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An assessment of the risk of element contamination of urban and industrial areas using *Taraxacum sect. Ruderalia* as a bioindicator

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Abstract Central Bohemia (Czech Republic) has highly developed industry and a dense rail network. Here, we aimed to determine the content of risk elements in dandelion plants (*Taraxacum sect. Ruderalia*) growing near train stations, industrial enterprises, and in the city parks of 16 cities in the Central Bohemian region. The highest element contents in the soils were found in industrial areas affected by the historical mining and smelting activities; contemporary industry showed no substantial effect on the soil element contents. The median values of element contents (As, Be, Cd, Co, Cr, Cu, Ni, Pb, and Zn) at the railway station sites were the highest among the monitored sites, where the differences between park and station sites were significant for Be, Co, and Zn. Although the intensity of the traffic at the individual stations differed, we found that long-term regular traffic enhanced the element contents in the soils and, subsequently, in the plants. For Cd, Co, Cr, Cu, Pb, V, and Zn, the highest median element contents were found in plant roots, regardless of the sampling site. For Cd and Zn, the contents in leaves were higher than in the inflorescences, and the opposite pattern was recorded for Co and Cu. As and Be were distributed equally among the plant parts. Among the sampling sites, the As, Be, Cd, Zn, and Pb contents in the plant roots tended to have higher median values at the station sites, confirming the results of our soil analyses. We detected a fairly good correlation between soil and plant content for cadmium, regardless of the sampling site, soil element content, or analyzed part of the plant. Thus, we propose that dandelion is a suitable bioindicator of cadmium pollution of soil.

Keywords Dandelion · Risk elements · Soil · Industrial areas · Railway stations · City parks

Introduction

An evaluation of the urban contamination with risk elements is often connected with traffic density in the individual cities, where the element contents in the soil, vegetation, and soil-dwelling animals are assessed in the vicinity of roadways. For example, elevated contents of Cd, Cr, Ni, and Zn were reported by Modrzewska and Wyszkowski (2014) in Poland, Zheng et al. (2016) in China, and Çolak et al. (2016) in Turkey. Decreasing element contents with increasing distance from the roadway confirmed the traffic as the contamination source in this case (França et al. 2017; Zhao and Hazelton 2016). However, significant enhancement of soil Pb due to intensive traffic is apparent only in the long term, where Carrero et al. (2013) observed substantial changes in the soil Pb contents 15 years after the beginning of the roadway service. In the Czech Republic, no significant

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increase in soil risk elements was reported along a busy highway (Kašparová et al. 2011). However, the Czech Republic is characterized by a very dense rail network, which was built in the nineteenth century, and was expanded after the First World War (Tikman and Vachtl 2010). Thus, the long-term utilization of the railway can also be considered as a potential source of the soil contamination. Elevated risk element contents in the soil and vegetation along the railway were reported by many authors (Staszewski et al. 2015; Malawska and Wiłkomirski 2001; Wiłkomirski et al. 2011). In the Czech Republic, no systematic monitoring of the railway soils has been done.

Dandelion (*Taraxacum sect. Ruderalia*) is a widespread plant species in Europe, often occurring in urban and industrial areas regardless of the soil quality. Plant communities growing on risk element contaminated sites could be considered as suitable accumulation bioindicators (Malizia et al. 2012), and *Taraxacum* spp. is frequently discussed in this context (Kobierski and Malczyk 2016; Čurlík et al. 2016). Remon et al. (2013) have shown that an analysis of the vegetation provided a characteristic fingerprint of metal bioavailability. A bioindicator plant should be able to take up the risk elements as related to their content in the soil. For *Taraxacum* spp., substantial element uptake by roots was observed, most of which are translocated to the aboveground biomass (Maleci et al. 2014; Bini et al. 2012; Gjorgieva et al. 2011). Root-shoot translocation was observed predominantly for Cd, Pb, and Zn. For the reasonable evaluation of the biomonitoring data, the seasonal variation of the element contents in the *Taraxacum* spp. plants should be taken into account. The concentrations of elements such as Cu, Fe, Mn, Pb, and Zn were significantly higher in leaves collected in the fall compared to those collected at the same sites in the spring (Keane et al. 2001).

Taraxacum spp. are able to survive in a constrained environment thanks to their high phenol content, which effectively suppresses the oxidative stress induced by a high content of risk elements in the urban soils (Vanni et al. 2015). Additionally, an elevated content of flavonoids and other antioxidants was observed, whereas the chlorophyll content decreased under stress conditions (Bretzel et al. 2014). Increasing lipid peroxidation rate with increasing content of risk elements also identifies *Taraxacum officinale* as a suitable plant species for the bioindication of risk element contaminated sites (Savinov et al. 2007). As a response to the long-term risk element exposure, decreasing genetic diversity among the *T. officinale* populations (Keane et al. 2005) and the genotoxicity symptoms (Ackova et al. 2016) were observed. Moreover, the *T. officinale* clones taken from unpolluted sites have much lower survival compared to clones from polluted sites when both were grown in polluted media, demonstrating the clonal difference in the risk element tolerance (Collier et al. 2010). When grown in polluted media, clones from polluted sites, on average, accumulated 4.2 times higher total Cu, 17.8 times higher total Pb, and 4.2 times higher total Zn in their tissues than clones sampled from unpolluted sites (Collier et al. 2017).

