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HEALTH RISK OF URBAN SOILS CONTAMINATED BY HEAVY METALS

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Abstract. The paper presents the results of geochemical investigations carried out in the city of Prague, Czech Republic, between the years 1994–1997, by the Czech Geological Institute, National Institute of Public Health and Hygiene Stations of Prague. Exposure assessment for children as the most sensitive population, based on soil ingestion pathway, indicates that lead is the major pollutant of concern, especially in the central regions of the city. Direct exposure assessment was done by analyzing blood and urine samples collected from children aged 3–6 years. Blood lead levels were the only biomarker significantly higher as compared to the control group (32.1 ± 17.4 μg/l, 25.1 ± 15.4 μg/l). This pilot study supports the establishment of a new sub-system within the already existing System of Monitoring the Environmental Impact on Population Health of the Czech Republic.

Key words:
Heavy metals, Risk assessment, Lead, Arsenic

INTRODUCTION

The interrelation between pollution and economic development in the Czech Republic, like in other countries, is accompanied by increased human activities resulting in enhanced emissions from different sources (e.g. increased transportation volume). In urban agglomerations, such as the city of Prague, sources of contamination, dense population and pathways of transfer form a potential exposure. Environmental and biological monitoring can determine the level of exposure and thus enable further decisions.

The aims of this pilot study in the city of Prague were: 1) to determine the extent and the intensity of soil contamination by selected metals and organic pollutants; 2) to detect the sites with increased contamination levels and identify the sources; 3) to carry out the health risk assessment; and 4) to elaborate the methods of sampling, analysis and assessment of contaminated soils as a preliminary stage of a large scale monitoring program in the Czech Republic.

This article covers only part of the pilot study concerning heavy metals in the soil.

MATERIALS AND METHODS

Environmental monitoring

Soil samples were collected from all districts of Prague during the years 1994–1997 (Fig. 1). The samples were

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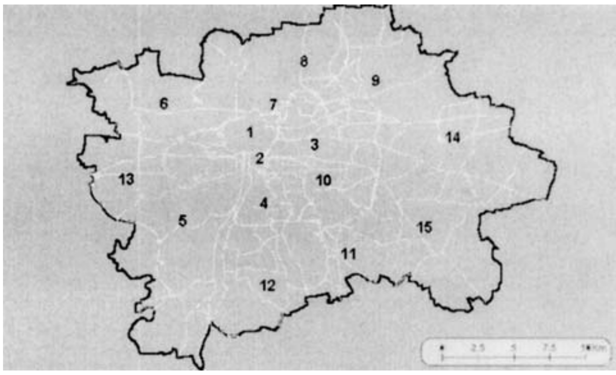

Fig. 1. District locations in the city of Prague.

taken from the area of 0.0–0.2 m, with sampling frequency of 9 samples/km^2. Each sample was analyzed for 21 elements using the following methods [1]:

1. XRF: As, Cr, Cu, Mo, Nb, Ni, Pb, Rb, Sn, Sr, U, Zn, Zr.
2. FAAS: Ag, Be, Cd, Co, Cr, Cu, Fe, Mn, Pb, Tl, V, Zn.
3. HGAAS: As, Sb.
4. Cold vapor: Hg.

Children aged 1-5 years were identified as the most sensitive sub-population due to their behavioral and physiological parameters. Thus risk evaluation based solely on children taken as the exposed population may satisfy risk characterization and decision-making for the population at large. Based on the soil analysis and the geographic location, two groups of children were selected. One group was sampled from polluted areas, the ”contaminated” group, while the other one, from relatively clean areas, the control group.

Exposure pathway

For contaminated soils, ingestion is usually by far the most important exposure route for small children [2]. For the purpose of this assessment, only the uptake of heavy metals by soil ingestion was considered.

Exposure estimation

The risk associated with chronic exposure to heavy metals in the soil was calculated by comparing the estimated exposure (Eq. 1) and the acceptable daily intake (ADI) [3]. This ratio is known as the individual exposure ratio (IER) and hazard quotient (HQ).

Table 1. Values used for intake assessment

Parameter	Definition (unit)	Value
CS	Average concentration in the soil (mg • kg-1)	Measured
IR	Ingestion rate (mg/d)	200
EF	Exposure frequency (days/year)	210
ED	Exposure duration (yrs)	5
BW	Body weight (kg)	15
AT	Average time period (days)	5 • 365

Exposure assessment due to ingestion of soil, was calculated as follows:

$$Intake(mg/kg_{bw} - day) = \frac{CS \bullet IR \bullet 10^{-6} kg/mg \bullet EF \bullet ED}{BW \bullet AT} \quad (1)$$

Currently no specific values for Eq. 1 are available for any population in the Czech Republic, therefore default values [4] were applied (Table 1).

Biological monitoring

Within the frame of biological monitoring, blood and urine samples from both groups of children were analyzed. Blood and urinary mercury (Hg) levels were determined directly (without mineralization) using the AMA 254 Hg-analyzer (Czech made). Blood copper (Cu) and zinc (Zn) were primarily mineralized in the microwave oven and then determined using flame atomic absorption spectrophotometry (AAS), while lead (Pb) and cadmium (Cd) were determined after mineralization by flameless AAS. Zn and Cu in urine were determined after dillution with demineralized water directly through flame AAS, whereas Pb and Cd, after dillution in flameless AAS. Due to technical reasons, the samples were collected during the winter.

