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Spatial distribution of soil pollutants in urban green areas (a case study in Belgrade)

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ABSTRACT

In urban areas, the presence of toxic microelements in the environment due to the anthropogenic impact (primarily of traffic) poses a serious problem. The negative impact of pollution on populated urban areas is particularly manifest in children. To establish the level of microelement pollution, at 40 localities in the municipality of Stari grad in Belgrade we sampled surface soil near kindergartens and schools during 2013. By applying remote sensing and GIS, small green areas were selected and the spatial distribution of microelements was determined. Because of their different origins and anthropogenic impact, three heavy metals, Cd, Ni and Zn, were examined; the level of soil pollution was assessed by determining their total content, pollution index (Pi), enrichment factor (EF), single risk factor (Ei) and ecological risk index (RI). The highest concentration established was that of Zn, with a mean value of 223.11 mg/kg. The Pi values for Zn (2.96) and Cd (2.98) were similar. Due to the prevailing geological substrate, Ni had the lowest EF (0.75) and Ei (3.09). The effect of the geological substrate on the Ni content was also confirmed by its very high concentration along the banks of the rivers Sava and Danube, while the total contents and factors for Cd and Zn indicated that they were concentrated in the city center. Our results show that 30.72% of the green areas in the city center have a moderate RI, which indicates that the examined pollutants do not present a danger to children.

1. Introduction

Harmful trace elements are one of the main pollutants in soil because of their enormous impact on ecological balance (Sastre et al., 2002), and their relatively strong bonding to soil particles and poor mobility that prevents their removal (Sieghardt et al., 2005). Although the main source of toxic trace elements is the geological substrate (Ross, 1994), the impact of trace element on soils in urban areas is complex due to the different origin and mixing of urban soil, diverse land use and a pronounced anthropogenic impact (Craul, 1985; Hollis, 1991; Paterson et al., 1996). According to Sieghardt et al. (2005), the difficulties in determining the influence of heavy metals include urban population growth, the different routes of metal intake (intake of small particles by respiration, skin-contact), as well as the mechanisms of the toxic effects of exposure to metals. Children are the group most exposed to the impact of harmful trace elements in urban areas due to their behavior (hygiene, playing on uncovered surfaces, position of body near the soil surface, etc.) (Mielke et al., 1998; Sanchez-Camazano et al., 1994; Granero and Domingo, 2002). The systematic and qualitative determination of the effects of toxic elements present in trace amounts in urban areas is a very complex undertaking because it is influenced by the subjective analysis of the population by the investigator, dissimilar national legislations, the naturally occurring composition of elements, the health impacts of the elements under investigation, the overall influence of the elements on a specific area, and finally, by the data analysis and interpretation.

The use of spatial analysis powered by GIS (Geographic Information Systems) technologies allows us to visualize and analyze spatially oriented objects in digital form (using vector and raster data models) in extensive urban areas. In the past, studies have employed GIS approaches to analyze the effects of anthropogenic and natural factors on the concentrations of heavy metals in soil (Ebbinghaus et al., 1997; Su et al., 2011; Cakmak et al., 2014; Zhou et al., 2015).

We used spatial analysis with different reference factors for locating

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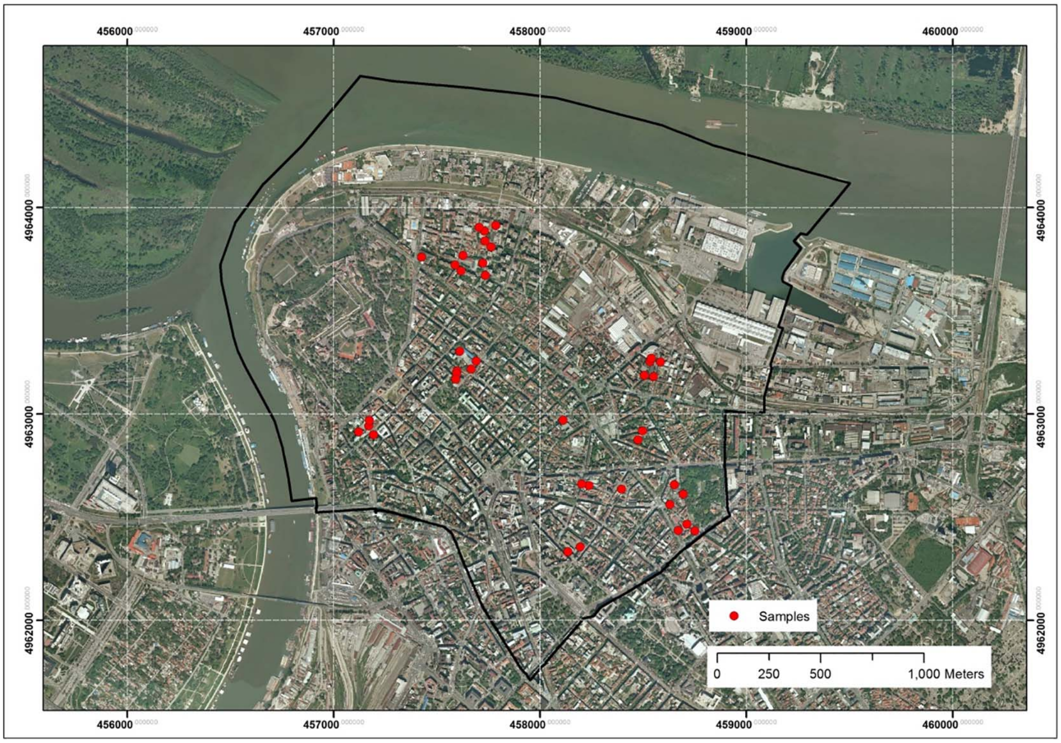

