The magnetic susceptibility of soils and alluvial sediments from Gdańsk region (northern Poland)

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The search for quick and cheap methods for environmental monitoring, being alternative or complementary to the geochemical mapping, has become an important challenge for geophysics. Magnetometric methods have been successfully applied in environmental studies of soils and sediments. Magnetic susceptibility maps of soils were constructed for the area of England and Wales. They reveal susceptibility anomalies related to large industrial centres (Hay et al., 1997). Similar maps of regional scale are prepared in Austria (Scholger, 1997) and Switzerland (Zergenyi et al., 1998).

This study presents the record of the low frequency magnetic susceptibility of soil, subsoil and alluvial sediments from the Vistula mouth area. The results of magnetic measurements were directly compared to geochemical spectra, which enabled to establish the correlation between higher contents of some elements and magnetic susceptibility values of investigated samples. Geochemical data base used in this study was adopted from Geochemical Atlas of Poland (Lis and Pasieczna, 1995), which significantly lowered the total costs of investigations.

Magnetic susceptibility ($k$) is a measure of the ease with which a material can be magnetised. Positive values of $k$ are directly related to the content of ferro- and paramagnetic particles in the sediment sample. Negative values of $k$ indicate influence of diamagnetic minerals. Magnetic susceptibility of topsoil might be of either natural (geogenic or pedogenic) or anthropogenic origin. The latter arises from accumulation of industrial dust, rich in strongly magnetic minerals. In this case easy measurable magnetic susceptibility might reflect an amount of industrial dust influx into soils (e.g. Heller et al., 1998). It has also been proved that fuel burning, cement production as well as metallurgical and other processes are the sources of magnetic particles released to the atmosphere as aerosols (e.g. Strzyszcz et al., 1996). These dusts usually contain a significant amount of heavy metals. It was revealed twenty years ago (Hullet et al., 1980) that most metals which occur in coal in the form of sulphides (Pb, Zn, Cd, V, Cr, Co, Ni and Cu), are present in ashes together with magnetic minerals.

INTRODUCTION

METHODS AND SAMPLING
Fig. 1. A. Magnetic susceptibility map of topsoils from the Gdansk region; B. Magnetic susceptibility map of alluvial sediments from the Gdansk region; C. Magnetic susceptibility map of subsoils (at the depth of 40–60 cm) from Gdansk region; D. Map of differential magnetic susceptibility between topsoil horizon and subsoil at the depth of 40–60 cm.
Fig. 2. Magnetic susceptibility of topsoils from Gdansk region versus concentration of selected elements

The last plot shows the magnetic susceptibility of topsoil (K1) versus differential magnetic susceptibility between topsoil and subsoil at the depth of 40–60 cm (K1–K2); magnetic susceptibility measurements and geochemical analyses were carried out on the same sample set.
The area of investigation is situated between 18 and 19.6° long. E, and between 53.7 and 54.8° lat. N. Its central part is the Vistula delta. Magnetic susceptibility measurements were performed for 1750 samples, which had been collected and used for the Geochemical Atlas of Poland (Lis and Pasieczna, 1995). About 600 samples was taken from the accumulation topsoil horizon. The same amount of samples was collected in the same points from the depth interval 40–60 cm. The rest of samples was taken from recent alluvial sediments. The soil sampling places were selected accordingly to the prevailing kinds of cultivation. If the forests prevailed in the area, the samples were taken from the forest soils. All the samples, after drying, were sieved to obtain the fraction finer than 1 mm. Volume magnetic susceptibility was measured with the KLY2 kappa bridge produced by AGICO (Brno).

MAGNETIC SUSCEPTIBILITY OF THE TOPSOIL HORIZON

Magnetic susceptibility of the topsoil horizon amounted from 6 x 10^{-6} SI units in some samples from the northwestern part of the investigated area to 7680 x 10^{-6} in the sample from Gdańsk agglomeration. Anomalously high values of magnetic susceptibility occur in the belt extending south-north, from Starogard Gdańsk, through Tczew, Gdańsk and Gdynia (Fig. 1A). Relatively high values of magnetic susceptibility were encountered also along the Nogat river, from Malbork to Elblag and Tolkmicko at Żelew Wświany. Two more anomalous points are located at the Mierzeja Helska near the cities Jastarnia and Hel.

