Pol. J. Environ. Stud. Vol. 29, No. 1 (2020), 841-852
DOI: *10.15244/pjoes/104356*

Original Research

Scrap Metal Deposits as Potential Sources of Enhanced Risk in Soil and Vegetation

Klára Tůmová, Jiřina Száková*, Jana Najmanová, Pavel Tlustoš

Department of Agro-Environmental Chemistry and Plant Nutrition, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Science Prague, Prague-Suchdol, Czech Republic

Received: 6 November 2018
Accepted: 12 February 2019

Abstract

High levels of soil pollution occur worldwide as a result of industrial and agricultural production, automotive and rail transport, and other human activities. In the metal-processing industry, risk elements (As, Be, Cd, Co, Cr, Cu, Ni, Pb, V, Zn, etc.) in the waste produced should be contained, and can be an environmental risk. Our experiment monitored soil contamination levels around metal scrap deposits and their potential impact as a risk to dandelion (*Taraxacum* sect. *Ruderalia*) biomass. Sampling was carried out in four open deposits of metallic scrap located in East Bohemia, Czech Republic. The results showed a variety of risk elements in the soils, with no relationship to the soil's physicochemical parameters, but affected by the amount, composition, and ageing of the deposited metallic scrap. The element contents in soils varied in a wide range and for some elements reached extremely high levels: 1.68±2.81 mg/kg of Cd, 62.0±71.8 mg/kg of Cr, 262±376 mg/kg of Cu, 193±355 mg/kg of Pb, and 495±475 mg/kg of Zn, but a very high environmental risk, estimated according to the Risk Assessment Code (RAC), was recorded only for Cd and Zn. Substantial soil-plant transport with predominant translocation to the above ground biomass was recorded for Cd (shoot/root ratio reached up to 2.1), whereas Zn remained equally distributed between roots and above ground biomass. The Zn bioaccumulation factors decreased with increasing soil Zn content. Although the results cannot be clearly generalized because of the different character of the scrap in the individual deposits, only cadmium was able to penetrate the surrounding environment regardless of the location. Scrap metal deposits do not currently represent a global environmental risk, but monitoring potential soil and plant contamination next to scrap metal deposits is recommended for identifying potential environmental hazards.

Keywords: metal scrap, soil, vegetation, risk elements, bioaccessibility

Introduction

Metals and the metalliferous industry play an important role in contemporary human communities, and their use is connected to rising industrial development and living standards. Metals are used in numerous sectors of industry and other human activities [1]. Metallurgy, however, is one of the most serious polluters of the environment. Sectors such as ore mining, smelting and steel production produce high amounts of waste that differ in consistency and in physicochemical and mineralogical composition. At the end of their life,

---

*e-mail: szakova@af.czu.cz

metallic products are collected in scrap disposal sites, and subsequently recycled in scrap processing factories. In 2016 there were 1,544 industrial plants operating in the Czech Republic, of which 242 were involved in the production and processing of metals. In the same year, over 2.5 million tons of iron waste were produced [2, 3].

The long-term negative impact of mining and metallurgical production, including the potential risk to the surrounding environment from the waste landfills resulting from these industrial activities, has been extensively investigated [4, 5]. The potential effect and risk of recycling electronic waste (e-waste) has been investigated [6, 7]. The recycling of steel scrap is also a possible source of environmental contamination [8, 9]. The dust originating from the scrap smelting process can also be a substantial environmental risk [10]. Karlaviciene et al. [11] and Ogunkunle et al. [12] identified Cd, Cr, Ci, Ni, Zn, and Pb as the risk elements predominantly connected with potential topsoil contamination around a metal recycling factory. According to Owoade et al. [13], the atmospheric dissemination of the metal particles *via* particulate matter (PM) should be taken into account. They identified metallurgical production and e-waste as the predominant sources of $PM_{2.5\text{-}10}$ in an area of the scrap iron and steel smelting industry.

The potential release of risk elements from mine tailings due to rainfall [14] and the leaching behavior of waste from the metallurgical industry were also investigated. For instance, Jensen et al. [15] reported the low leachability of Pb, Cu, Cd and Zn from scrap dirt originating from iron scrap and metal recycling facilities, most probably due to the alkaline pH of the samples. Lin et al. [16] presented a comprehensive assessment of the potential impact of steelmaking processes on the risk element in soils in the area surrounding a factory. They highlighted the storage facility of waste iron as one of the most important sources of contamination, and surface runoff and rain wash as the main routes of risk element distribution into the surrounding environment. However, no significant release of Pb and As was observed by Pinto and Al-Abed [17] if the soil contaminated by the industrial wastes was extracted using an artificial solution simulating rainfall (in slightly acidic conditions: pH 4.2).

Diluted acids are applied as a pre-treatment when leaching the waste materials for potential recycling of metallic scrap. For instance, Rudnik et al. [18] compared the leaching behavior of various Zn waste materials, including slag from smelting mixed metallic scrap (containing 50 % of Zn), and zinc spray metallizing dust (containing about 77% Zn) in a 10% solution of H_2SO_4. They found leachable proportions of Zn at around 80%, indicating the good solubility of these materials. Similarly, Sakultung et al. [19] reported effective leaching of Co and Ni from e-waste by using diluted H_2SO_4, and HNO_3. The effective application of organic acids (citric acid, oxalic acid), together with bioleaching supported by *Aspergillus niger* for Cd, Cu, Pb, and Zn release from e-waste has been noted [20], although at lower concentrations, the organic acids are important components of soil solution, and the leachability of metals can also be supported by the soil microbiota. Jensen et al. [15] reported that the leachability of the risk elements from scrap samples is low, but they reported a substantial increase in risk element leachability if the scrap material was covered by an organic matter-rich material such as compost. The accessibility of the scrap metals could thus be affected by the presence of active soil organic matter.

