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REDUCTION OF SOIL CONTAMINATION UNCERTAINTY ASSESSMENT USING MAGNETIC SUSCEPTIBILITY MEASUREMENTS AND Co_Est METHOD

REDUKCJA NIEPEWNOŚCI OCENY ZANIECZYSZCZENIA GLEB PRZY WYKORZYSTANIU POMIARÓW PODATNOŚCI MAGNETYCZNEJ I METODY Co_Est

Abstract: The deposition of anthropogenic dusts originating mostly from industrial processes and solid fuel combustion causes the substantial changes in magnetic susceptibility of topsoil layers. Consequently, the magnetic susceptibility is one of the soil properties, which makes it possible to assess the soil contamination with heavy metals. Moreover, *in situ* field measurements of magnetic susceptibility are significantly less expensive and time-consuming than laboratory chemical analyses. However, the geochemical measurements are usually sparse and precise, whereas the magnetometric ones are numerous or even excessive, but not very exact. For these reasons, in order to assess the extent of soil contamination it should be performed both geochemical and magnetometric measurements at the same time, and then integrate them using some geostatistical methods such as cokriging. Because of usually too small set of geochemical measurements, this integration may be highly difficult task. In most cases, the modeling of auto-semivariance of primary variable and especially cross-semivariance in ordinary cokriging procedure become almost impossible.

This study presents the Co_Est procedure potential to reduce soil contamination uncertainty when geochemical measurements are too sparse, and magnetic susceptibility measurements serve as secondary data. For this purpose, topsoil pollution at few different size areas placed in forests or parks, located within the Upper Silesian Industrial Area was measured and analyzed. Then the maps of contaminations obtained using kriging and Co_Est methods were compared. In particular, reduction of uncertainty in soil contamination was quantified and discussed.

Key words: field magnetometry, topsoil magnetic susceptibility, heavy metals, geostatistics, data integration, Co_Est method, risk analysis

Magnetic susceptibility is one of the soil properties, which enables to assess the extent of soil contamination with heavy metals. The development of field magnetometry resulted from a need for fast and cheap methods for the detection of industrial pollution of soil. Recently, these measurements became recognized as a useful and effective

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method for detecting the potential soil pollution with heavy metals. Dust deposition of anthropogenic origin at the soil surface, which is a source of many magnetic particles, and amongst them heavy metals that cause also the increase of magnetic susceptibility of top soil layers. An increasing number of studies were carried out using magnetometry to assess the soil contamination with heavy metals [1–6]. Significant positive correlations were found between the magnetic susceptibility and the content of heavy metals of anthropogenic origin in soil [7, 8]. Due to these correlations, it is possible to estimate the extent of areas with heightened values of soil magnetic susceptibility, and simultaneously potentially polluted with magnetic compounds and accompanying heavy metals. Consequently, fast and cheap field magnetometric measurements can supplement or, in some specific situations, completely replace the chemical analyses.

Accordingly, field magnetometry offers a few types of measurement [9]. Most common types are surface measurements of soil magnetic susceptibility and measurements in the soil profile. In order to improve the precision of analyses, it may be advantageous to use simultaneously different types of soil magnetic susceptibility measurements and chemical ones. This can be done using some geostatistical methods, which enable to integrate information from different types of measurements.

This study presents the potential of Co_Est procedure to reduce soil contamination uncertainty when geochemical measurements are too sparse, and magnetic susceptibility measurements serve as secondary data. For this purpose, the topsoil pollution was measured and analyzed at few different areas placed in forests or parks within the Upper Silesian Industrial Area. Then the contamination maps obtained with kriging and Co_Est methods were compared. In particular, reduction of uncertainty in soil contamination was quantified and discussed.

Geostatistical methods

Geostatistics offers several tools for the data integration. Theses methods are useful when apart from measurements of primary variable, which are difficult to perform, expensive, time-consuming or too rarely sampled, also some additional measurements are available. Additional data are usually cheaper, less time-consuming, but also less precise in comparison with primary variable. Geostatistical data integration [10–12] enables to use both types of measurements and obtain spatial distributions more precise in comparison with the ones obtained with the use of only one type of measurement. One of the most common data integration methods is cokriging. Cokriging is a variety of kriging, which allows using multiple variables, correlated with each other. However, in some cases the application of cokriging can be difficult, especially in cases when only small data set of primary variable is available or samples are placed in very irregular way. In such situation, it is necessary to use different method of data integration. One of these methods is Co_Est [12].