Fig. 1. Spatial distribution of soil samples in district Stari Grad (Belgrade).

the pollution sources in the center of Belgrade (the Stari Grad municipality), with particular emphasis on areas close to schools and kindergartens. The main aims of this research were to determine the concentrations and origins of selected toxic microelements and their spatial distribution, to measure the levels of soil pollution and its impact on urban green environments, and finally to set up an effective but easier methodology for establishing the pollution state of small green urban areas.

2. Materials and methods

Soil research was focused on the central municipality of Stari Grad in Belgrade, which occupies 688 ha, with 79.73 ha being small green areas. The district is located at 44° 49′ 29″ latitude and 20° 27′ 10″ longitude. Forty soil samples from a depth of 0–10 cm were collected from areas concentrated mainly around elementary schools and kindergartens (Fig. 1) in April–May 2013. Each soil sample was composed of 5 sub-samples taken according to the "LUCAS" project methodology, which includes, aside from a central sample, four soil samples oriented according to cardinal directions at 2 m distance (LUCAS: Land Use/Cover Area frame Statistical Survey). The initial quantity of the samples was about 0.5 kg. The soil samples were taken using a stainless-steel hand auger and stored in polyethylene bags. The contents and spatial distribution patterns of selected microelements (As, Cd, Cr, Pb, Ni, Zn and Cu) in particular of Cd, Ni and Zn were examined.

After air drying, the soil samples were ground with an inert steel crusher with a 2-mm mesh. For the analysis of microelements, the samples were sieved through a 150 μm mesh. The total contents of microelements (As, Cd, Cr, Pb, Ni, Zn and Cu) were determined with an ICAP 6300 optical emission spectrometer (Thermo Electron Corporation, Cambridge, UK) after digestion in *aqua regia*.

All chemical analyses were performed in two replications. For verification of results, the referent soil was examined for the presence of microelements (reference ERM-CC141 loam soil, Belgium, with the exact concentration of microelements soluble in *aqua regia* to provide for increased accuracy of the measuring apparatus). The lower limits of detection for the elements were as follows: 0.6436 (As), 0.0166 (Cd), 0.2897 (Cr), 2.3233 (Cu), 0.2239 (Ni), 2.8597 (Pb), 8.5106 (Zn), 81.4905 (Fe) mg/kg.

The total soil carbon was measured with an elemental CNS analyzer (Vario model EL III, Elementar Analysensysteme GmbH, Hanau, Germany). The granulometric composition of the soil was established by a combination of wet sieving and the pipette method, which were used to separate the sample into three grain size fractions: sand (> 63 μm), silt (63–2 μm) and clay (< 2 μm) (Rinklebe et al., 2016).

Statistical analyses were performed with SPSS (version 16) software. The significance of their correlation was analyzed via Pearson's correlation matrix and PCA with Varimax normalized rotation (SPSS, 2007).

The GIS is a powerful set of tools for collecting, storing, analyzing, transforming and displaying spatial data from the real world, using two basic data models, raster and vector. Supervised classification was performed with specialized GIS software for spectral image processing (remote sensing), ENVI version 4.7, by employing the Region of Interest (ROI) tool. Selection of green areas was carried out using remote sensing aerial photographic images (raster data model) with a spatial resolution of 2.5 m. The software that was used for the interpretation of photographic images implements the algorithms for raw data processing, and also enables individual storing of the results of each pixel. The classification of aerial photographic images served to categorize all image pixels into classes, using two main groups of computer operations: supervised (semi-automated) classification, and unsupervised (automated) classification. The classification method was determined according to the research area. Unsupervised classification does not use fixed classes; the algorithm interprets unknown pixels and classifies them. In this research, a supervised classification was applied to obtain the map of land use. Sets of classes were identified before starting the supervised classification process. The set of classes integrates the parameters of the research area as precisely as possible, during which a sample grid for each class is created. The represented samples were taken from the field at the beginning of the research using GPS devices. Each created sample must be relatively homogeneous, representing its