Elevated risk element contents in soils covering industrial waste dump sites, and in plants growing in these soils, which indicate that the risk elements released from the wastes can be released to the soil and subsequently enter the food chain, are well documented [21, 22]. Conversely, there is less information concerning the impact of open metallic scrap deposits, where the metallic material is separated and stored until recycling, on the surrounding environment. This manuscript gives basic information concerning the soil risk element contamination level and potential soil-plant transport of these elements, and considers the possibility of their entering the food chain *via* herbivores living in the impacted areas.

Material and Methods

Sampling

Four open deposits of metallic scrap, differing in length of operation, but all located in East Bohemia, Czech Republic, were chosen for the study. All the deposits were located in an area relatively unaffected by industrial activities in order to minimize the potential effect of other risk element sources. Location A (50.000° 25,000′38.979′′N; 15.000°19.000′20.283′′E) was the oldest, where the deposit was operated since 1994, Location B (50.000°30.000′2.567′′N; 15.000°17.000′ 13.746′′E) was established in 2000, and Locations C (50.000°27.000′58.578′′N; 15.000°10.000′5.313′′E) and D (50.000°22.000′13.431′′N; 15.000°12.000′49.427′′E) were established in 2011. Five sampling points were chosen at each location to cover the whole area of the deposit. *Taraxacum* sect. *Ruderalia* was chosen as the model plant species. Although there is some evidence of risk element uptake by these plants, *Taraxacum* spp. is considered by many authors to be a suitable bioindicator of risk element-contaminated soil, most recently, for instance, by Gomez-Arroyo et al. [23], Fröhlichová et al. [24], and Krolak et al. [25].

At each sampling point, three whole plants were sampled in full flowering stage. Composite soil samples were collected at the same time at a depth of 0-10 cm, where each sample represented an average of three sub-samples taken from each sampling point. Soil samples were air-dried at 20ºC, ground in a mortar, and passed through a 2-mm plastic sieve. The plant samples were separated into roots, leaves, and inflorescences, dried at 60ºC to constant mass, and subsequently ground into a fine powder using a laboratory mill. All samples were collected in spring 2017.

Analytical Methods

The pH values of the soils were determined in a 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, shaken for 2 h) [26]. The pseudo-total contents of elements in the soils were determined in the digests obtained by the following decomposition procedure: the 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 210ºC. An aliquot (~500 mg of dry matter) of the plant sample was weighed in a digestion vessel for determining element contents in the plant biomass. 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 220ºC. 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. The proportion of bioaccessible element content in the sediment was determined by adding 0.5 g of each sample to 10 mL of a 0.11 mol/L solution of CH_3COOH; this mixture was then shaken overnight [27]. Each extraction was carried out in triplicate. Extracts were centrifuged in a Hettich Universal 30 RF (Germany) at 3000 rpm (i.e., 460 g) for 10 min at the end of each extraction procedure, and the supernatants were stored at 6ºC prior to analysis. 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 results, certified reference materials were used as follows: 1) For verification of the element contents in the soils a certified reference material RM 7003 Silty Clay Loam (Analytika, Czech Republic) was applied for the quality assurance of analytical data. The certified values of the *Aqua regia* soluble contents of elements in this material are: As 11.6±0.7 mg/kg, Cd 0.32±0.03 mg/kg, Cr 42.4±3.6 mg/kg, Cu 25.4±0.9 mg/kg, Ni 28.8±1.2 mg/kg, Pb 25.2±1.1 mg/kg, Zn 69.4±1.8 mg/kg. Within this study, the following *Aqua regia* soluble element contents were determined in this material: As 10.8 mg/kg, Cd 0.36 mg/kg, Cr 40.7 mg/kg, Cu 26.1 mg/kg, Ni 29.2 mg/kg, Pb 24.1 mg/kg, Zn 70.8 mg/kg; 2). For verification of the total element contents in plants a standard reference material NIST 1515 Apple leaves (NIST, USA) was applied. The certified values of elements in this material are: As 0.038±0.007 mg/kg, Cd 0.013±0.002 mg/kg, Cu 5.64±0.24 mg/kg, Ni 0.91±0.12 mg/kg, Pb 0.470±0.024 mg/kg, V 0.26±0.03 mg/kg, Zn 12.5±0.3 mg/kg. Within this study, following total element contents were determined in this material: As<0.3 mg/kg, Cd 0.015 mg/kg, Cu 5.78 mg/kg, Ni 1.03 mg/kg, Pb 0.485 mg/kg, V 0.22 mg/kg, Zn 12.1 mg/kg.

Data Processing

The analytical data was processed using the Statistica 10 Cz software package, and the Kruskal-Wallis test with $\alpha = 0.05$ was used as the criterion for significance, because the data did not meet the criteria for normal distribution. Correlation analysis was used for the assessment of relationships between variables, where Spearman's correlation coefficients were applied [28]. The risk assessment code (RAC) considers the ability of metals to be released and subsequently enter the food chain, and is calculated as the mobile proportion of an element extractable with 0.11 mol/L acetic acid to a pseudototal content of the element. When the percentage of the extractable element is less than 1% there is no risk. There is low risk at a range of 1-10%, medium risk at a range of 11-30%, high risk at 31-50%, and very high risk at 51-100% [29]. The bioaccumulation factor (BAF), quantifying the element transfer from soil to plants, was used as the ratio of element content in the above ground biomass of plants to the pseudo-total element content in soil [30].

