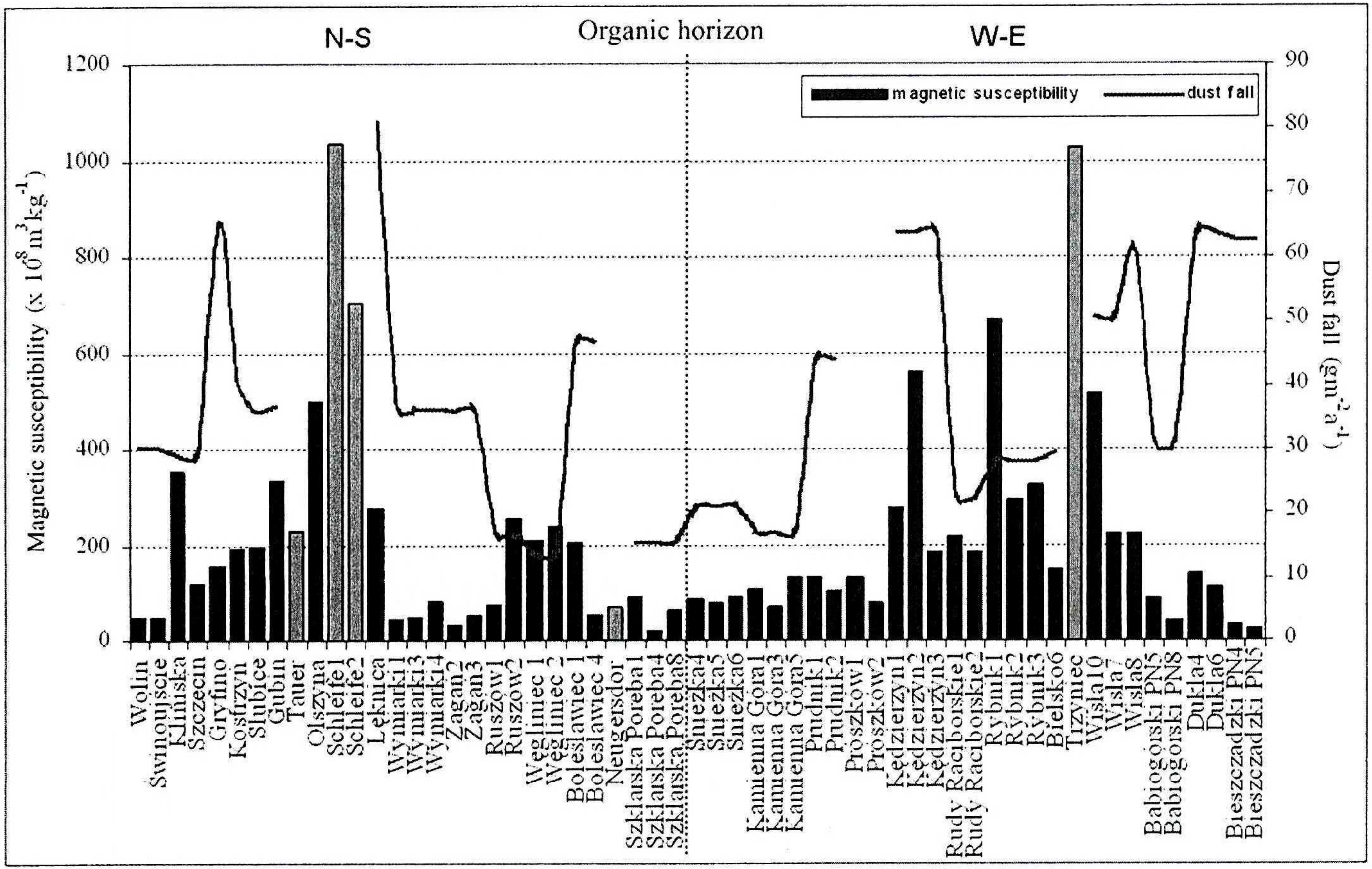

Fig. 2. Magnetic susceptibility values and annual average of dust fall along the western (from the north to the south – N-S) and southern (from the west to the east – W-E) border of Poland (black – Polish pit soils; gray – German and Czech pit soils)

could be concluded that the dust emissions from neighboring countries have a big impact on contamination of Polish soils.

