The effect of intensive traffic on soil and vegetation risk element contents as affected by the distance from a highway

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ABSTRACT

The potential effect of intensive traffic on detrimental element contents in soil and vegetation was investigated in the vicinity of a selected section (1 km) of a highly frequented highway as affected by the distance from the roadway (1 m, 35 m, and 70 m). *Aqua regia* and 0.11 mol/L acetic acid soluble contents of As, Cd, Cr, Cu, Mo, Ni, Pb, and Zn in soils and total contents of these elements in the aboveground biomass of *Achillea millefolium* L. (Asteraceae) and *Vicia cracca* L. (Fabaceae) were determined. The main physicochemical parameters of the soils were determined, as well. The element contents did not exceed the maximum permissible limits for both soils and plants (evaluated as fodder crops). Moreover, high variability of element contents in soils and plants, and soil characteristics did not allow us to estimate the rate of potential effect of road traffic. Some of the elements however tightly related to atmospheric deposition caused by traffic such as Pb and Zn tended to decrease in soils with increasing distance from the roadway.

Keywords: toxic elements; atmospheric deposition; contamination; *Achillea millefolium* L.; *Vicia cracca* L.

Atmospheric deposition belongs to the main sources of soil contamination with risk elements characterized by long persistence in upper layer of the soils. Therefore, element contents in top layer of soils in urban areas can be a good indicator of atmospheric deposition. Elevated contents of risk elements such as Cd, Cu, Pb, and Zn were determined in soils affected by intensive traffic (Garcia and Millán 1998, Li et al. 2001). Simultaneously, statistical analyses proved the effect of traffic on Cd, Pb, and Zn contents in grass species in the vicinity of the roadway (Garcia and Millán 1998). Also spatial distribution of Cu, Pb, Cr and Zn in soils documented higher contents of these elements in the vicinity of frequented highways (Wei et al. 2009). Viard et al. (2004) reported elevated element contents up to the distance of 320 m from the roadway with slow decrease with the increasing distance. Among the risk elements they recommended lead as the best indicator of risk element contamination due to intensive traffic.

Duong Trang and Lee (2011) demonstrated the effect of traffic density, car speed, and type of roadway surface. However, Olajire and Ayodele (1997) did not determine significant differences in soil and plant contents among the areas with heavy and rare traffic indicating that the element contents along the highways are affected by several factors. The risk element accumulation in the soils proved elevated contents of these elements along the highways decreasing with the distance from the roadway. However, the knowledge of the element mobility in the soils is necessary for the estimation of potential risk of soil elements for their uptake by plants (Li 2006). Sequential extraction procedures estimated the element bioavailability in urban dust and in highway soils in decreasing order Cd > Zn > Pb > Cu (Li et al. 2001).

Various species such as bryophytes, lichens, mushrooms, higher plants (*Taraxacum* sp.) etc. are considered species with the ability to absorb the elements from wet and/or dry deposition (Kabata-

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Pendias and Pendias 2001, Hejcman et al. 2010). Nabulo et al. (2006) described decreasing Pb contents in *Amaranthus dubius* leaves with increasing distance from the roadway in accordance with decreasing Pb content in soil. They suggested that the atmospheric deposition was the main source of soil and plant contamination in the investigated area. Therefore, these authors recommended to cultivate leafy vegetables in distance exceeding 30 m from roadways. Moreover, they observed a significant reduction of Pb levels by gently washing of the plant leaves. Žalud et al. (2012) showed in a model pot experiment that the element uptake by plant biomass (lettuce (*Lactuca sativa* var. *capitata*)) and chard (*Beta vulgaris* var. *cicla* were tested) was significantly higher *via* foliar application of urban particulate matter (PM), simulating the atmospheric deposition, than *via* the roots from soil. In the case of Fe, Pb, and Zn, the content in plants increased rapidly as compared to the element uptake *via* roots. Concerning the plants treated *via* foliar application, even gently washed leaves contained elevated amounts of Fe, Pb, and Zn as compared to control. However, the majority of Pb was removed by washing and the Pb levels dropped from 3000% to 500% compared to the control treatment. The effect of PM application on Cd contents in plant leaves was negligible in most cases. No significant differences were reported for particle size fractions of PM whereas the effects of plant species as well as physicochemical parameters of soils on element accumulation in vegetable biomass were evident.