Results and Discussion

Risk Element Accumulation and Mobility in Soils

The results of the determination of the main physicochemical parameters of the soils showed a relatively narrow range of soil pH values, where the data varied from slightly acidic to neutral values, (from 6.1 to 7.2) regardless of the location. Conversely, the CEC values varied more substantially, even within one location. The CEC values ranged between 168 and 315 $mmol_+$/kg at Location A, between 131 and 260 $mmol_+$/kg at Location B, between 29 and 296 $mmol_+$/kg at Location C, and between 181 and 258 $mmol_+$/kg at Location D. Due to the inconsistency in the variability of the data in both data sets, no significant correlation was recorded if the pH, and CEC values were related.

The pseudo-total contents of the elements investigated in soils are summarized in Table 1, and the data documents a high variability in element contents within the individual locations. The public notice characterizing the conditions for the protection of

Table 1. Pseudo-total (i.e.,*Aqua Regia* soluble) contents of the investigated elements in soils.

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location A										
Minimum	5.89	0.522	0.636	5.72	39.7	65.9	24.2	40.1	25.4	259
Maximum	9.38	1.13	11.1	10.7	70.3	281	66.0	439	51.4	1303
Average	7.34	0.697	3.31	8.09	60.7	171	45.6	198	39.0	766
STD[a]	1.21	0.223	3.91	2.02	11.4	72.0	16.3	158	9.00	404
Median	7.30	0.639	1.62	8.74	65.6	149	39.1	101	41.6	872
MAD[b]	0.89	0.111	0.36	2.00	4.65	65	14.8	61	8.79	432
Location B										
Minimum	5.02	0.407	0.104	5.23	31.4	25.9	19.3	16.4	29.0	85.9
Maximum	14.9	1.26	7.72	8.98	356	729	62.3	1306	66.3	1762
Average	7.97	0.751	2.20	7.11	108	228	35.7	295	42.3	571
STD[a]	3.58	0.299	2.90	1.35	125	262	14.4	507	14.4	627
Median	6.46	0.738	0.466	7.43	48.2	95.7	32.5	37.8	33.9	260
MAD[b]	1.44	0.231	0.36	1.47	13.9	70	3.19	21.4	5.0	174
Location C										
Minimum	7.02	0.370	0.146	5.78	27.9	21.0	21.6	19.4	22.7	79.2
Maximum	8.37	0.884	2.63	7.89	95.3	724	83.6	1038	46.4	823
Average	7.95	0.692	0.787	6.80	48.0	315	35.7	235	34.8	349
STD[a]	0.48	0.175	0.952	0.736	24.1	331	24.0	402	7.93	252
Median	8.16	0.752	0.213	6.74	37.7	87.0	24.4	35.0	35.2	306
MAD[b]	0.15	0.083	0.07	0.55	4.0	66	1.1	15.6	4.39	93
Location D										
Minimum	3.81	0.400	0.048	3.62	13.5	10.2	10.3	5.18	17.7	27.2
Maximum	7.59	1.15	1.29	8.93	46.5	1492	41.4	101	48.4	829
Average	6.11	0.675	0.436	5.45	31.5	332	22.4	46.3	30.4	293
STD[a]	1.56	0.272	0.450	1.86	12.0	581	10.9	40.9	10.8	308
Median	6.97	0.623	0.295	5.09	29.5	40.3	18.0	22.2	26.5	109
MAD[b]	0.63	0.182	0.19	0.92	13.2	30	7.7	17.0	8.8	82

[a]standard deviation, [b]median of absolute deviations

agricultural soil quality in the Czech Republic [31] was chosen for an assessment of the risk element levels in the soils, although the analyzed soils do not belong to the agricultural soils. The vegetation cover at these places can serve as a source of nutrition for wild herbivores, however, which can be endangered in a similar way as the livestock grazing pasture land. The maximum values of Cd, Cr, Cu, Ni, Pb, and Zn exceeded the preventive values of these elements in soil (0.5 mg/kg for Cd, 90 mg/kg for Cr, 60 mg/kg for Cu, 50 mg/kg for Ni, 60 mg/kg for Pb, and 120 mg/kg for Zn). The maximum values for As, Be, Co and V did not reach safe values, i.e., 20 mg/kg for As, 2 mg/kg for Be, 30 mg/kg for Co, and 130 mg/kg for V. The maximum levels for Cd and Pb exceeded the indicative values; these soil element contents are a potential crop contamination risk (i.e., 2 mg/kg for Cd, and 300 mg/kg for Pb). The maximum Zn and Cu levels are a risk to plant growth and soil biological value (i.e., 400 mg/kg for Zn, and 300 mg/kg for Cu), and maximum Pb levels can directly threaten human and animal health (i.e., 400 mg/kg for Pb).

The differences among the element levels in soils at the individual locations were not proven as statistically

Table 2. Mobile contents of the risk elements in soils (extractable with 0.11 mol/L CH_3COOH).