Close correlations between pseudo-total Cu contents in soil and aboveground biomass and Cu and Pb in roots of plants including *Taraxacum* spp. were reported by Wiłkomirski et al. (2011). In the case of Cd, no significant relationships were observed between soil and plant contents, but the close relationships between root and shoot Cd contents confirmed a high mobility of Cd within the plant. Higher contents of mobile element (Cu, Pb, Zn) proportions in soil were generally associated with increased plant uptake of these elements (Mossop et al. 2009; Lyubomirova et al. 2015). The ability of *Taraxacum* spp. to accumulate Cd was also confirmed by Wei et al. (2008). They recommended *Taraxacum mongolicum* as a potential Cd accumulator, reporting a bioaccumulation factor (i.e., concentration ratio in plant shoot to soil; bioaccumulation factor (BAF)) of up to 4.4. Higher BAFs for Cd compared to other elements (Pb, Ni, Zn) were also observed by Kováčik et al. (2016), and Hammami et al. (2016) recommended *T. officinale* as a promising plant species for phytoremediation of Cd-contaminated soil. Although the BAF levels for As content in *Taraxacum* spp. growing in the As-contaminated mining area was substantially lower, not exceeding 0.4, this value was higher than most of the analyzed plant species in this area (Vaculík et al. 2013).

In this experiment, the soil contamination level and subsequent uptake of the detectedelements by *Taraxacum* spp. plants were assessed in the area of train stations, to estimate the impact of long-term railway service on the risk elements contamination level, as well as the potential plant availability of these elements. As a sampling area, Central Bohemia (Czech Republic) was chosen. This area surrounds the capital city, Prague, which was not included in the investigation due to its much larger size. Central Bohemia is characterized by a well-developed historical industry and a high density of the rail network. Soils in industrial cities and their surrounding sare considered to be highly contaminated by risk elements (such as Cr, Cu, Pb, Zn, As, and Cd) due to the intense industrialization and urbanization. In this context, the different periods of historical development are linked to enrichment of different elements (Li et al. 2013, 2017; Mcllwaine et al. 2017). Soil contamination from historical metalliferous mining and smelting industry on agriculture and human exposure to metals require particular attention (Thornton 2012). In the Czech Republic (Bednářová et al. 2016), high concentrations of Cd, Pb, and Zn were found in well-known mining areas (the Ore Mountains, the Upper Silesian Basin, the towns of Kutna Hora and Příbram in Central Bohemia), and elevated Cd and As are connected with coal mining and heavy industry (Vácha et al. 2015). Thus, three contrasting sampling sites were chosen in each city: (i) train station; (ii) the area of the dominating industrial enterprise (predominantly mining, smelting, and metal processing companies), where the elevated risk element contents in soil are expected; and (iii) city parks or other green relaxation zones in the cities, where low anthropogenic loads of risk elements are expected. The contents of As, Be, Cd, Co, Cr, Cu, Ni, Pb, V, and Zn in soils and *Taraxacum sect. Ruderalia* plants were determined and assessed.

Material and methods

Sampling

Roots, leaves, and inflorescences samples of the dandelion (*Taraxacum sect. Ruderalia*) plants were collected in 16 cities in Central Bohemia, the Czech Republic, differing in size (between 5 and 70 thousand inhabitants), intensity and type of industry, and density of traffic. In each city, three sampling areas were chosen: (i) the vicinity of the main industrial enterprise (the industry included a wide spectrum of activities, such as mining and smelting, munitions factory, cement works, chemical industry, an automobile factory, and bakeries [Supplementary Table S1]); (ii) train station (in most cases, historical stations were built during the nineteenth or at the beginning of twentieth century, and sampling was done next to the platforms); and iii) city park or another green relaxation zone (in many cases, the sampling was done next to the historic castles situated in the individual cities). In several cities, the environment is affected by former industrial activities, mainly mining (coal, metal ores) or smelting. These aspects are also highlighted as follows in the discussion of the results. Detailed characteristics of the sampling points, including GPS coordinates, are summarized in the Supplementary material (Supplementary Table S1). At each point, three whole plants were sampled in the full flowering stage. Simultaneously with the plant samples, composite soil samples were collected at a depth of 0–10 cm, where each sample represented an average of three sub-samples taken from each sampling square. Soil samples were air dried at 20 °C, ground in a mortar and passed through a 2-mm plastic sieve. The plant samples were separated into roots, leaves, and inflorescences; dried at 60 °C to constant mass; and subsequently ground into a fine powder using a laboratory mill. All samplings were provided in spring 2016.

Analytical methods

The pH values of the soil were determined in 0.01 mol/L $CaCl_2$ extract (1 : 10 *w*/*v*). The cation exchange capacity (CEC) was calculated as the sum of Ca, Mg, K, Na, Fe, Mn, and Al extractable in 0.1 mol/L $BaCl_2$ (1 : 10 *w*/*v* for 2 h) (ISO 1994). The pseudo-total contents 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 a ratio of 1:3). The mixture was heated in an Ethos 1 (MLS GmbH, Germany) microwave-assisted wet digestion system for 33 min at 210 °C. For determination of element contents in the plant biomass, an aliquot (~ 500 mg of dry matter) of the plant sample was weighed in a digestion vessel. Concentrated nitric acid (8.0 mL) (Analytika Ltd., Czech Republic) and 30% H_2O_2 (2.0 mL) (Analytika Ltd., Czech Republic) were added. The mixture was heated in an Ethos 1 (MLS GmbH, Germany) microwave-assisted wet digestion system for 30 min at 220 °C. After cooling, the digests were quantitatively transferred into a 25-mL glass tube, topped up with deionized water, and kept at laboratory temperature until measurements were taken. For the determination of the potentially mobilizable fractions of elements in soils, an extraction with 2 mol/Lsolutions of HNO_3 at a ratio of 1:10 (*w*/*v*) at 20 °C for 6 h (Borůvka et al. 1996) was applied. Each extraction was carried out in three replicates. For the centrifugation of extracts, a Hettich Universal 30 RF (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 measurements. Inductively coupled plasma-optical emission spectrometry (ICP-OES, Agilent 720, Agilent Technologies Inc., USA) was used for the determination of elements in soil extracts and plant digests. For quality assurance of the data, certified reference materials RM 7003 Silty Clay Loam and SRM NIST RM 1515 Apple Leaves were used.

