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Urban geochemical mapping for spatial risk assessment of multisource potentially toxic elements — A case study in the city of Ajka, Hungary

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ABSTRACT

Urban soils may concentrate contaminants in large quantities due to intensive human activities. In the period of centrally dictated industrialization in the 20th century, industrial activity such as mining, coal fired power plants and alumina industry produced huge amount of waste and pollution emission in Hungary. Consequences could be toxic element enrichment in urban public and private areas such as soil of playgrounds and parks.

This study focuses on the spatial distribution of potentially toxic element (PTE: As, Pb, Hg, Cd, Ni, Zn and Cu) concentrations of urban soil at playgrounds, parks and other communal areas in Ajka town (western Hungary) in order to find a link between contamination sources and the receiving urban soils.

Ajka town has a long-established industrial history with multiple contamination sources of heavy alumina industry and lignite-fired power plants supplied by the nearby bauxite and coal mines. At 8 playgrounds, 11 parks and 25 other open communal areas soil samples have been collected at a depth of 0–10 cm along a 1 × 1 km grid. The whole grid covers an area of 64 km^2. The laboratory analyses include ICP-OES and CV-AAS method measurements for PTEs of the soil samples.

Our results show that Hg is the only PTE having concentrations above the Hungarian environmental pollution limit, at two sampling sites, whereas Ni seems to be the most widely spread PTE in the studied urban topsoil. The spatial and statistical analysis, based on low density sampling with detailed exploratory statistical data analysis, identified the lignite-fired power plant and the lignite mines as the most important point sources; in contrast showed that the alumina industry had no effect on the urban soil samples. According to enrichment factor, correlation and regression analysis, two main PTE groups were distinguished. The first group contains As, Ni, Cu and Zn, whereas Pb, Hg and Cd belong to the second group. Lead, Hg and Cd have a distinct nature in the studied soils due to their non-soluble and non-reactive forms originating from mixed industrial and traffic sources. Risk assessment with the 8 sampled playgrounds shows that sampling sites situated close to the lignite mining area have As, Pb, Ni and Zn concentrations above the Hungarian Regional Geochemical Background (HRGB) value. This geochemical study has revealed the spatial correlation of contamination sources and the contaminated areas with special attention to risk assessment of playgrounds and parks at sensitive human receptors in an industrial urban area.

1. Introduction

According to the United Nations Report (United Nations, 2012), more than half of the world's population lives in urban areas and this rate will increase to 67% by 2050. Thus, urban environmental pollution has received significant attention in the past few decades. Numerous studies have been published on urban soil potentially toxic elements' (PTEs) pollution in the USA (Kaminski and Landsberger, 2000; Yesilonis et al., 2008), China (Luo et al., 2011a,b; Shi et al., 2008; Wei and Yang, 2009; Yang et al., 2010), South America (Figueiredo et al., 2011) and Europe (Ajmone-Marsan et al., 2008; Andersson et al., 2010; Baltrėnas and Vaišis, 2006; Birke and Rauch, 2000; Bityukova et al., 2000; Fordyce et al., 2005; Ljung et al., 2006a; Puskás and Farsang, 2009; Szolnoki et al., 2013). Sensitive contamination receptor locations such as playgrounds and schools received special attention in papers of Ljung et al. (2006b), Ottesen et al. (2008), Massas et al. (2010), Figueiredo et al. (2011), Kumpiene et al. (2011), Taylor et al. (2013), Reis et al. (2014), Zhao et al. (2014).

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Soil is the interface between the rock, plant, animal and anthropogenic ecosystem compartments and it plays a crucial role in regulating a number of life-sustaining natural biological and chemical cycles (SOER, 2010). Soil affects significantly the plant nutrient uptake and groundwater filtration and hence, it has an indirect impact on human food production and quality (Garrett, 2005).

Humans are indirectly exposed to soil contamination through accidental hand to mouth actions, dermal contact and through the ingestion from inhalable soil particles (Guney et al., 2010; Laidlaw and Filippelli, 2008; Laidlaw and Taylor, 2011; Mielke et al., 1999, 2005). In our study, children are considered to be the most sensitive group. Principal sources of urban soil pollution are traffic by vehicle emissions and leaded gasoline, as well as industry, waste disposal and heating, releasing both organic and inorganic pollutants (Ajmone-Marsan and Biasioli, 2010). PTEs from these very diverse sources can accumulate in urban soils (Albanese et al., 2008; Fuge, 2005) and cause health problems via inhalation, ingestion and dermal contact (Broadway et al., 2010; Farmer et al., 2011; Ljung et al., 2006c; Poggio et al., 2008). Industry has a great impact on the urban environment since industrial sources are found close to or within settlements. The most important inorganic hazardous substances in the urban environment are As, Pb, Hg, Cd, Be, Co, Ni, Zn, Cr, U, Ra, Th, Rn and Cu (ATSDR, 2013).