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location A										
Minimum	<0.3	<0.005	0.037	0.105	<0.05	0.533	0.232	0.526	<0.05	17.2
Maximum	0.900	0.033	3.99	1.09	0.512	5.89	1.51	11.0	0.612	557
Average	0.458	0.017	1.12	0.608	0.245	3.28	1.06	4.31	0.155	252
STD[a]	0.381	0.011	1.45	0.341	0.177	1.74	0.43	4.27	0.237	190
Median	0.670	0.015	0.50	0.668	0.194	3.22	1.18	1.44	<0.05	223
MAD[b]	0.230	0.010	0.21	0.293	0.172	0.79	0.08	0.91	c	132
Location B										
Minimum	<0.3	<0.005	0.035	0.113	<0.05	0.243	0.189	<0.2	<0.05	10.5
Maximum	0.694	0.030	1.97	1.16	0.792	43.9	4.78	44.3	0.144	490
Average	0.389	0.015	0.55	0.457	0.158	9.86	1.36	9.20	0.029	146
STD[a]	0.319	0.013	0.74	0.382	0.317	17.0	1.72	17.6	0.058	179
Median	0.618	0.016	0.11	0.233	<0.05	2.19	0.533	<0.2	<0.05	60.3
MAD[b]	0.076	0.015	0.07	0.120	c	1.91	0.309	c	c	49.8
Location C										
Minimum	<0.3	<0.005	0.056	0.386	<0.05	0.337	0.639	<0.2	<0.05	9.52
Maximum	1.15	0.044	1.07	0.643	0.148	16.1	8.82	34.1	0.294	422
Average	0.361	0.020	0.279	0.506	0.103	3.96	2.51	6.94	0.130	129
STD[a]	0.468	0.014	0.395	0.112	0.053	6.09	3.16	13.6	0.115	149
Median	<0.3	0.021	0.066	0.450	0.118	0.780	1.14	<0.2	0.158	68.2
MAD[b]	c	0.009	0.010	0.064	0.020	0.44	0.44	c	0.136	26.1
Location D										
Minimum	<0.3	<0.005	0.024	0.162	<0.05	<0.05	0.280	<0.2	<0.05	5.68
Maximum	0.836	0.077	0.512	0.507	0.213	21.7	1.27	3.01	0.416	403
Average	0.167	0.024	0.164	0.318	0.135	5.17	0.788	0.984	0.217	114
STD[a]	0.334	0.028	0.182	0.125	0.077	8.29	0.356	1.10	0.147	152
Median	<0.3	<0.005	0.079	0.310	0.159	<0.05	0.911	<0.2	<0.05	16.8
MAD[b]	c	c	0.056	0.099	0.052	c	0.360	c	c	11.1

[a]standard deviation, [b]median of absolute deviations, [c]not calculated

significant due to the heterogeneity of the results. These findings indicate a necessity of the more dense sampling net for more detailed description of the contamination levels at the individual locations, as well as for achieving more significant statistics. Although the risk element contents in soils did not show any significant differences between the individual locations, the median values tended to higher levels in the soils at Location A, the oldest deposit. Denton et al. [32] monitored the soil risk impact of metallic debris (residues of military hardware, etc.) at WWII dumpsites. Older depositions of metalliferous wastes resulted in heterogeneous soil contamination, where the levels of Cu, Pb, and Zn exceeded 1000 mg/kg in several cases, and Cd levels exceeded 10 mg/kg. Thus, although the origin of the metallic scrap and the ages of the deposition differed, the maximum levels of Cd and Zn had reached similar values, indicating possible soil contamination due to the long-term deposition of scrap metal in contact with the soil. The extreme values of elements at some sampling points can be connected with the specificities of the composition of the scrap deposited at the individual locations. For instance, high contents of Cr (and to a lesser extent of Be and As) at Location B could be

Table 3. Total contents of the investigated elements in the roots of *Taraxacum sect. Ruderalia.*

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location A										
Minimum	<0.3	0.028	0.088	0.537	4.73	10.1	3.21	4.11	2.44	41.7
Maximum	0.617	0.063	3.18	0.823	7.26	45.5	5.63	27.8	4.55	175
Average	0.123	0.044	0.859	0.621	5.69	23.8	4.25	16.3	3.31	96.2
STD[a]	0.247	0.015	1.17	0.105	0.906	12.0	0.895	9.69	0.770	49.2
Median	<0.3	0.033	0.300	0.590	5.62	23.8	4.11	19.0	3.24	92.0
MAD[b]	c	0.016	0.150	0.038	0.61	13.7	0.83	11.0	0.56	46.5
Location B										
Minimum	<0.3	0.028	0.028	0.695	5.11	8.98	3.75	3.05	3.59	22.8
Maximum	2.38	0.122	1.85	1.43	15.8	169	8.58	148	6.51	616
Average	0.763	0.076	0.544	1.01	10.7	55.6	6.30	35.8	5.26	189
STD[a]	0.869	0.034	0.673	0.334	3.89	57.7	1.75	56.3	1.15	218
Median	<0.3	0.077	0.178	0.808	11.1	35.8	5.76	5.67	5.45	113
MAD[b]	c	0.025	0.150	0.086	2.8	12.6	0.65	2.62	1.06	69
Location C										
Minimum	<0.3	<0.005	0.092	0.110	2.02	7.24	1.21	1.96	1.07	28.2
Maximum	2.97	0.188	0.419	2.67	29.9	51.3	16.7	29.4	13.1	183
Average	1.52	0.105	0.182	1.31	12.3	22.7	7.50	8.63	7.22	65.6
STD[a]	1.30	0.067	0.127	0.860	9.64	15.4	5.33	10.4	4.01	58.7
Median	1.88	0.092	0.097	1.01	7.84	16.7	5.11	4.16	6.71	39.8
MAD[b]	0.89	0.025	0.005	0.60	4.73	8.6	2.81	2.19	1.06	11.6
Location D										
Minimum	<0.3	0.029	0.063	0.478	5.48	11.4	3.21	2.13	2.33	30.7
Maximum	0.997	0.076	0.290	0.917	7.97	48.4	6.01	7.26	4.47	125
Average	0.199	0.053	0.164	0.646	6.44	22.4	4.15	4.83	3.61	63.1
STD[a]	0.399	0.016	0.080	0.153	0.876	13.3	0.967	2.02	0.727	33.7
Median	<0.3	0.051	0.148	0.656	6.33	19.0	3.89	4.67	3.90	51.4
MAD[b]	c	0.022	0.085	0.178	0.85	0.1	0.68	2.27	0.57	13.2