Data processing

For facilitation of the data presentation, the samples originating from the stations were labeled “Station,” the samples from the industrial areas “Industry,” and the samples from the green relaxation zones “Park.” The analytical data were processed using the software package Statistica 10 Cz, and the Kruskal-Wallis test was used with $\alpha = 0.05$ as the criterion for significance. Correlation analysis was used for the assessment of relationships between variables, where Spearman’s correlation coefficients were applied (Meloun and Militký 2004). The so-called bioaccumulation factor (BAF), quantifying the element transfer from soil to plants, was used as a parameter for an evaluation of the uptake of soil elements by plants (as the ratio of the element content in plant leaves to the pseudo-total element content in the soil). Moreover, for an estimation of the mobility of the individual elements, the shoot/root ratio was calculated.

Results and discussion

The risk element contents and mobility in soils

In accordance with the heterogeneous character of the sampling sites, a high variability of the physicochemical properties of the soils was expectable. Table 1 documents the wide range of the CEC levels in the experimental soils. In the case of soil pH, the values were more balanced, varying between 5.3 and 7.3 regardless of the sampling site (park vs. station vs. industry), and no significant difference was determined among the sites for both pH and CEC results. However, the correlation analysis indicated significantly increasing CEC values with increasing soil pH ($r = 0.49$). Taking into account the sampling sites, the close relationships between pH and CEC levels were observed only in the case of the park ($r = 0.75$), and industry ($r = 0.53$), whereas at the station sites, no significant correlation was recorded. These findings indicate the anthropogenic effect on the soils close to the station platforms.

The pseudo-total (aqua regia soluble) contents of the investigated elements are summarized in Table 2, where the results document the high variability of the concentrations with the occurrence of the extreme values. According to the public notice characterizing the conditions for the protection of the agricultural soil quality in the Czech Republic (Anonymous 2016), the maximum values of all the investigated elements exceeded the preventive values of these elements in soil (20 mg/kg for As, 2 mg/kg for Be, 0.5 mg/kg for Cd, 30 mg/kg for Co, 90 mg/kg for Cr, 60 mg/kg for Cu, 50 mg/kg for Ni, 60 mg/kg for Pb, 130 mg/kg for V, and 120 mg/kg for Zn). For As, Cd, Ni, and Pb, the maximum levels exceeded the indicative values; these soil element contents represent a potential risk for crop contamination (i.e., 40 mg/kg for As, 2 mg/kg for Cd, 200 mg/kg for Ni, and 300 mg/kg for Pb). Additionally, the maximum Zn, Ni, and Cu levels represent risk for plant growth and soil biological value (i.e., 400 mg/kg for Zn, 200 mg/kg for Ni, and 300 mg/kg for Cu), and maximum As and Pb levels can directly threaten human and animal health (i.e., 40 mg/kg for As and 400 mg/kg for Pb).

The lowest occurrence of the limit-exceeding values was observed in the soil from parks, where no median value exceeded the preventive values of the elements (Table 2). In the Czech Republic, a comparison between soil risk element levels of industrial Ostrava (North Moravia) and residential Prague (Central Bohemia) was provided by Galušková et al. (2011, 2014). They found differences among the element contents in parks in both cities, where Prague was characterized by elevated concentrations of As (22 mg/kg), Cu (50 mg/kg), Pb (67 mg/kg), and Ni (27 mg/kg) and Ostrava by Cd (0.8 mg/kg), Zn (152 mg/kg), and Cr (43 mg/kg). Similarly, Li et al. (2001) found elevated contents of Cd, Cu, Pb, and Zn in the industry-affected urban soils in Hong Kong (China). In our case, the median values of elements did not reach these levels, but in particular cases, the preventive and/or indicative values of elements were exceeded. For As, the maximum levels were found in Kutná Hora City, characterized by former intensive silver mining (Horák and Hejcman 2016), which was

Table 1 The pH and cation exchange capacity (CEC) of the investigated soils

	pH			CEC (mmol$_{H+}$/100 g)		
	Park	Station	Industry	Park	Station	Industry
Minimum	5.29	5.89	5.55	19.4	20.3	24.8
Maximum	7.10	7.21	7.34	51.9	64.5	60.6
Average	6.53	6.80	6.71	36.9	41.5	36.5
Standard deviation	0.59	0.30	0.465	9.14	12.8	9.40
Median	6.89	6.85	6.83	36.5	43.7	35.8
MAD[a]	0.19	0.09	0.260	4.9	10.3	4.31

[a] Median of absolute deviations

connected with enrichment of soil arsenic content. The maximum levels of Cd, Ni, Pb, and Zn were found in Příbram and Mníšek pod Brdy Cities, characterized by intensive mining and smelting industry (Supplementary Table S1). These results document that the intensive industrial activity can result in elevated contents of risk elements (As, Pb, Ni, Zn) in the quiet zones of cities, such as playgrounds or parks. However, the elevated element contents in the soils might also be related to their geogenic source. The maximum levels of Cd, Pb,