Values of an annual dust fall vary from ~ 13 to 80 g/m^2 and they do not exceed the permissible value 200 g/m^2. The highest dust fall values were noted in Olszyna, Łęknica, Kędzierzyn-Koźle and Wisła, that is, the places where the χ was also very high. The dust fall distribution shown in Figure 2 does not reveal an expected compatibility with the magnetic susceptibility distribution. Only in several cases the high or low values of dust fall correspond to the χ values. The correlation coefficient between dust fall and magnetic susceptibility is also dissatisfying. The localization of the dust fall measurement points could be the cause of this. However, very high concentration of Cd and Pb in wet and dry precipitation was found in the Giant Mountains and Beskidy – regions where increased values of χ were measured [7].

Three types of pit soils, as regards a vertical magnetic susceptibility distribution, are distinguished. In almost all pit soils the vertical distribution of magnetic susceptibility is characteristic of profiles with technogenic influence on magnetic susceptibility, which means that the χ has a strong enhancement at the depth of about 2–6 cm and then it decreases downwards (Fig. 3a). In pit soils collected in the Giant Mountains there are two enhancements: in uppermost organic horizons (Of, Oh) and in the bed-rock (Fig. 3b), which suggests both technogenic and lithogenic background of the increasing magnetic susceptibility. The last type of the vertical profile is characterized by higher values of χ along a whole profile and it is typical of soils with strong lithogenic influence on the magnetic susceptibility (Fig. 3c).

The results of heavy metal content exhibit a large diversification (Table 1). The Fe content ranges from 400 to 20500 mg/kg, Zn content: 27.7–162.5 mg/kg, Pb content: 25.0–296.0 mg/kg and Cu content: 5.0–84.2 mg/kg. Similar results are published by Matýsek *et al.* [13] who investigated soils in the Ostrava-Karviná Industrial Region.

The highest heavy metal content is observed in mountainous areas where the impact of geological structure is apparent, but in many samples the industrial dust fall has the big contribution to the heavy metal content, what is confirmed by the well and positive correlation coefficients (especially between χ and zinc, Table 1) calculated for clustered areas (I, II, III and IV). The areas of clusters III and IV seem to be the most influenced by industrial emission. Literature data [6, 13, 17, 26] show, that elements typical of industrial emissions in Central Europe i.e. Fe, Mn, Zn, Pb, Cd, or Cu reveal considerably higher correlation coefficients with χ than these obtained for the study area. Dissatisfied correlation coefficient between χ and lead in clusters I and II indicated the lithogenic character of magnetic anomaly, originating from bedrocks occurring in the study areas.

CONCLUSIONS

The study confirmed that magnetic susceptibility is a parameter which can be effectively used as a proxy to detect soils affected by technogenic dust emissions. Increase in magnetic susceptibility along the border of Poland, on either side of the border, pointed at the long-distance transport of pollutants as a decisive factor.

Technogenic, magnetic particles can be treated as tracers of the presence of heavy metals, based on the knowledge that they both originate from the same combustion source. This statement is certified by a positive correlation between magnetic susceptibility