The main objectives of our study were to describe in details a selected section of highly frequented highway with regards to soil physicochemical parameters, risk element content in soil including their mobility, and element uptake by selected plant species. Comprehensive approach was chosen to assess relationships among the variables measured to define potential importance of the impact of intensive traffic on soil and vegetation contamination within the studied highway section.

MATERIAL AND METHODS

Sample collection. The sampling area was selected at the highway R6 representing route Prague–Karlovy Vary (Carlsbad)–Cheb (Czech Republic) with direction to Germany. The selected section was 1 km long part between villages Malé Přítočno and Pletený Újezd (direction from Prague, between 50°6'14.231''N, 14°7'10.114''E and 50°6'8.781''N, 14°8'0.351''E). The intensity of traffic represented between 15 001 and 25 000 cars per 24 h http://scitani2010.rsd.cz/pages/map/default.aspx). The sampling section was regularly divided to 10 sampling sections linearly alongside the roadway. In each section three sampling points were established as follows: distance A 1 m, distance B 35 m, and distance C 70 m from the roadside. In total the sampling map represented 30 points, all of them were at the windward side from the roadway. Both soil and plant samples were collected in July 2010.

In each point, representative sample of whole aboveground biomass of *Achillea millefolium* L. (Asteraceae) and *Vicia cracca* L. (Fabaceae) was sampled in the flowering stage. The plant samples were dried at 60°C to a constant mass and then ground to a fine powder in a laboratory mill. Laboratory soil samples were collected in each sampling point from a depth of 0–25 cm where each sample represents an average of three subsamples taken from each sampling square. Soil samples for determination of total and mobile concentrations of arsenic and other elements were air dried at 20°C, ground in a mortar, and passed through a 2-mm plastic sieve.

Analytical methods. The pseudototal concentrations of elements in the soils were determined in the digests obtained by the following decomposition procedure: Aliquots (~0.5 g) of air-dried soil samples were decomposed in a digestion vessel with 10 mL of *Aqua regia* (i.e. nitric and hydrochloric acid mixture in ratio 1 + 3). The mixture was heated in an Ethos 1 (MLS GmbH, Leutkirch, Germany) microwave assisted wet digestion system for 33 min at 210°C. After cooling, the digest was quantitatively transferred into a 25 mL glass tube, topped up by deionized water, and kept at laboratory temperature until measurement. A certified reference material RM 7003 Silty Clay Loam (Analytika, Prague, Czech Republic) was applied for the quality assurance of analytical data.

Plant samples were decomposed using the dry ashing procedure as follows: An aliquot (~1 g) of the dried and powdered aboveground biomass was weighed to 1 mg into a borosilicate glass test-tube and decomposed in a mixture of oxidizing gases ($O_2 + O_3 + NO_x$) at 400°C for 10 h in Dry Mode Mineralizer Apion (Tessek, Prague, Czech Republic). The ash was dissolved in 20 mL of 1.5% HNO_3 (electronic grade purity, Analytika, Prague, Czech Republic) and kept in glass tubes until the analysis (Miholová et al. 1993). Aliquots of the certified reference material RM NCS DC 73350

Poplar leaves (purchased from Analytika, Prague, Czech Republic) were mineralized under the same conditions for quality assurance of the total element contents in experimental plants.