Table 2 The pseudo-total contents of the investigated elements in soils

	As (mg/kg)	Be (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)
Park										
Minimum	6.80	0.392	0.062	2.81	15.6	12.3	6.98	18.3	21.1	53.7
Maximum	140	2.39	3.62	14.4	66.3	39.7	94.7	282	71.3	600
Average	25.3	0.998	0.447	8.16	34.6	24.5	22.6	49.5	43.8	135
Standard deviation	30.4	0.435	0.787	2.94	12.5	7.99	17.9	57.9	13.5	113
Median	14.5	0.844	0.174	8.35	33.7	22.3	19.4	31.2	42.7	104
MAD[a]	5.18	0.220	0.066	1.72	7.95	5.18	3.15	8.30	11.6	20.4
Station										
Minimum	12.0	0.742	0.119	5.91	23.1	22.7	12.6	18.2	31.8	125
Maximum	94.3	2.61	6.56	42.7	422	2330	799	411	107	1260
Average	36.3	1.32	1.19	13.0	75.1	197	79.4	106	54.5	431
Standard deviation	28.0	0.505	1.43	7.92	86.2	540	187	92.6	19.1	299
Median	21.6	1.17	0.782	10.8	49.3	47.3	26.8	86.0	46.9	317
MAD[a]	9.13	0.243	0.435	2.27	20.5	10.7	7.36	46.1	8.12	132
Industry										
Minimum	6.23	0.414	0.103	5.40	16.9	9.25	12.8	20.4	20.1	88.3
Maximum	1730	2.18	14.33	24.7	430	511	491	45,100	1180	1660
Average	124	1.08	1.41	10.2	82.4	76.7	51.6	2640	114	316
Standard deviation	400	0.403	3.30	4.18	109	120	87.6	10,000	239	386
Median	16.8	0.973	0.259	10.1	47.1	29.8	24.5	32.6	55.3	134
MAD[a]	6.13	0.180	0.090	1.95	14.0	9.25	7.17	9.57	14.3	31.0
Preventive value[b]	20	2	0.5	30	90	60	50	60	130	120

[a] Median of absolute deviations

[b] According to Anonymous (2016)

and Zn among all the cities were found in Příbram, part of a mining and smelting district, known for its Pb-Ag-Zn polymetallic mineral deposits, which were mined and processed from the Middle Ages until the 1970s (Ettler et al. 2007). A similar source of these elements is also supported by their close correlations: the correlation coefficients among these elements varied between 0.98 and 0.99. The smelter is most probably responsible for the maximum Ni levels in the castle park in Mníšek pod Brdy City. The elevated contents of Be in the environment are connected with coal mining and processing due to the relatively high content of Be in coal. For instance, the Be levels in coals in the USA varied between 0.2 and 3.2 mg/kg and in Bulgaria even reached up to 35 mg/kg (Taylor et al. 2003; Eskenazy 2006). Thus, expectably, the highest Be content in soil was found in the castle park of Kladno City, characterized by historical mining of the bituminous coal.

The median level of Zn from the industrial areas exceeded the preventive value in only one case, and Zn contents in the soils from industrial sites were significantly higher compared to parks. However, the maximum levels dramatically exceeded the preventive and/or indicative values of all the elements except Co, for which extreme values were reached (Table 2). These values were again connected with the smelters in Příbram (As, Cd, Pb) and Mníšek pod Brdy (Cr, Cu, Ni, V, and Zn). Fairly good correlations among As, Cd, and Pb (*R* values up to 0.99) and among Be, Co, Cr, Cu, Ni, V, and Zn (*R* values between 0.55 and 0.98) indicate that these element groups could originate from similar sources, i.e., emissions from the smelters. The maximum contents of Be and Zn were identified in Kladno City, due to former bituminous coal mining and steel works. Thus, the high levels of soil contamination in the individual cities seem to be more connected with the historical industrial activity rather than the current enterprises. Sharma et al. (2015) investigated the contamination level in several cities in the USA, characterized by former intensive industrial activity during the nineteenth and twentieth centuries. For instance, in Cleveland, the soil element contents were 10.8 mg/kg As, 0.99 mg/kg Cd, 16.3 mg/kg Cr, 281 mg/kg Pb, and 182 mg/kg Zn. Evidently, the Cd and Pb contents were higher compared to this study, and, on the contrary, Cr contents were lower. These data are only weakly comparable because of the different industries and the different characters of the sites. However, these findings support the importance of the historical industry on the contemporary soil contamination level in the industrial areas.

The element contents in the soils at the stations did not reach the extreme levels found at the industrial sites. The maximum element levels (except for V) exceeded the preventive and/or indicative values of the element contents in soil (Table 2). The highest As values were found in the cities Příbram and Kutná Hora, affected by the former silver mining (and the elevated element contents in soils were expectable in the whole area), but similar As values were found in the station soils in the more agricultural cities without heavy industry, such as Benešov and Mělník (Supplemental Table S1). The highest Co, Cr, and Ni levels were determined in the station soil in one of the smallest investigated cities, Zruč nad Sázavou. These elements should be connected with the abrasion of the mechanical parts of the trains. In the less industrialized cities, low contents of the mentioned elements were determined at the industrial and park sites. The median values of element contents at the station sites were the highest among the monitored sites (except V), where the differences between park and station sites were significant for Be, Co, and Zn. For As, Cd, Pb, and Zn, the median values exceeded the preventive values of these elements in soils. Thus, the abundance of elevated levels was greater at the stations compared to the other experimental sites. Although the intensity of the traffic at the individual stations differed, the results indicated the impact of the long-term regular railway traffic on the enhanced risk element contents in soils in accordance with other investigations (Staszewski et al. 2015; Malawska and Wiłkomirski 2001; Wiłkomirski et al. 2011). Especially the contents of Cu, Pb, and Zn substantially exceeded the element contents determined in the vicinity of the highly frequented highway in the Czech Republic (Modlingerová et al. 2012). Comparing these two studies, the Cu contents at the station sites were tenfold higher than along the highway; soil Pb contents were sixfold and Zn fourfold higher. Regardless of the limited comparability of the results from the different sites, no elevated contents of elements were found by Modlingerová et al. (2012) along the highway, whereas this study showed the soil element enrichment at the station sites; it also suggests that the long-lasting railway traffic represent higher detrimental effect on the soil contamination level compared to more recent (less than 50 years old) highway net in the Czech Republic.