The Co_Est method consists in the transformation of the secondary dataset into the primary one using the so-called pedotransfer functions (PF). PF's are regression equations or model, which relate the hard-to-measure field samples $Z(x_j)$ to k = 1, 2, ..., t more basic and easy-to-measure properties $W(x_i)$.

$$Z(x_j) = \beta_0 + \sum_{k=1}^{t} \beta_k W(x_i) + \varepsilon_j$$

$Z(x_j)$ – values of the hard-to-measure filed samples – main variable;
$W(x_i)$ – values of the more basic and easy-to-measure properties – additional variables;
β_0, β_k – constants;
ε_j – random variable with mean equal zero and variance equal σ.

This transformation results in a larger data set of primary variable, which can be subsequently used in different geostatistical procedures like ordinary kriging. The Co_Est method also permits to estimate measurements errors both in primary and secondary data. In kriging method, the value estimated at unknown location, is calculated using linear combination of both variables:

$$Z^*(\mathbf{x}_0) = \sum_{k=j}^{N_1} a_j\, z(\mathbf{x}_j)$$

where $Z^*(\mathbf{x}_0)$ is the prediction at location $\mathbf{x}_0$, $z(\mathbf{x}_j)$ is the j^{th} nearby sample primary value weighted by a_j, N_1 is the number of nearby samples of primary values.

Exemplary application in field magnetometry

The study area was located within Upper Silesian Industrial Area region, in the Repecki Park, located near Tarnowskie Gory town. The study area had irregular shape

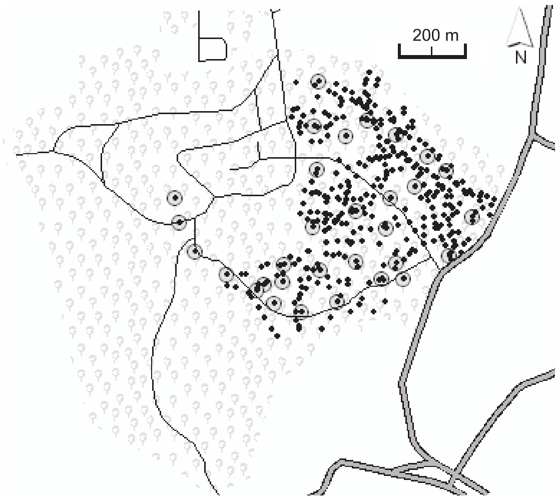

Fig. 1. The location of the study area and sample location of surface (denoted by black dot) and vertical measurements (denoted by gray dot)

with dimensions of about 1 km and 800 m. The park is placed near to the local public road but the area of the park is closed for traffic, and only available only for pedestrians.

At study area, different types of trees were present, both coniferous and deciduous ones. Some small areas were overgrown with brushwood. At entire study area, no water bodies or rivers were present.

The area was sampled with two types of measurements. The first one was the surface measurement of soil magnetic susceptibility carried out with MS2D Bartington sensor. The second one was the measurement of soil magnetic susceptibility in soil profile, carried out with SM400 sensor. The penetration range of MS2D sensor is about 10 cm, and for that reason, this measurement gives as a result an averaged soil magnetic susceptibility from depth from 0 to 10 cm [2–9]. The measurement in soil profile gives as a result a plot of magnetic susceptibility against the depth. In comparison with surface measurements, it is more precise, but it is also more time-consuming one. Results of these two types of measurements can be analyzed using geostatistical data integration in order to improve the precision of analyses.

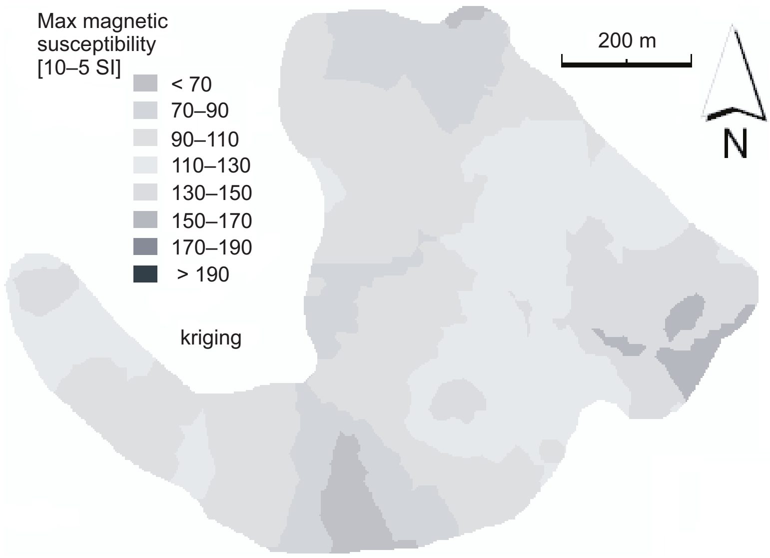

Fig. 2. Distribution of magnetic susceptibility in soil profile

The magnetic susceptibility usually shows characteristic distribution in the soil profile, and frequently maximum value of magnetic susceptibility is observed at the depth of several centimetre. This depth is directly connected with the thickness of the soil organic horizon. From each plot of the magnetic susceptibility in soil profile, the maximum value was picked up and used in further analysis as a main variable. Surface measurements of soil magnetic susceptibility were used as an additional one. In case of measured data set, the significant correlation exists between surface and vertical measurements, and the Pearson correlation coefficient was equaled about 0.64.