The soil pH was determined using deionised water or 0.2 mol/L KCl (w/v = 1 + 2.5) (Novozamsky et al. 1993). Cation-exchange capacity (CEC) was calculated as the sum of Ca, Mg, K, Na, Fe, Mn, and Al extractable in 0.1 mol/L $BaCl_2$ (w/v = 1 + 20 for 2 h) (ISO 1994). Total organic carbon (TOC) was determined spectrophotometrically after the oxidation of organic matter by $K_2Cr_2O_7$ (Sims and Haby 1971). For the determination of mobile fractions of elements in soils, extraction with a 0.11 mol/L solution of CH_3COOH at a ratio of 1:20 (w/v) for 16 h (Quevauviller et al. 1993) was applied. Each extraction was carried out in three replicates. For the centrifugation of the extracts, a Hettich Universal 30 RF (Tuttlingen, Germany) device was used. The reaction mixture was centrifuged at 3000 rpm (i.e. 460 g) for 10 min at the end of each extraction procedure, and the supernatants were kept at 6°C prior to measurement. Element concentrations in the digests and extracts were determined by ICP-OES (Varian, VistaPro, Mulgrave, Australia).

Statistics. The analytical data were processed using NCSS 7.1 and Statistica 10 Cz statistical softwares (StatSoft Inc., Tulsa, USA). The normality of the individual sets of data the Shapiro-Wilk test was (Hintze 2007) applied and median was used as mean value if the data set did not agree with the Gauss distribution. If the normality of the data was confirmed, average was found for the evaluation of the data (Meloun and Militký 2004). A one-way analysis of variance (ANOVA) at a significance level of $\alpha = 0.05$ followed by Tukey-Kramer test were applied for the data characterized by the normal data distribution. If the normality of the data was declined a non-parametric Kruskal-Wallis test was used at $\alpha = 0.05$. Correlation analysis was used for assessment of the relationships among the variables where Pearson correlation coefficients were applied for the data characterized by the normal data distribution and non-parametric Spearman correlation was used in the remaining cases (Meloun and Militký 2004).

Table 1. The main soil characteristics as affected by the distance from the roadway

Characteristics	Distance A	Distance B	Distance C
CEC (mmol/kg)	138 ± 14	113 ± 42	144 ± 20
TOC (%)	2.81 ± 0.65	3.05 ± 0.66	2.75 ± 0.93
pH	6.80 ± 0.33	7.40 ± 0.22	6.87 ± 0.37

Data expressed as mean ± standard deviation; *n* = 10, air-dried matter; CEC – cation exchange capacity; TOC – total organic carbon

RESULTS AND DISCUSSION

The main characteristics of the investigated soils are summarized in Table 1. The soil sorption capacity varied in wide range where CEC levels varied between 66.6 and 184 mmol/kg and most of the measured samples can be considered as medium CEC levels (Sáňka and Materna 2004). CEC levels in the distance B were significantly lower compared to the distance A whereas the C levels did not differ significantly due to high variability of the data. The content of TOC plays an important role in the ability of soil to immobilize risk element ions (Komarnicki 2005) and to affect their potential bioavailability. Similarly to the CEC levels, the TOC values varied in the wide range from 1.38 to 4.37% and can be characterized as medium CEC levels according to Sáňka and Materna (2004). The pH levels of the soils varied in the range between 5.96 and 7.63 and Kruskal-Wallis test confirmed significantly increased pH levels with the increasing distance from the roadway ($P < 0.05$). Because of high variability of the soil properties within the investigated section, probably affected by substantial soil transfer during road construction, it is very difficult to determine the key factor responsible for the element contents and bioavailability in soils is very difficult.