For an estimation of the potential mobility of the risk elements in soil, and the role of the anthropogenic activity in this context, the element proportions extractable with 2 mol/L solution of HNO_3 were determined (Table 3). The results corresponded with the trends observed in the case of the pseudo-total element contents in the soils, including the occurrence of the extreme values of the elements. For all the elements, the highest median values were recorded for the station sites, where the differences between station and park sites were significant for Be, Cr, and Zn. For Cr, the significantly higher values were also found at the industrial sites compared to the parks. The highest extractable proportions among the risk elements were determined for Cd,which reached almost 100% of the pseudo-total Cd contents, regardless of the sampling site. Thus, Cd seems to present the highest environmental risk among the investigated elements. Also,Li et al. (2017) considered Cd as the element with high environmental risk among other elements in the urban soils. Relatively high mobile proportions varying between 68 and 92% of the pseudo-total content were determined for Cu, Pb, and Zn, whereas the extractable proportions of As, Be, Co, Ni, and V did not exceed 50%, and the mobilizable proportions of Cr were lower than 25% of the pseudo-total content. No significant differences were recorded among the extractable proportions of elements at the individual sampling sites. However, the extractable proportions of As, Cr, and V tended to be higher at the station site compared to park and industry, indicating the more apparent anthropogenic impact on these soils.

The risk element contents in *T. sect. Ruderalia* plants

The element contents in the *T.* sect. *Ruderalia* plants are summarized in the Tables 4, 5, and 6. Regardless of the element mobility in the soils and different uptake rate of the individual elements, some similarities in the element behavior were found: for Cd, Co, Cr, Cu, Pb, V, and Zn, the highest median element contents were found in the roots, regardless of the sampling site. For Cd and Zn, the contents in leaves were higher than in the inflorescences,

Table 3 The potentially mobilizable (2 mol/L HNO_3 extractable) contents of the investigated elements in soils

	As (mg/kg)	Be (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)
Park										
Minimum	1.62	0.188	0.108	1.16	1.98	8.03	2.19	12.9	4.79	31.0
Maximum	85.7	1.06	2.77	7.61	18.3	40.4	10.4	259	22.2	511
Average	10.4	0.454	0.415	3.53	5.39	18.2	5.48	46.7	10.9	95.0
Standard deviation	20.2	0.229	0.623	1.70	3.67	7.71	2.30	55.5	4.45	111
Median	3.46	0.412	0.215	3.45	4.31	16.4	5.42	28.8	9.94	64.7
MAD[a]	1.41	0.100	0.078	0.810	1.12	3.30	1.67	10.5	2.94	19.4
Station										
Minimum	3.82	0.341	0.119	1.39	4.11	17.4	3.52	14.7	9.29	99.3
Maximum	46.9	1.53	3.82	14.9	37.6	2580	225	515	29.5	1090
Average	16.5	0.677	1.00	4.88	13.7	203	25.4	110	17.8	394
Standard deviation	15.0	0.308	0.904	3.15	9.18	612	52.6	110	5.30	293
Median	9.03	0.642	0.800	4.18	10.7	36.8	8.32	92.0	16.6	258
MAD[a]	4.19	0.216	0.368	0.710	3.73	9.85	2.41	51.1	3.25	142
Industry										
Minimum	1.20	0.272	0.119	1.72	3.21	9.72	3.80	16.5	6.69	37.9
Maximum	1430	0.894	9.35	9.04	67.1	496	134	39,200	440	1210
Average	92.5	0.461	1.07	4.09	13.4	59.8	16.3	2480	40.2	207
Standard deviation	333	0.192	2.16	1.85	17.8	116	28.1	9390	102	293
Median	4.74	0.391	0.312	3.99	6.20	20.7	7.16	33.2	11.6	88.2
MAD[a]	2.37	0.103	0.143	1.20	2.67	8.15	2.49	11.3	2.81	31.3

[a] Median of absolute deviations

Table 4 The total contents of the investigated elements in roots of *Taraxacum sect. Ruderalia*