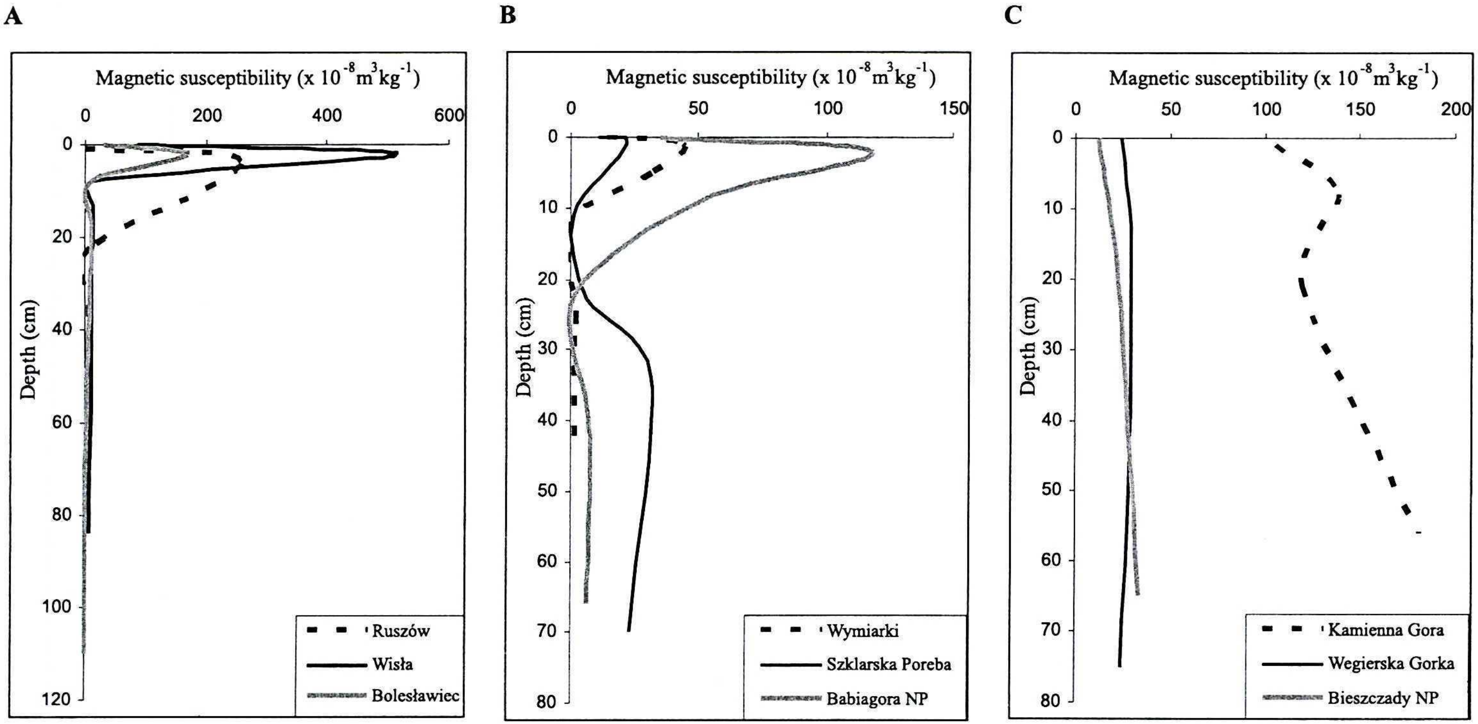

Fig. 3. Typical vertical magnetic susceptibility distributions of pit soils from a study area

Table 1. Heavy metal content in the organic horizon of investigated soils and the values of correlation coefficient between magnetic susceptibility and heavy metal content calculated for particular studied regions