Table 2. The pseudototal (*Aqua regia* soluble) contents of elements in experimental soils (mg/kg of air-dried matter)

	Distance A	Distance B	Distance C
As	10.7 ± 3.9	9.6 ± 1.4	10. 6 ± 3.4
Cd	0.452 ± 0.117	0.542 ± 0.142	0.507 ± 0.338
Cr	36.4 ± 5.6	37.6 ± 3.9	43.3 ± 11.3
Cu	19.1 ± 9.6	18.4 ± 3.7	19.7 ± 7.1
Mo	1.16 ± 0.79	0.864 ± 0.122	0.972 ± 0.300
Ni	21.5 ± 3.1	21.7 ± 2.1	20.5 ± 3.9
Pb	23.5 ± 2.4	22.7 ± 2.9	14.4 ± 5.5
Zn	106 ± 71	92.7 ± 25.5	95.3 ± 51.3

Data expressed as mean ± standard deviation; *n* = 10

Table 3. The mobile (0.11 mol/L CH_3COOH soluble) contents of elements in experimental soils (mg/kg of air-dried matter)

	Distance A	Distance B	Distance C
As	0.408 ± 0.162	0.504 ± 0.203	0.492 ± 0.142
Cd	0.117 ± 0.019	0.136 ± 0.027	0.078 ± 0.019
Cr	0.053 ± 0.025	0.045 ± 0.017	0.057 ± 0.021
Cu	0.276 ± 0.069	0.271 ± 0.062	0.181 ± 0.030
Mo	0.087 ± 0.026	0.105 ± 0.026	0.105 ± 0.029
Ni	1.128 ± 0.380	1.261 ± 0.205	0.371 ± 0.249
Pb	0.140 ± 0.084	0.129 ± 0.046	0.139 ± 0.060
Zn	12.6 ± 8.2	13.3 ± 9.0	12.8 ± 4.7

Data expressed as mean ± standard deviation; n = 10

Table 2 summarizes the pseudototal contents of elements in soils. The maximum permissible limits of element contents in soils given by the public notice (Anonymous 1994) the 'pseudo-total' element concentrations in loamy soils cannot exceed a maximum of 30, 1.0, 200, 80, 100, 5.0, 140 and 200 mg/kg for As, Cd, Cr, Ni, Cu, Mo, Pb and Zn, respectively. The measured contents did not exceed these levels but showed different trends within the distance from the roadway. Low changes in element content could be caused by relatively recent construction of new higway, less than twenty years ago and limited usage of leaded petrol within this period (banned since 2000 in the Czech Republic). Whereas As and Cu levels remained unchanged, Cd and Cr tended to increase, and opposite pattern was observed for Mo, Ni, Pb, and Zn. Viard et al. (2004) and Nabulo et al. (2006) described decreasing levels of Zn and Pb in soils with the distance from the roadway up to 320 m. In our case, however, no such unambiguous trend was observed although the levels tended to slight decrease. The mobile contents of elements differed according to individual elements (Table 3) confirming high mobility of Cd, Mo, and Zn in contrast to low mobile portions of Cr (not exceeding 0.5% of the total content) Cu and Pb (not exceeding 3% of the total content). The mobile Pb contents increased with increasing distance from the roadway whereas the remaining elements tended to decreasing mobility according to the distance. The correlation analysis proved increasing mobility of Mo with increasing CEC levels, especially in the distance A. The higher TOC levels resulted in decrease of Cu and Ni mobility. Concerning soil pH, decrease of mobile Cd, Cu, Mo, and Ni portions was reported with increasing level of this variable whereas Pb and Zn remained unaffected and in some cases even tended to the opposite relationship. Thus, higher mobility of elements in the more acidic soils (Voutsa et al. 1996) was confirmed in our experiment.

The contents of investigated elements in aboveground dry biomass of *Vicia cracca* and *Achillea millefolium* are summarized in Tables 4 and 5. According to the Directive No. 2002/32/ES (Anonymous 2002) the maximum values of elements in raw feedstuffs (we calculated 12% of humidity) are 2 mg/kg of As and 1 mg/kg of Cd. A maximum permissible limit of 30 mg/kg in fodder was defined in the case of lead. According to this criterion the element contents did not exceed the limits and should not represent any potential risk for grazing animals. The element contents in plants as affected by the distance from the roadway were affected predominantly by the plant species and

Table 4. The total contents of elements in the aboveground biomass of *Vicia cracca* (mg/kg of dry matter)