	As (mg/kg)	Be (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)
Park										
Minimum	0.664	0.008	0.027	0.131	0.708	7.51	0.712	0.526	1.47	18.6
Maximum	3.77	0.118	1.41	1.52	12.7	33.8	21.5	13.3	7.31	80.5
Average	1.18	0.039	0.321	0.351	2.52	16.2	2.59	2.59	2.90	37.1
Standard deviation	0.691	0.027	0.293	0.281	2.31	6.11	3.72	2.86	1.51	13.1
Median	0.953	0.030	0.208	0.264	1.85	15.6	1.66	1.57	2.35	32.7
MAD[a]	0.153	0.015	0.051	0.114	0.57	2.73	0.461	0.906	0.480	5.44
Station										
Minimum	0.664	0.005	0.039	0.130	0.929	7.54	0.773	0.572	0.929	26.8
Maximum	8.70	0.132	4.78	1.16	9.78	236	15.7	32.7	6.58	236
Average	1.68	0.048	0.656	0.533	3.25	28.6	3.00	7.16	2.89	83.7
Standard deviation	1.72	0.033	1.04	0.350	2.29	49.6	3.31	8.32	1.49	56.7
Median	1.04	0.040	0.440	0.412	2.33	14.8	2.19	3.18	2.52	63.1
MAD[a]	0.179	0.023	0.238	0.238	1.08	5.38	0.998	2.47	1.10	28.0
Industry										
Minimum	0.640	0.007	0.050	0.107	0.501	6.30	0.449	0.460	0.781	13.1
Maximum	13.4	0.105	10.5	1.11	19.67	61.4	15.8	701	66.7	125
Average	1.81	0.035	0.887	0.455	3.72	18.6	3.16	46.0	6.49	45.3
Standard deviation	2.96	0.026	2.48	0.296	4.12	12.0	3.07	168	14.2	26.5
Median	1.01	0.034	0.237	0.443	2.92	15.4	2.48	1.55	2.78	41.0
MAD[a]	0.137	0.0203	0.116	0.268	1.62	3.03	0.968	0.883	1.03	10.6

[a] Median of absolute deviations

and the opposite pattern was recorded for Co and Cu. As and Be were distributed equally among the individual parts of the plants. Cr and V were distributed in the following order: roots > leaves > inflorescences at the industrial sites and roots > inflorescence > leaves at the park and station sites. This order in element distribution was also observed for Ni at the station and industry, but at the park sampling sites, the highest Ni contents were found in inflorescences. Also, Collier et al. (2017) observed that various *Taraxacum* spp. clones accumulated significantly more Cu, Pb, and Zn in their root tissues than in their leaves, regardless of the sampling area.

The median results determined at the park sites were good compared with the risk element contents found at a park area in Italy (Giacomino et al. 2016). In the leaves of *Taraxacum* spp., Giacomino et al. (2016) detected 0.13 mg/kg of Cd, 1.41 mg/kgof Cr, 14.7 mg/kg of Cu, 0.54 mg/kg Pb, and 45 mg/kg of Zn. These results indicate (with respect to the different element values in soils) that the element values found in this study could represent the background levels of risk elements in *Taraxacum* spp. In the urban area, the higher Pb accumulation in leaves of *T. officinale* compared to roots was attributed to atmospheric deposition (Kleckerová and Dočekalová 2014). These findings were not confirmed by our results: Pb was predominantly retained in roots, indicating that the soil-plant transport of these elements is the main source of plant contamination and the role of atmospheric deposition remains ambiguous, because the element uptake can be affected by both factors. Similarly to our results, in the study by Giacomino et al. (2016), the contents of Cd, Cr, Cu, Pb, and Zn were determined in *T. officinale* plants growing in the vicinity of streets without any serious contamination levels of these elements. Also, Malinowska et al. (2015) and Modlingerová et al. (2012) reported no effect of the distance from the roadway on risk element contents in aboveground biomass of *Taraxacum* spp. and other plant species, such as *Achillea millefolium* and *Vicia cracca*. The potential contamination of soil and plants

Table 5 The total contents of the investigated elements in leaves of *Taraxacum sect. Ruderalia*

	As (mg/kg)	Be (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)
Park										
Minimum	0.961	0.017	0.038	0.160	0.234	6.41	0.242	0.641	0.173	16.5
Maximum	1.79	0.298	1.72	0.832	3.49	14.1	4.89	3.09	3.34	113
Average	1.32	0.089	0.251	0.246	0.968	9.01	0.917	1.19	0.628	34.5
Standard deviation	0.222	0.096	0.382	0.113	0.828	1.75	0.885	0.635	0.649	20.7
Median	1.37	0.025	0.139	0.231	0.666	9.25	0.594	0.958	0.338	31.6
MAD[a]	0.164	0.006	0.044	0.027	0.296	1.10	0.194	0.159	0.147	5.61
Station										
Minimum	0.931	0.016	0.033	0.155	0.221	5.43	0.158	0.621	0.158	18.8
Maximum	1.73	0.289	2.43	0.289	2.25	39.1	7.19	7.94	1.62	114
Average	1.28	0.098	0.347	0.213	0.896	9.95	1.03	1.42	0.457	45.9
Standard deviation	0.211	0.103	0.534	0.035	0.624	7.19	1.52	1.66	0.345	28.0
Median	1.27	0.023	0.217	0.211	0.674	7.67	0.596	0.868	0.337	33.0
MAD[a]	0.147	0.005	0.116	0.025	0.243	0.903	0.387	0.147	0.138	10.2
Industry										
Minimum	0.896	0.015	0.031	0.149	0.202	6.26	0.156	0.597	0.149	15.5
Maximum	1.98	0.314	5.37	0.330	6.55	14.2	2.76	93.5	3.68	96.8
Average	1.32	0.098	0.452	0.220	1.15	8.99	0.883	6.20	0.617	38.3
Standard deviation	0.283	0.102	1.26	0.047	1.16	2.07	0.676	20.5	0.713	21.7
Median	1.24	0.027	0.111	0.206	0.816	8.39	0.702	0.875	0.436	33.3
MAD[a]	0.145	0.010	0.068	0.024	0.438	0.791	0.412	0.127	0.210	7.27