	Profile name	Soil horizon, site type	$\chi \times 10^{-8}$ [m^3/kg]	Fe [mg/kg]	Zn [mg/kg]	Pb [mg/kg]	Cu [mg/kg]
Cluster I	Kliniska	Ofh, fresh coniferous forest	356,5	17975	69,5	89	39,2
	Gryfino 1	Ofh,, mixed fresh forest	158	3222	50,7	35,5	31
	Szklarska Poreba 1	Ofh, mountain riparian forest	92,3	10125	50,6	91,4	45,1
	Szklarska Poreba 4	Ofh, mountain coniferous forest	21,8	8525	27,7	133	28,2
	Śnieżka 4	Ofh, mixed mountain forest	87	13550	63	109,5	35
	Śnieżka 5	Of, high-mountain coniferous forest	102,9	12100	61,2	188	59,4
	Śnieżka 6	Oh, mixed mountain forest	90	9000	56,7	147,7	45,3
			Correlation coefficient χ/	0,5	0,7	-0,4	0
Cluster II	Kamienna Góra 1	Of, mountain coniferous forest	105,4	8400	59,5	164,2	45,3
	Kamienna Góra 3	Ofh, mixed mountain coniferous forest	69,6	10700	48,7	126,7	43,1
	Kamienna Góra 5	Ofh, mountain forest	130,9	5675	42	118	47,6
	Prudnik 1	Ofh, mountain coniferous forest	132,5	400	150	50	-
	Prudnik 2	O, mountain coniferous forest	105	1025	130	52,5	-
	Prószków 1	O, coniferous forest	131,3	995	95,5	25	-
			Correlation coefficient χ/	-0,7	0,4	-0,5	1
Cluster III	Kędzierzyn 1	O, mixed fresh coniferous forest	277,5	1636,7	95,3	76,7	8,3
	Kędzierzyn 2	O, mixed fresh forest	515	1443,3	57	30	6,7
	Kędzierzyn 3	O, mixed fresh coniferous forest	180,8	1423,3	90,3	36,7	6,7
	Rudy Raciborskie 1	O, fresh coniferous forest	220	1950	111,7	86,7	10
	Rudy Raciborskie 2	O, mixed forest	185	1373,3	115	50	10
	Rybnik 1	O, coniferous forest	668,8	2725	122	190	-
	Rybnik 2	O, mixed forest	291,3	1625	124,5	110	-
	Rybnik 3	O, mixed coniferous forest	355	1586,7	52,7	66,7	5
			Correlation coefficient χ/	0,7	-0,1	0,6	-0,5
Cluster IV	Bielsko 6	Ofh, mixed mountain forest	147,5	11060	92,1	161,6	38,5
	Wisła 10	Ofh, mixed mountain forest	514,1	20200	162,5	200,5	84,2
	Wisła 7	Ofh, mixed mountain coniferous forest	224,3	9575	114,3	192,3	48
	Wisła 8	Ofh, mountain coniferous forest	222,2	9075	121,5	249	60,7
	Babiogórski PN5	Ofh, high-mountain coniferous forest	85	8050	102,4	236,3	34,6
	Babiogórski PN8	Ofh, high-mountain pine complex	42	14987	98,5	121,4	40,2
	Dukla 4	Oh/A, mountain forest	142,2	19075	93,2	296	83,2
	Dukla 6	Ofh/A, mixed upland forest	110,1	5950	101	114	43
	Bieszczadzki PN4	Ofh, protective high-mountain area	31,4	12490	78,1	95,1	16
	Bieszczadzki PN5	Oh/A, mixed mountain forest	25,4	20500	64,9	77,7	26,1
			Correlation coefficient χ/	0,2	0,9	0,4	0,8

and heavy metal content. Dissatisfied correlation coefficient values could be caused by the bedrocks from the study areas.

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ZMIANY WARTOŚCI PODATNOŚCI MAGNETYCZNEJ GLEB LEŚNYCH WZDŁUŻ ZACHODNIEJ I POŁUDNIOWEJ GRANICY POLSKI

Celem prezentowanych badań było określenie wielkości podatności magnetycznej obszarów przygranicznych Polski zachodniej i południowej. Badania prowadzono na obszarach leśnych w wybranych nadleśnictwach. Próbki pobierano selektywnie z występujących poziomów genetycznych odkrywek glebowych. Niskopolową podatność magnetyczną zmierzono w laboratorium przy użyciu aparatury MS2B Bartington. Zawartość niektórych metali ciężkich (Fe, Zn, Pb i Cu) oznaczono metodą ASA po uprzedniej mineralizacji próbek roztworem 70% $HClO_4$ + HNO_3. Wyniki badań podatności magnetycznej są bardzo zróżnicowane, ale w ponad 80% próbek jej wartości przekraczają $50 \cdot 10^{-8}$ m^3/kg, czyli wartość, powyżej której można się spodziewać występowania anomalii magnetycznej. Zawartość metali ciężkich waha się w szerokim zakresie, przy czym najwyższe wartości obserwuje się w rejonach górskich, gdzie wpływ na ich zawartość ma budowa geologiczna. Jednak wysokie współczynniki korelacji między podatnością magnetyczną a zawartością metali ciężkich w rejonie badań III wskazują emisje pyłów przemysłowych jako źródło metali ciężkich, zwłaszcza ołowiu.