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Review

Mathematical forecasting methods for predicting lead contents in animal organs on the basis of the environmental conditions

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A B S T R A C T

The main objective of this study was to determine and describe the lead transfer in the soil–plant–animal system in areas polluted with this metal at varying degrees, with the use of mathematical forecasting methods and data mining tools contained in the Statistica 9.0 software programme. The starting point for the forecasting models comprised results derived from an analysis of different features of soil and plants, collected from 139 locations in an area covering 100 km^2 around a lead–zinc ore mining and processing plant ('Boleslaw'), at Bukowno in southern Poland. In addition, the lead content was determined in the tissues and organs of 110 small rodents (mainly mice) caught in the same area. The prediction models, elaborated with the use of classification algorithms, forecasted with high probability the class (range) of pollution in animal tissues and organs with lead, based on various soil and plant properties of the study area. However, prediction models which use multilayer neural networks made it possible to calculate the content of lead (predicted versus measured) in animal tissues and organs with an excellent correlation coefficient.

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1. Introduction

Lead does not easily migrate in the environment (Kabata-Pendias and Pendias, 2001), which is why its natural distribution in a soil profile reflects the content of the parent rocks, and its occurrence in the soil surface layers depends on anthropogenic influences. The main anthropogenic sources include mining and metallurgy of non-ferrous metals, pesticides and phosphatic fertilizers, and motorization (Cai Qiu et al., 2009; Kopittke et al., 2007; Singhl Rana et al., 1997). The transfer of lead from soil to plant tissues depends on many factors (Rogival et al., 2007; Brink van den et al., 2010). In acid soils, mobile types of lead occur

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mainly in the form of Pb^{2+} and $PbHCO_3^+$ as well as organic complexes whereas in alkaline soils these forms occurr mainly as cations $PbOH^+$ and $Pb(CO_3)_2^{2-}$. In soils with pH higher than 6.5, precipitation of lead in the form of carbonates and phosphates represents the process which has a significant influence on its immobilization (Kabata-Pendias and Pendias, 2001).

In order to prevent excessive accumulation of heavy metals in plant tissues and their transfer to organisms feeding on these plants, a standard was established in Poland. This standard determines the permissible lead content in soils of agricultural use, which amounts to 100 mg Pb kg^{-1} (Regulation of the Minister of Environment of 9 September, 2002). A standard equivalent to the one mentioned above, which is effective in the European Union, is the maximum permissible lead content (provided in the European Union Directive, 2002) for soils designated for plant cultivation, and this content limit is 300 mg Pb kg^{-1}.

The amount of heavy metals in the soil, plants and animal indicates how they are transferred in the environment and the potential hazard to organisms caused by their toxic effect (Torres and Johnson, 2001). Particularly in regions of zinc and lead ore mining and processing, the soils are characterized by high concentrations of harmful elements, including lead (Piaseczna, 2008; Cai Qiu et al., 2009; Bech et al., 2012). In these places excessive concentrations of lead can be found, above all, in the soil surface layer, which may be a result of the present and past methods of acquiring and processing Zn–Pb ores (Piaseczna, 2008).

As numerous research studies show (Notten et al., 2005; Rogival et al., 2007; Beernaert et al., 2008; Bech et al., 2012), in order to successfully implement activities to limit the accumulation of heavy metals in the food chain, monitoring studies must first be conducted, and then an optimal strategy developed for managing this problem, based on the findings of these studies. Preparation for such procedures seems to be particularly important in regions with high concentrations, for instance, of lead in the environment, due to the possibility of it being accumulated by living organisms for which this element display its toxic effect (Wolterbeek and Verburg, 2001; McDermott et al., 2011). However, conducting monitoring programmes is generally time-consuming and requires considerable expenditure. That is why the introduction of any modifications (including, for instance, mathematical forecasting methods) which contribute to lowering costs and the monitoring time required is desired (European Commission, 2001).