[a]standard deviation, [b]median of absolute deviations, [c]not calculated

related to the deposit of bituminous coal close to the sampling area. Bituminous coal was not analyzed in this study to verify this speculation, but elevated contents of Cr in coal has been demonstrated in studies by other authors [33, 34]. The high content of Cu in soil at Location D may be related to high amounts of copper wires and cables deposited in this area. Similarly, high contents of Pb in soil (especially at Locations B and C) are connected with the deposition of wreckage and lead-acid batteries. As found by Chaney [35], galvanized sheet metal could be a source of Zn in soils, as also indicated in this study.

A comparison of soil element contents within scrap metal deposits shows higher soil element levels compared to hazardous waste landfills [36, 37]. Similarly, lower risk element contents than those in this study were found in urban soils loaded by traffic-bearing risk elements [38]. Industrial areas (especially those connected with mining and smelting activities) can show even higher levels of risk elements in soil [24], and therefore scrap metal deposits can be considered serious point sources of soil pollution through risk elements, where particular contamination levels depend on the composition of the scrap deposited.

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

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location A										
Minimum	<0.3	<0.005	0.104	<0.05	0.335	6.27	0.790	<0.2	<0.05	26.5
Maximum	<0.3	<0.005	1.63	0.242	0.863	9.18	9.53	1.52	0.533	81.9
Average	<0.3	<0.005	0.437	0.048	0.630	7.66	3.19	0.701	0.310	46.5
STD[a]	c	c	0.596	0.097	0.193	1.22	3.24	0.614	0.179	19.3
Median	<0.3	<0.005	0.143	<0.05	0.645	7.42	2.03	0.825	0.344	42.2
MAD[b]	c	c	0.038	c	0.155	1.15	1.05	0.699	0.082	9.7
Location B										
Minimum	<0.3	<0.005	0.043	<0.05	0.520	5.71	0.682	<0.2	0.313	15.8
Maximum	<0.3	<0.005	1.15	0.241	2.06	29.8	4.67	13.8	0.708	148
Average	<0.3	<0.005	0.302	0.089	0.921	12.5	2.69	3.16	0.486	53.4
STD[a]	c	c	0.423	0.109	0.583	8.85	1.37	5.32	0.140	48.2
Median	<0.3	<0.005	0.108	<0.05	0.641	8.14	2.34	0.930	0.433	34.8
MAD[b]	c	c	0.026	c	0.121	2.43	1.35	0.930	0.120	7.8
Location C										
Minimum	<0.3	<0.005	0.047	<0.05	0.502	8.02	0.651	<0.2	0.227	19.5
Maximum	<0.3	<0.005	0.167	0.204	1.16	10.4	1.60	2.52	0.791	31.4
Average	<0.3	<0.005	0.109	0.041	0.702	9.41	1.19	1.14	0.419	24.3
STD[a]	c	c	0.039	0.082	0.245	0.766	0.360	1.08	0.193	4.08
Median	<0.3	<0.005	0.117	<0.05	0.591	9.59	1.07	<0.2	0.362	22.6
MAD[b]	c	c	0.022	c	0.088	0.14	0.41	c	0.016	3.0
Location D										
Minimum	<0.3	<0.005	0.051	<0.05	0.412	7.38	0.650	<0.2	0.237	23.6
Maximum	<0.3	<0.005	0.265	0.242	0.870	13.3	6.30	2.12	0.660	133
Average	<0.3	<0.005	0.152	0.048	0.592	11.0	1.95	0.886	0.355	56.8
STD[a]	c	c	0.369	0.114	0.179	1.14	2.57	3.71	0.165	4.19
Median	<0.3	<0.005	0.109	<0.05	0.545	11.0	0.889	1.10	0.278	39.7
MAD[b]	c	c	0.058	c	0.133	1.5	0.23	1.02	0.041	8.7

[a]standard deviation, [b]median of absolute deviations, [c]not calculated

The potential bioaccessibility of the elements should be assessed regarding potential environmental risk. The RAC values based on the mild extraction of the soils with 0.11 mol/L acetic acid were applied. The acetic acid extractable proportions of elements showed high variability in the data, as did the pseudo-total soil element contents (Table 2). Except for As Be, and V, fairly good relationships were recorded between the pseudo-total and 0.11 mol/L acetic acid extractable element contents, where the correlation coefficients varied within the range $r = 0.56$, and $r = 0.99$, and were significant at $p<0.05$. Although the bioaccessibility of risk elements in soil is related to the soil's physicochemical parameters, especially pH [39-41], neither pH nor CEC levels correlated significantly with the 0.11 mol/L acetic acid extractable element contents. This finding indicates the potential release of elements from the scrap metal regardless of the particular soil characteristics. Jensen et al. [42] reported elevated contents of Pb, Cu, Zn, Cd, Cr, and Ni in the surface soil surrounding scrap iron and metal recycling facilities, but the migration of elements below the surface was limited. Similarly, Száková et al. [21] reported the limited penetration of risk elements through the thick soil layer cover of a galvanic sludge