Statistical analysis

Statistical evaluation of the contaminated and control groups was performed using the BMDP30 software. Statistical significance was considered at p = 0.05. A standard two-sample t-test was performed unless the variance of the compared samples was found to be significantly different. In that case a Welch modified two-sample t-test was performed.

Table 2. Locations of samples with the highest concentrations of selected heavy metals

District and street	Lead (mg/kg)	Arsenic (mg/kg)	Copper (mg/kg)	Mercury (mg/kg)	Zinc (mg/kg)
Praha 3 Seifertova	1184–1650	318–522	368–458	1.47–2.13	3000–5000
Praha 9 Fučikova	961–1441	157–207	193–343	12.3	616–1837
Praha 1 Na Florenci	1088	163	264	–	1916
Praha 1 Za obch. d. Kotva	959	137	395	7.25	1461
Praha 3 U nákladového nádraži	773	66–77	186	1.39–1.44	1093–1686
Praha 1 Haštalské nám.	738	114	361	5.3	1343
Praha 3 Kubelíkova	619	99	309	–	1737
Praha 9 Pod Šancemi	599	151–648	–	1.58–4.8	2600–10000
Praha 8 Pernerova	513–570	148–162	239	–	1696–1828
Praha 8 Hlávkův most, pravý břeh	446–570	106	248–262	1.25	1080–1110
Praha 8 Libeňský most	315–525	81	208	1.31	583–614
Praha 1 Navrátiloava	504–520	139–150	223	3.04–3.52	2156–2223

Table 3. Estimated exposure-ADI ratio (HQ)

District and street	Lead (% ADI)	Arsenic (% ADI)	Mercury (% ADI)
Praha 3 Seifertova	352	190	1.5
Praha 9 Fučikova	307	76	13
Praha 1 Na Florenci	232	59	–
Praha 1 Za obch. d. Kotva	204	50	8
Praha 3 U nákladového nádraži	165	28	1.5
Praha 1 Haštalské nám.	157	42	5.7
Praha 3 Kubelikova	132	36	–
Praha 9 Pod Šancemi	128	237	5.2
Praha 8 Pernerova	121	60	–
Praha 8 Hlávkův most, pravý břeh	121	39	1.3
Praha 8 Libeňský most	112	30	1.4
Praha 1 Navrátiloava	111	55	3.8
ADI (μg/kg/d) [5]	3.6	2.1	0.71

RESULTS

Risk assessment via environmental monitoring and intake models

Findings of the soil analysis (Table 2) indicate that the most polluted areas are the center of Prague (Prague 1, 3) and the industrial district (Prague 9). The risk associated with these findings, estimated by the exposure model (Eq. 1), shows that lead and arsenic are the only elements to reach above HQ of 1 (Table 3). Maximum estimated HQ for Pb is 3.5 whereas for As is 2.3. The estimated risk suggests that Pb levels in the topsoils are the main issue of concern.

Risk assessment using biological markers

The sample sizes, mean, median, standard deviation and ranges for the measured variables in blood for the children from relatively clean and contaminated areas are presented in Tables 4 and 5. Pb in the contaminated group was the only element to show significantly higher mean value compared to the control group ($p < 0.05$).

Table 4. Concentration of metals in the blood of children from relatively clean areas (μg/l)

	Cd	Cu	Hg	Pb	Zn
n	38	39	37	39	39
Mean	0.29	1063	0.61	25.1	4825
Median	0.25	1080	0.58	24.1	5040
Min.	0.01	450	0.15	6.1	3090
Max.	1.1	1480	1.42	69.6	7330
Std.	0.21	188	0.29	15.4	785

Table 5. Concentration of metals in the blood of children from contaminated areas (μg/l)

	Cd	Cu	Hg	Pb	Zn
n	81	81	86	75	81
Mean	0.31	1073	0.73	32.1	4896
Median	0.3	1020	0.6	29.4	4780
Min.	0.01	440	0.12	4.3	3400
Max.	1.8	1760	4.89	95.8	7250
t	0.288	0.279	1.5	2.1	0.46
p-value	0.77	9.78	0.13	0.03	0.64
Std.	0.26	202	0.62	17.4	771

Compared with representative heavy metals mean blood levels for children in the Czech Republic [5], Pb and Zn were found to be significantly lower ($p < 0.05$). Urine samples did not depict any significant difference compared with the control group.

DISCUSSION

Risk assessment based on soil ingestion by children indicates the excess intake of Pb and As in some locations in the city of Prague. Maximum HQ values of 3.5 for Pb and 2.3 for As were estimated. Limits of 40 μg/kg for As and of 300 μg/kg for Pb in the soil, are considered to provide a high level of protection against excessive intake by children [2]. These levels were remarkably exceeded in some locations.

Direct exposure assessment based on levels of heavy metals in the blood depicts significantly higher level only for Pb in children from the contaminated areas (32.1 ± 17.4 μg/l). Yet, all individual values were below the common intervention level of 10 μg/dL and generaly low as compared to other studies in large agglomerations [6]. Low blood levels of Pb and Zn, compared with nation-wide representative values (37.4 μg/l, 5303 μg/l), are probably due to the sampling period (winter). Thus it may reflect the significance of the soil ingestion pathway.

The results of this pilot study do not support a decisive conclusion concerning the health risk associated with heavy metals in the soils. The parameters adjustment of the intake model, inclusion of bioavailability of ingested metals, sampling and analysis methods are among the issues to be considered in future studies. Following the precautionary principle, a nation-wide monitoring subsystem within the already existing System of Monitoring the Environmental Impact on Population Health of the Czech Republic in urban centers is under design.

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