A remarkable example for multi-source industrial areas (“hot spots”) with a potentially high level of emitted pollutants is the former heavy industrial city of Ajka in Hungary (Fig. 1). Industrial activity in Ajka started at the end of the 19th century. In addition to aluminium and alumina industry, lignite mining, lignite-fired power plant and glass industry sites have generated numerous waste heaps and waste dumps, which act as multi-contamination sources in the area. In October 2010 the dam of the Ajka red mud tailings' pond failed causing the catastrophic regional contamination of international significance.

The objective of this study is a targeted investigation for the concentrations and the spatial distribution of As, Pb, Hg, Cd, Ni, Zn and Cu PTEs' contamination in urban soils and to observe and characterize their geochemical behaviour. The specific goal is to support human health risk assessment in the multisource Ajka industrial area based on urban soil samples as contamination receptor. This study provides a detailed spatial analysis and data modelling example for the characterization of PTE distribution in relation to the potential sources and sensitive urban receptors such as playgrounds in Ajka city, which is one of the examples of the centrally-directed industrialization in Eastern Europe during the second part of the 20th century.

2. Study area

Ajka has a total area of 95 km^2, with a population over 29,000 inhabitants (Fig. 1). The prevailing soil types of the region are brown forest soil with clay illuviation, meadow soil and rendzina (AGROTOPO, 2015). The underlying geology is characterized by the Thethyan Triassic limestone and dolomite together with Cretaceous limestone. The Cenozoic cover is composed of Eocene marl and limestone, Miocene-Pliocene sediments and basalt. The most abundant sediments are Quaternary loess and gravel. Besides the Cretaceous lignite, the Jurassic manganese ore was also mined until recently in the neighbouring villages (Császár, 2005). The studied area is located in Geochemical Landscape Region 2 of Hungary characterized by a major element association (Ca^{2+}, Mg^{2+}, Sr^{2+}, CO_3^{2-}, SO_4^{2-}, PO_4^{3-}) typical to carbonate terrains (Ódor et al., 1996). The region has a wet continental climate with an annual average

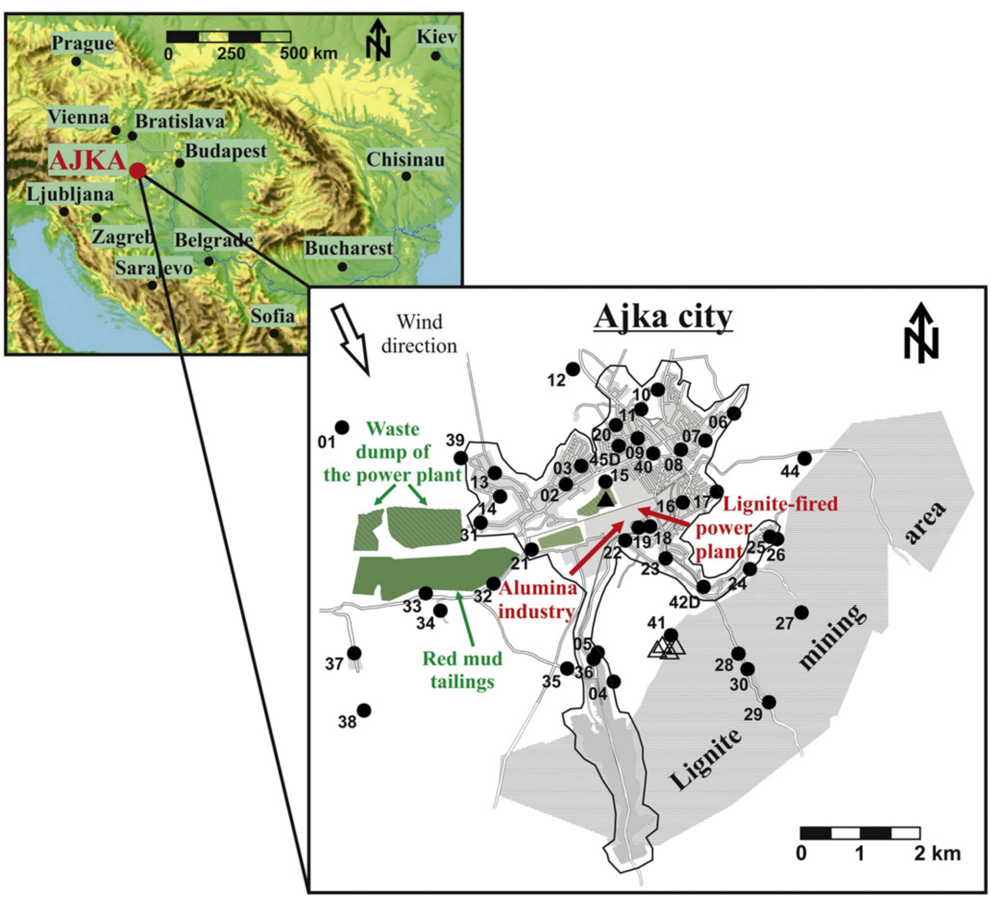

Fig. 1. Map of the Ajka town study area with the urban soil sampling sites illustrated with solid circles. Solid triangle represents the samples from the waste dump of the lignite-fired power plant, open triangle shows the location of the samples from the lignite mining area.