Table 5. Total contents of the investigated elements in the inflorescens of *Taraxacum* sect. *Ruderalia*

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location A										
Minimum	<0.3	<0.005	0.044	<0.05	0.613	8.52	1.20	0.832	<0.05	22.4
Maximum	<0.3	<0.005	0.683	0.550	3.94	13.0	5.48	1.61	1.93	39.6
Average	<0.3	<0.005	0.189	0.152	1.59	10.2	2.45	1.16	0.594	31.5
STD[a]	c	c	0.247	0.215	1.22	1.61	1.53	0.274	0.683	5.46
Median	<0.3	<0.005	0.072	0.125	1.34	9.82	1.89	1.17	0.303	32.0
MAD[b]	c	c	0.008	0.030	0.65	1.01	0.15	0.25	0.178	0.7
Location B										
Minimum	<0.3	<0.005	<0.01	<0.05	0.764	7.96	2.03	0.483	0.416	18.8
Maximum	<0.3	<0.005	0.522	0.336	5.90	23.9	3.63	7.22	1.35	67.8
Average	<0.3	<0.005	0.144	0.211	2.59	13.2	2.80	2.08	0.815	35.4
STD[a]	c	c	0.191	0.119	1.77	5.71	0.590	2.57	0.340	17.0
Median	<0.3	<0.005	0.059	0.209	1.98	11.4	2.59	0.926	0.717	28.1
MAD[b]	c	c	0.040	0.101	0.69	2.4	0.56	0.072	0.300	7.3
Location C										
Minimum	<0.3	<0.005	0.041	<0.05	0.717	8.42	1.26	<0.2	0.200	19.8
Maximum	<0.3	<0.005	0.125	0.200	1.70	12.6	3.37	3.25	0.509	28.6
Average	<0.3	<0.005	0.062	0.119	1.01	11.0	2.44	1.26	0.341	25.1
STD[a]	c	c	0.032	0.097	0.355	1.43	0.746	1.10	0.127	3.21
Median	<0.3	<0.005	0.046	0.198	0.886	11.6	2.68	0.794	0.307	24.6
MAD[b]	c	c	0.005	0.002	0.103	1.0	0.69	0.653	0.107	3.7
Location D										
Minimum	<0.3	<0.005	<0.01	<0.05	0.465	8.04	1.42	<0.2	<0.05	20.4
Maximum	<0.3	<0.005	0.100	0.254	2.80	12.2	3.95	1.61	1.01	50.0
Average	<0.3	<0.005	0.041	0.150	1.15	10.3	2.55	0.983	0.378	29.3
STD[a]	c	c	0.038	0.123	0.903	1.42	1.13	0.554	0.345	10.6
Median	<0.3	<0.005	0.050	<0.05	0.558	10.6	1.83	0.954	0.250	24.7
MAD[b]	c	c	0.027	c	0.092	1.0	0.41	0.444	0.200	2.4

[a]standard deviation, [b]median of absolute deviations, [c]not calculated

deposit. The only exception was for Cd, which showed significant penetration into the upper layers of the soil. The high mobility of Cd was also confirmed in this case, because the RAC level reached 62%, indicating the very high environmental risk of this element. Similar levels of RACs reaching 54% and 66% were calculated for Co and Zn, respectively. Conversely, the mobility of Cr can be characterized as no risk (RAC = 0.8%), and of V and Pb as low risk (RAC = 1.3%, and 8%, respectively). The RAC values of the remaining elements varied between 11 and 17%, i.e., represented a medium environmental risk.

Soil-Plant Transport of Risk Elements and their Accumulation in *T.* sect. *Ruderalia* Biomass

The risk element content in individual *T.* sect. *Ruderalia* plant parts are summarized in Tables 3-5. Due to the high variability of the results, no significant differences were identified among the individual locations. The maximum allowable levels of these elements in the feedstuff of grazing livestock were used to assess the potential risk of the element contents in plant biomass to wild herbivores. Directive No. 2002/32/ES [43] defines the maximum values

Table 6. BAF values characterizing the soil-plant transfer of risk elements to the individual tissues of *Taraxacum* sect. *Ruderalia.*

	As	Be	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
Roots										
Min	<0.001	<0.001	0.124	0.019	0.039	0.032	0.009	0.006	0.046	0.002
Max	0.355	0.509	4.417	0.397	0.526	1.863	0.099	1.161	2.889	0.143
Median	<0.001	0.079	0.267	0.118	0.173	0.172	0.030	0.098	0.187	0.015
Leaves										
Min	a	a	0.046	<0.001	0.005	0.007	0.005	0.001	0.000	<0.001
Max	a	a	5.539	0.067	0.065	1.304	0.173	1.216	0.269	0.013
Median	a	a	0.209	<0.001	0.015	0.108	0.022	0.033	0.025	0.001
Inflorescens										
Min	a	a	<0.001	<0.001	0.005	0.007	0.004	0.002	<0.001	<0.001
Max	a	a	1.038	0.069	0.144	1.083	0.083	0.755	0.141	0.012
Median	a	a	0.072	0.024	0.027	0.112	0.018	0.043	0.033	0.002