[a] Median of absolute deviations

along roadways has been widely investigated and discussed in the literature. Substantially less attention was paid to the risk element contents in soil and plants along the railway, although this type of traffic represents an important segment of the traffic in Central Europe, including the Czech Republic and, in many cases, was built in the nineteenth century. Thus, long-term risk element loads were expected. Wiłkomirski et al. (2011) monitored the risk element contents in soil and vegetation within the whole area of the station, where the highest levels of Pb, Zn, and Cd were established in the railway siding area (i.e., the place which consists of many tracks where goods trains wait for unloading) compared to the platform. On the contrary, the contents of Cu and Cr in soil were higher near the platform, reaching up to 480 mg/kg of Cu and 208 mg/kg of Cr. The risk element contents in plants, including *T. officinale*, collected at the platform and in the siding area were higher compared to the control area (Wiłkomirski et al. 2011; Staszewski et al. 2015). In the Czech Republic, the impact of railway transport on the surrounding environment has not yet been systematically monitored. As discussed previously, the station soil element contents tended to contain higher levels compared to industrial and especially park sites, but the median values of Cu and Cr were one order of magnitude lower than presented by Wiłkomirski et al. (2011). In plant roots, except for Zn (with significantly higher contents at the station sites compared to both industry and park sites), the differences were not statistically significant; nevertheless, As, Be, Cd, and Pb contents tended to have higher median values at the station sites. No significant differences among the sampling sites were recorded for leaves and inflorescences, suggesting limited transport of elements to the aboveground biomass of plants growing in the soils with elevated risk element contents.

To quantify the plant's ability to take up and translocate the risk elements, the BAFs and root/shoot ratios were calculated (Table 7). The BAFs characterizing the soil-plant transfer of elements showed that the median BAF values did not exceed one, indicating that *T.* sect.

Table 6 The total contents of the investigated elements in inflorescens of *Taraxacum sect. Ruderalia*

	As (mg/kg)	Be (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	V (mg/kg)	Zn (mg/kg)
Park										
Minimum	1.06	0.018	0.037	0.176	0.221	6.94	0.688	0.706	0.176	18.9
Maximum	2.23	0.037	0.557	0.371	0.972	14.0	7.94	2.52	1.66	46.2
Average	1.55	0.026	0.091	0.259	0.647	10.8	2.35	1.09	0.512	24.9
Standard deviation	0.300	0.005	0.114	0.050	0.227	1.65	1.67	0.324	0.324	5.84
Median	1.51	0.025	0.053	0.251	0.677	10.9	1.70	1.02	0.450	23.6
MAD[a]	0.180	0.003	0.010	0.030	0.165	1.07	0.760	0.132	0.192	1.68
Station										
Minimum	0.698	0.012	0.023	0.116	0.288	8.19	0.654	0.465	0.134	21.7
Maximum	2.11	0.035	1.22	0.352	2.05	34.6	5.96	2.88	1.42	60.1
Average	1.44	0.024	0.145	0.241	0.885	12.1	2.34	1.19	0.518	31.1
Standard deviation	0.372	0.006	0.266	0.062	0.469	5.53	1.42	0.591	0.326	8.73
Median	1.46	0.024	0.058	0.243	0.747	10.6	1.63	1.09	0.422	28.3
MAD[a]	0.296	0.005	0.017	0.050	0.232	1.06	0.247	0.276	0.205	4.00
Industry										
Minimum	1.01	0.017	0.034	0.169	0.212	8.67	0.990	0.675	0.183	20.5
Maximum	2.19	0.037	2.49	0.365	3.46	19.1	5.16	105	5.23	50.5
Average	1.57	0.026	0.214	0.261	1.06	11.5	2.41	8.10	0.795	30.6
Standard deviation	0.355	0.006	0.578	0.059	0.777	2.10	1.10	24.7	1.08	8.24
Median	1.54	0.026	0.054	0.256	0.701	11.2	2.14	1.06	0.409	27.9
MAD[a]	0.270	0.005	0.012	0.045	0.382	0.962	0.703	0.240	0.188	4.54

[a] Median of absolute deviations

Ruderalia does not belong to the highly accumulating plants (Kabata-Pendias and Pendias 2001), although numerous authors reported the accumulation ability of *Taraxacum* spp. for various elements and particularly Pb (Bech et al. 2016; Sun et al. 2016). The high Pb uptake ability by the *Taraxacum* spp. shoots was observed by Bech et al. (2016) and Sun et al. (2016) in plants growing at mine tailings and metallurgy waste deposits. In this study, however, the BAF value for Pb in the mining and smelting area (Příbram) was the lowest among the whole set of samples at the park and industry sites. In this context, the Cd accumulation ability of *T. mongolicum* has been widely discussed (Wei et al. 2008). The highest rate of soil-plant transfer was

Table 7 The median values of the shoot/root ratios and bioaccumulation factors of the investigated elements within the *Taraxacum sect. Ruderalia* plants