Therefore, it was decided to conduct research whose main objective was to determine and describe the lead transfer in the soil–plant–animal system, in areas polluted with this metal to varying degrees, with the use of mathematical forecasting methods and data mining tools contained in the Statistica 9.0 software.

2. Material and methods

2.1. Description of the research area and the field research conducted

The research area covered 100 km^2 in the neighbourhood of the Boleslaw mine and metallurgical plant (MMP) in Bukowno (Fig. 1). It is located between two provinces, namely the Malopolska province and the Silesia province in southern Poland (Cabała, 2009).

The research area was divided into two regions: an area directly adjacent to the Boleslaw mine and metallurgical plant, where the density of sampling was 2 samples from 1 km^2 and areas located further from the plant, where 1 sample was taken from each 1 km^2 (Fig. 1).

In the first stage of the research, the following soil and plant material were collected from 139 locations established by GPS:

- soil from two layers – 0–10 cm and 40–50 cm,
- monocotyledonous and dicotyledonous plants.

After the initial inspection of the sampling area, we selected the following plants species: monocotyledonous: *Festuca ovina*, *Calamagrostis epigeios*, *Elymus regens*, and dicotyledonous: *Taraxacum officinale*, *Biscutella laevigata* L. and *Plantago lanceolata* L.

The next stage of the field research comprised catching small rodents (mice). These animals are used in biomonitoring tests by many researchers (Damek-Poprawa and Sawicka-Kapusta, 2003; Rogival et al., 2007; Martiniaková et al., 2010). The mice were caught in two periods, from June to October 2009 and 2010. A total of 110 specimens from 101 points were collected during the two catching seasons (Fig. 1).

2.2. Laboratory tests

The collected soil samples were dried until they attained a constant weight before being passed through a sieve with a 2 mm mesh. The soil samples were prepared and the basic soil properties were determined: pH by potentiometric

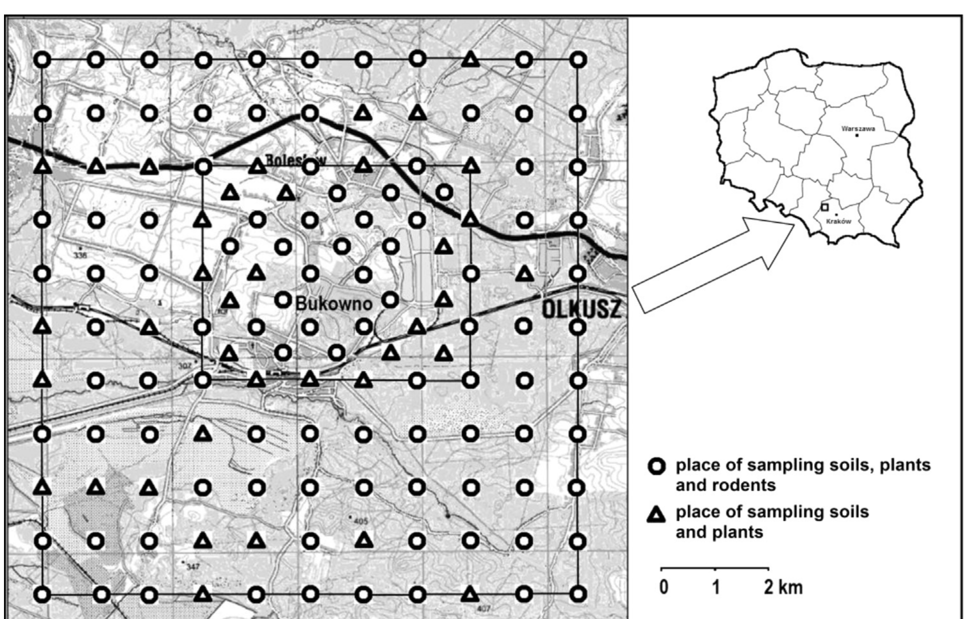

Fig. 1. Sample collection sites in the region of Boleslaw Mine and Metalurgical Plant in Bukowno (http://www.wspinet.pl, 2012, Environment Protection Programme in the Bukowno district 2005).