^{a}not calculated

of elements in raw feedstuff at 2 mg/kg for As, 30 mg/kg for Pb, and 1 mg/kg for Cd. No median value exceeded these limits; but the maximum levels of these three elements exceeded these limits in plant roots (Table 3). Soil analyses identified several extreme values for other elements, such as Cu and Zn, in plants, and significant correlations (P<0.05) were found among the element contents in roots and both the pseudo total and acetic acid extractable element proportions in soil for Cd, Cu, Ni, Pb, and Zn, with correlation coefficients varying between r = 0.47 and r = 0.98. The median element contents in the leaves and inflorescens returned lower element contents (Tables 4 and 5) than the roots. The maximum Cd levels in leaves exceeded the limits, especially at Locations A and B, but the element contents in the inflorescens did not.

Generally, the element contents within the plants decreased in the order roots > leaves > inflorescens for Cd, Ni, V, and Zn, and in the order roots > inflorescens > leaves for Co, Cr, Cu, and Pb. The As and Be element contents in the above ground biomass were under the detection limit of the analytical technique used. Thus, the sensitivity of the analytical technique represents the limitation of the assessment of the element uptake by plants. For more detailed assessment of the bioaccessibility of the scrap metal-derived risk elements in further research, a method characterized by the lower detection limits should be chosen. The element contents in leaves and inflorescens were fairly well related to both pseudototal and acetic acid-extractable element proportions in the soil for Cd, Cr, Cu, Pb, and Zn, (significant correlation coefficients varied from r = 0.68 and r = 0.98, P<0.05). Fröhlichová et al. [24] investigated the relationships between soil and *T.* sect. *Ruderalia* plants, where significant correlations between the pseudototal soil element contents and the contents of these elements in plants were identified for Cd, Ni, Pb, and Zn, regardless of the plant tissues, and for Cr only in the case of leaves. Their results are thus in accordance with this study in many aspects, including the weak relationship between soil Cr and its content in roots, and the significant relationship between these element contents in soil and leaves. Diluted acetic acid is an extractant, releasing element fractions specifically sorbed in soil clay minerals. This extractant is therefore recommended as a suitable test to predict the changes in element mobility in contaminated soils [44]. This study demonstrated that 0.11 mol/L extractable acetic acid is also a suitable extraction agent for the prediction of the soil-plant behavior of some risk elements (especially Cd, Pb, and Zn) in the contaminated soil.

The bioaccumulation factors (BAFs) and shoot/root ratios were calculated as parameters supporting the assessment of the ability of plants to take up and translocate risk elements (Tables 6 and 7). As noted in other studies [24], the highest rate of soil-plant transfer was observed for Cd (Table 6), confirming the high plant-availability of soil Cd already described by many authors, such as Sauerbeck [45], and Kabata-Pendias and Pendias [46]. High BAFs were observed for the essential element Cu, as expected, whereas the BAF values for other essential elements such as Co, Ni, and Zn were low, indicating that the plant uptake of these elements did not reflect the elevated contents of these elements in soil. This statement is supported by the negative correlation of BAF values with the Co, Ni, and Zn contents in soil (the significant correlation coefficients varied between r = -0.46, and r = -0.67, P<0.05). Low BAFs were also determined for Cr. Čurlík et al. [47], who reported the low uptake of Co and Cr by *T. officinale* through both roots and shoots, as did Fröhlichová et al. [24]. Low BAFs for As, Cr, and Zn, indicating the limited

Table 7. Shoot/root ratio values characterizing the translocation of risk elements to the aboveground biomass of *Taraxacum* sect. *Ruderalia.*

	Cd	Co	Cr	Cu	Ni	Pb	V	Zn
Min	0.247	<0.001	0.017	0.177	0.285	<0.001	<0.001	0.142
Max	2.070	0.448	0.363	1.326	3.281	0.543	0.346	1.063
Median	0.779	<0.001	0.089	0.410	0.984	0.053	0.091	0.604

transport of these elements from soil contaminated by the multi-industry activities to root vegetables, were documented by Ahmed et al. [48]. Conversely, high BAF levels were reported in root vegetables for Cd and Cu. In our study, Pb and V showed the potential to be accumulated by the plants, especially through the roots. Their translocation ability to the above ground biomass was limited, however. According to the shoot/root ratios (Table 7), the elements should be categorized into three groups: Cd and Ni showed high translocation ability to the above ground biomass; Cu and Zn were equally distributed between roots and shoots, with predominant accumulation in the roots; and Co, Cr, Pb, and V showed low root-to-shoot translocation ability.

The results thus confirmed the high mobility and plant-availability of Cd, and also demonstrated the important role of *T.* sect. *Ruderalia* as a suitable bioindicator of Cd soil contamination levels. The plants showed a limited uptake ability in highly contaminated soils for essential elements such as Cu and Zn, where the plant element contents did not reflect the substantially elevated contents of these elements in soils. According to Alloway [49], contents of Zn higher than 400 mg kg^{-1} of dry matter are toxic to plants. As apparent from Tables 3-5, this value of plant Zn content was exceeded only occasionally in roots, whereas the Zn contents in above ground biomass remained far below the potential phytotoxicity levels. The results thus indicate a plant's ability to regulate the uptake of essential elements according to their requirements. The results for the remaining elements showed either limited translocation from roots to shoots (Pb, V), or even limited uptake of the elements by roots (As, Be, Co, Cr, Ni). Krolak et al. [25] found an increasing content of risk elements in the leaves and roots of *Taraxacum* spp., with increasing soil element contents, without any significant effect of the soil properties on BAFs for roots. This study found no significant relationship between soil pH and/or CEC values and element uptake by plants.