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
Shoot/root ratio										
Park	1.22	1.39	0.63	0.88	0.33	0.61	0.35	0.67	0.15	0.95
Station	1.20	1.80	0.56	0.53	0.27	0.53	0.29	0.30	0.18	0.57
Industry	1.30	2.65	0.51	0.50	0.29	0.52	0.27	0.59	0.16	0.79
Bioaccumulation factor										
Park	0.094	0.034	0.557	0.029	0.019	0.412	0.037	0.029	0.009	0.299
Station	0.056	0.024	0.290	0.020	0.014	0.161	0.014	0.015	0.006	0.105
Industry	0.073	0.035	0.334	0.020	0.018	0.274	0.023	0.024	0.008	0.190

observed for Cd, confirming the high plant availability of soil Cd (Sauerbeck 1985). High BAFs were observed for the essential elements Cu and Zn, as expected, and low uptake of Co, Cr, and V by *T. officinale* plants (both roots and shoots) was also reported by Čurlík et al. (2016). According to the shoot/root ratios, the elements should be categorized into three groups: As and Be showed high translocation ability to the aboveground biomass; Cd, Co, Cu, Pb, and Zn were equally distributed between roots and shoots, with predominance in the roots; and Cr, Ni, and V had low root-to-shoot translocation ability. We also detected lower (not significantly) median values for BAFs and shoot/root ratios at the station sites compared to the industry and park sites suggesting (i) lower plant uptake of elements in the soil with elevated contents of these elements and (ii) partially limited root-shoot transport of these elements at the station sites. These findings suggest a potential adaptation of the plants growing in the long-term contaminated soil, but this information needs to be confirmed by further research.

Concerning the element contents in plants, the potential input of the element into the food chain via herbivores was assessed. For this, plant element contents were compared with the maximum allowable limits in feedstuffs. For the risk elements, the Directive No. 2002/32/ES (ES 2002) defined the maximum values of elements in raw feedstuffs at 2 mg/kg for As, 30 mg/kg for Pb, and 1 mg/kg for Cd. No median value exceeded these limits; however, as for the soil analyses, several extreme values were detected (e.g., for As, Cd, and Pb) (Tables 4, 5, and 6). These values were connected with the historical mining and smelting areas Kutná Hora and Příbram, with the highest levels in the industrial zones (industrial zones > stations > parks). In Příbram City, these activities resulted in extremely high soil and plant element levels in the vicinity of the smelter, where the Pb contents reached up to 700, 93.4, and 104 mg/kg and Cd contents 10.5, 5, 37, and 2.48 mg/kg in roots, leaves, and inflorescences, respectively. Elevated contents of Cd in *Taraxacum* spp. within the historical mining area have previously been reported by Králová et al. (2010).

Taraxacum spp. belongs to a group of important medicinal and nectar-producing plants, containing vitamins, bittering agents, and tannins. Inflorescences are used for the production of homemade “honey” or “wine”; roots and leaves are preferred for their detoxification and anti-inflammatory effect in humans and also can be used in cosmetics without any allergic response of the organism (Jeon et al. 2008; Paulsen 2002). The young leaves of *Taraxacum* spp. are used as a vegetable. Thus, for an assessment of the potential environmental risk of element contents in plants, we used the WHO guidelines for assessing the quality of herbal medicines (WHO 2007). The WHO recommends limits of 0.3 mg/kg for Cd and 10 mg/kg for Pb. For Pb in the leaves and inflorescences, the limit value was exceeded only in the samples from the vicinity of the smelter in Příbram. However, four root samples collected at stations exceeded this limit, indicating risk of *Taraxacum* spp. sampling for medicinal use close to stations. The limit of maximum acceptable Cd level in inflorescences was exceeded only in the samples from Příbram City, but numerous samples exceeded this limit in leaves and roots, regardless of the sampling site; although these limits were most frequently exceeded at the stations (at five stations in leaves and at ten stations in roots). These findings should be considered when collecting medicinal plants. According to Commission Regulation (EC) No 1881/2006 (Anonymous 2006), the threshold limits for Cd and Pb contents in leafy vegetables are 0.2 and 0.3 mg/kg of fresh matter; estimating ca. 10% of the dry matter, the re-calculated limits will be 2 and 3 mg/kg of dry matter for Cd and Pb, respectively. According to these limits, the leaves collected in the cities with smelting activities are not suitable for direct human consumption.

The relatively good ability of *Taraxacum* sp. plants to accumulate risk elements could allow investigators to use this species as an indicator of the environmental contamination. This aspect was discussed by Wei et al. (2008) in the case of *T. mongolicum*, for which fairly good correlations between soil and plant Cd concentrations were reported. These findings were confirmed by our results, where the correlation coefficients characterizing the relationships between plant and pseudo-total soil Cd varied between $r = 0.88$ and $r = 0.98$, regardless of the sampling site, soil contamination level, and part of the plant. Weaker, but still significant correlations between pseudo-total soil and total plant contents varying between $r = 0.35$ and $r = 0.98$ were found for Ni, Pb, and Zn. For the remaining elements, the relationships between pseudo-total soil and total plant contents were ambiguous. For instance, the significant correlations varying between $r = 0.37$ and $r = 0.58$ were recorded for Cr and Be in leaves and between $r = 0.71$ and $r = 0.99$ for As in roots. For Cd, similar conclusions ($r = 0.56$–0.98) could be done for the relationships between

2 mol/L HNO_3 extractable element proportions and plant contents. For other elements (except Be), the significant correlations were recorded for roots at the station site. This indicates that the plant roots could reflect anthropogenic soil contamination, but this finding was not confirmed for the aboveground biomass, lowering the possible use of this plant as the indicator of anthropogenic contamination of the soil.

In summary, here, we show that dandelion is a suitable bioindicator of environmental contamination, but that such an approach should be supported by soil analysis. Our findings demonstrate the importance of soil contamination for element uptake by plants, whereas the potential role of atmospheric contamination was unclear. Moreover, our data indicate that railways and stations are a source of long-term contamination of soil and vegetation and should be carefully evaluated in future research.

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