	Distance A	Distance B	Distance C
As	0.436 ± 0.346	0.535 ± 0.431	0.316 ± 0.189
Cd	0.080 ± 0.035	0.139 ± 0.103	0.084 ± 0.039
Cr	0.100 ± 0.058	0.127 ± 0.138	0.101 ± 0.067
Cu	5.50 ± 1.07	5.29 ± 0.95	5.10 ± 1.01
Mo	2.57 ± 2.67	3.53 ± 1.69	2.94 ± 0.87
Ni	0.706 ± 0.512	0.906 ± 0.360	0.834 ± 0.375
Pb	0.256 ± 0.090	0.310 ± 0.097	0.273 ± 0.084
Zn	20.0 ± 4.0	22.9 ± 4.9	26.0 ± 6.1

Data expressed as mean ± standard deviation; n = 10

Table 5. The total contents of elements in the aboveground biomass of *Achillea millefolium* (mg/kg of dry matter)

	Distance A	Distance B	Distance C
As	0.272 ± 0.073	0.366 ± 0.183	0.428 ± 0.265
Cd	0.254 ± 0.171	0.153 ± 0.094	0.115 ± 0.102
Cr	0.302 ± 0.264	0.290 ± 0.258	0.171 ± 0.080
Cu	8.13 ± 3.70	7.25 ± 1.50	5.13 ± 1.06
Mo	0.425 ± 0.277	0.453 ± 0.198	0.291 ± 0.080
Ni	0.711 ± 0.335	0.693 ± 0.296	0.610 ± 0.311
Pb	0.286 ± 0.151	0.234 ± 0.066	0.216 ± 0.065
Zn	14.7 ± 7.2	17.4 ± 8.8	11.7 ± 1.1

Data expressed as mean ± standard deviation; n = 10 did not show any unambiguous relationships. The plant biomass was not washed before analysis to include potential impact of atmospheric deposition of investigated elements on the plant surface. The importance of foliar uptake of elements was highlighted for example by Komarnicki (2005) who has reported that the portion of plant Cd taken up via soil vary between 64% and 90%.

For comparison of element uptake intensity among the plant species, a biological absorption coefficient (BAC), defined as the ratio of total element content in aboveground biomass and in soil, is used. As an example, Ge et al. (2002) determined a BAC index of up to 10 in the case of Cd for green plants growing at an Cd contaminated site, as well as indexes of 0.7 for Cu, 0.08 for Ni, 0.7 for Pb, and 1.0 for Zn. We observed the BAC levels for *Vicia cracca* varied between 0.01 and 0.15 for As, 0.08 and 0.64 for Cd, 0.13 and 0.61 for Cu, 0.87 and 6.3 for Mo, 0.01 and 0.07 for Ni, 0.01 and 0.04 for Pb, and 0.05 and 0.57 for Zn, respectively. In the case of *Achillea millefolium* the BAC levels varied between 0.01 and 0.15 for As, 0.07 and 3.8 for Cd, 0.13 and 1.4 for Cu, 0.14 and 1.7 for Mo, 0.01 and 0.09 for Ni, 0.01 and 0.04 for Pb, and 0.05 and 0.38 for Zn, respectively. Evidently, the element uptake rate is affected by element mobility in soil, element essenciality for plants (especially for Cu and Mo), and plant species. For example, high Cd uptake by *Achillea millefolium* among other plant species was observed by Králová et al. (2010).

We can summarize that the unambiguous effect of intensive traffic within the investigated section of the R6 highway on soil and plant contamination with risk elements was not confirmed at least in the case of As, Cd, Cr, Cu, Mo, Ni, Pb, V, and Zn. The effect of soil characteristics and plant species on mobility and bioavilability of elements was predominant in this experiment. Although the effect of traffic-derived risk element contamination cannot be underestimated, exact determination and quantification of these effects is more difficult because of high number of variables. Further research will be necessary in this field to obtain higher amount of the experimental data and for more precise estimation of the adequate conclusions.

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