MAGNETIC SUSCEPTIBILITY OF THE RECENT ALLUVIAL SEDIMENTS

The magnetic susceptibility map of alluvial sediments reveals several positive anomalies, which correlate well with anomalies observed in the topsoil susceptibility map. Anomalously high values of susceptibility of alluvial sediments are noted in the area of Gdańsk agglomeration and between Malbork and Elblag (Fig. 1B). High values of magnetic susceptibility are observed also at Mierzeja Wiślania and Mierzeja Helska. Origin of these anomalies is difficult to interpret without more detailed investigations. They might result either from extensive pollution of the areas or from the concentration of heavy minerals in the beach sands.

MAGNETIC SUSCEPTIBILITY OF SUBSOILS AT THE DEPTH OF 40–60 CM

Magnetic susceptibility of the ground at the depth 40–60 cm varied between 3 x 10^{-6} and 8523 x 10^{-6} SI units. Positive anomalies observed in the investigated horizon are localised mostly in the same places as those occurring in the topsoil horizon (see Figs. 1A and C). However, the amplitude of the anomalies is generally smaller (near Gdynia and Elblag) with two exceptions (the seaside part of the Gdańsk agglomeration and Tolkmicko area). Anomaly of the Jastarnia (Mierzeja Helska) is not manifested at the map.

DIFFERENTIAL MAGNETIC SUSCEPTIBILITY BETWEEN TOPSOIL HORIZON AND SUBSOIL AT THE DEPTH OF 40–60 CM

Well defined positive anomalies in the differential susceptibility map are concentrated in the area of Gdynia, southern part of Gdańsk, Starogard Gdańsk, Tczew, Malbork, Elblag, Jastarnia and Hel (Fig. 1D). Their close correlation with urban areas indicates that differential susceptibility map most reliably defines the regions of environmental pollution. Large positive anomaly between Gdańsk and Tczew is no more visible at the map. In this sector the basement susceptibility is even greater than the topsoil susceptibility, which might indicate geogenic origin of this anomaly.
MAGNETIC SUSCEPTIBILITY VS. CONTENTS OF SELECTED ELEMENTS

Positive correlation is observed between magnetic susceptibility of topsoil and such elements as Ba, Co, Mg, Mn and Ni (Fig. 2). The correlation is definite for magnetic susceptibility values higher than $1200 \times 10^6$ SI units. A positive correlation might be inferred also for Sr, Ti, V and Y, but this is not as evident as in the former case. Quite another type of correlation might be observed in the case of Zn and Pb. Up to $1500 \times 10^6$ SI units a weak positive correlation is observed, while in the higher susceptibility range an opposite, negative correlation seems apparent.

Topsoil magnetic susceptibilities correlate well with differential susceptibility values (Fig. 2), which means that in most cases positive anomalies on the surface are not accompanied by susceptibility increase at the depth 40–60 cm (except an anomaly between Tczew and Gdańsk).

CONCLUSIONS

1. Volume magnetic susceptibilities higher than $1200 \times 10^6$ SI units might reflect high contents of some elements (e.g. Ba, Co, Mg, Mn and Ni) in the topsoil horizon.

2. Close correlation of distinct positive anomalies of differential magnetic susceptibility with urbanised regions indicates that differential susceptibility map displays the geochemical anomalies of anthropogenic origin, related to environmental pollution.

3. Anomalies in the magnetic susceptibility map of topsoil horizon are resultant effects of anthropogenic and geogenic origin. Negative anomalies of differential magnetic susceptibility might indicate to its dominant geogenic component.

4. Differential magnetic susceptibility map might be a useful tool for preliminary detection of heavy metal pollution in soils. The method is cheap and quick, especially when measuring magnetic susceptibility directly in the field.

REFERENCES