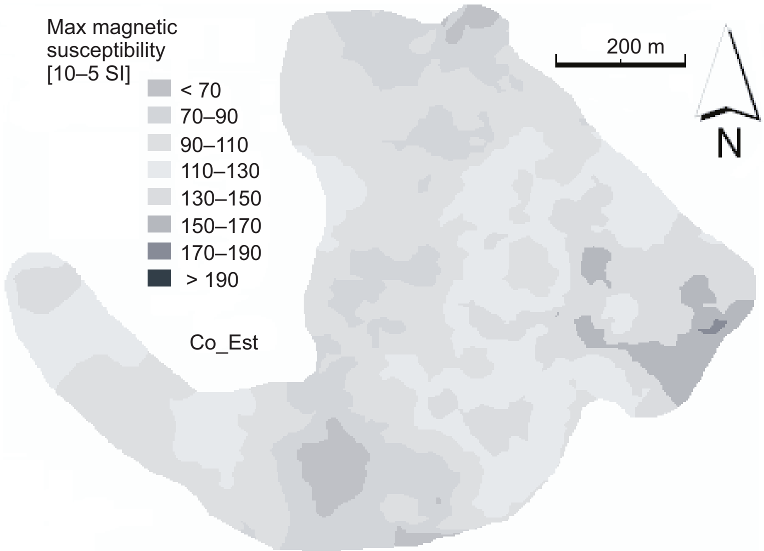

Fig. 3. Distribution of magnetic susceptibility in soil profile

In addition to the spatial distribution obtained with Co_Est method, kriging method was used, in order to compare precision of both methods.

Table 1

Prediction errors for spatial distributions calculated with Co_Est and kriging method

	Prediction error			
	Mean	Root mean square std.	Mean	Root mean square std.
	Area 1		Area 2	
Kriging	1.034	0.977	0.039	1.224
Co_Est	0.024	0.993	0.031	1.265

Conclusions

The results show that, it is possible to integrate different types of magnetometric measurements using Co_Est method. In case of the measurements of magnetic susceptibility at soil surface and in the soil profile, it is possible to obtain more precise spatial distributions in comparison with kriging method.

In case of chemical measurements data integration Co_Est method may also improve the precision of calculated spatial distributions. It is especially important in case of small and irregular datasets of chemical measurements.

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Abstrakt: Depozycja pyłów pochodzenia antropogenicznego, pochodzących głównie ze źródeł przemysłowych i spalania paliw stałych, powoduje znaczne zmiany podatności magnetycznej górnych warstw gleby. Z tego względu podatność magnetyczna jest jedną z właściwości gleby, które mogą być wykorzystane w celu określenia stopnia zanieczyszczenia gleby metalami ciężkimi. Terenowe pomiary podatności magnetycznej są znacznie tańsze i mniej skomplikowane w porównaniu do analiz chemicznych. Ponadto pomiary chemiczne są zazwyczaj dokładniejsze i wykonywane z mniejszą gęstością powierzchniową niż pomiary magnetometryczne. Z powyższych powodów, celowe jest wykonywanie pomiarów obu rodzajów, a następnie zintegrowanie ich za pomocą metod geostatystycznych, takich jak np. cokriging. Jednak zazwyczaj ze względu na małą ilość danych chemicznych tego typu integracja jest bardzo trudna. Dokładne wymodelowanie wariogramów i wariogramów krzyżowych dla metody cokrigingu może być niemożliwe.

Niniejsza praca prezentuje możliwości zastosowania metody Co_Est w celu redukcji niepewności oceny zanieczyszczenia gleb, w przypadku gdy dostępna jest mała ilość pomiarów geochemicznych, a pomiary magnetometryczne służą jako dane uzupełniające. W tym celu wykonane zostały pomiary zanieczyszczenia gleb oraz pomiary magnetometryczne na kilku obszarach leśnych zlokalizowanych na terenie Górnośląskiego Okręgu Przemysłowego. Następnie wykonane i przeanalizowane zostały mapy rozkładów przestrzennych metodami krigingu i Co_Est.

Słowa kluczowe: magnetometria terenowa, podatność magnetyczna, metale ciężkie, geostatystyka, integracja danych, metoda Co_Est, analiza ryzyka