Conclusions

In summary, the data showed elevated contents of both pseudo total and mobile (i.e., diluted acetic acid-extractable) contents of elements, especially Cd, Cr, Cu, Ni, Pb, and Zn, where the element contents were not related to the soil physicochemical parameters, but most probably to the amount, composition, and storage conditions of the deposited scrap. Although not proven by the statistical evaluation, the results also indicated the role of ageing in potential soil contamination level. For instance, lower soil contents were found for most of the elements at Locations C and D (established in 2011), compared to Locations A and B, established in 1994, and 2000, respectively. The deposit at Location C was made on an uncontaminated meadow, whereas the deposit at Location B was made on a brown field with the residues of the storage from agricultural machines and chemicals. We can conclude that: i) metallic scrap deposits can be responsible for the elevated levels of risk elements in soils in the close vicinity; the contamination level is heterogeneous, depending on the character of the deposit and/or the amount and composition of the scrap material; ii) although the RAC levels indicated the high potential bioaccessibility of most of the investigated elements, a potentially hazardous element uptake by the *T.* sect. *Ruderalia* plants was observed only in the case of Cd, including facile translocation of this element to the above ground biomass. Cadmium is therefore, a real potential risk to wild herbivores living in the investigated area, and consuming the contaminated vegetation. The regular monitoring of the risk element content in soil and vegetation in the vicinity of the metallic scrap deposits could be recommended in further research in order to avoid the potential increase of the soil contamination levels.

Acknowledgements

The authors thank the GAČR 17-00859S project for financial support, and the European Regional Development Fund – project No. CZ.02.1.01/0.0/0.0/16_019/0000845. Correction and improvement of language was provided by Proof-Reading-Service.com.

Conflict of Interest

The authors declare no conflict of interest.

References

1. WERNICK I.K., THEMELIS N.J. Recycling metals for the environment. Ann. Rev. En. Environ. **23**, 465, **2017**.

2. BATULA J., ŘEPKA V. The possibilities of recycling of fine-grained mining wastes from aged deposits. VSB – Technical University, Ostrava, **2002** [In Czech].
3. ANONYMOUS Integrated system of waste management. Available at: https://isoh.mzp.cz/, **2016a**. [In Czech].
4. KARA M., DUMANOGLU Y., ALTIOK H., ELBIR T., ODABASI M., BAYRAM A. Spatial distribution and source identification of trace elements in topsoil from heavily industrialized region, Aliaga, Turkey. Environ. Monit. Assess. **186** (10), 6017, **2014**.
5. BURDZIEVA O.G., ALBOROV I.D., TEDEEVA F.G., MAKIEV V.D., GLAZOV A.P. Mining caused pollution of the natural landscape. Int. J. GEOMATE **15** (51), 195, **2018**.
6. HE K.L., SUN Z.H., HU Y.A., ZENG X.Y., YU Z.Q., CHENG H.F. Comparison of soil heavy metal pollution caused by e-waste recycling activities and traditional industrial operations. Environ. Sci. Pollut. Res. **24** (10), 9387, **2017**.
7. UTIMURA S.K., ROSARIO C.G.A., BOTELHO A.B., TENORIO J.A.S., ESPINOSA D.C.R. Bioleaching process for metal recovery from waste materials. In: ZHANG L., DRELICH J.W., NEELAMEGGHAM N.R., GUILLEN D.P., HAQUE N., ZHU J., SUN Z., WANG T., HOWARTER J.A., TESFAYE F., IKHMAYIES S., OLIVETTI E., KENNEDY M.W. (Eds.). Energy Technology: Carbon Dioxide Management and Other Technologies. Book Series: Minerals Metals & Materials Series, 283, **2017**.
8. YATKIN S., BAYRAM A. Investigation of chemical compositions of urban, industrial, agricultural, and rural top-soils in Izmir, Turkey. Clean-Soil Air Water **39** (6), 522, **2011**.
9. ŠORŠA A., MILER M., GOSAR M., HALAMIĆ J. Follow-up geochemical studies and mineralogical investigations by scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) of soil samples from the industrial zone of Sisak, Croatia. J. Geochem. Explor. **187**, 168, **2018.**
10. HE X.W., CHAI Z., SHI J.J., LI Y., FANG Z.Q., LI F.P. Leaching of elements from flue dust produced in copper scrap smelting process. Toxicol. Environ. Chem. **95** (6), 932, **2013**.
11. KARLAVICIENE V., HOGLAND W., KRIIPSALU M., KANGSEPP P. Pre-investigation of the distribution of heavy metals at metal scrap processing plant. In: CYGAS D., FROEHNER K.D. (Eds.) Proc. 6Th Int. Conf. Environ. Eng. Vols 1 and 2, May 26-27, Vilnius, Lithuania, 373, **2005**.
12. OGUNKUNLE C.O., VARUN M., DAWODU O.F., AWOTOYE O.O., FATOBA P.O. Ecological vulnerability assessment of trace metals in topsoil around a newly established metal scrap factory in southwestern Nigeria: geochemical, geospatial and exposure risk analyses. Rend. Lincei-Sci. Fis. **27** (3), 573, **2016**.
13. OWOADE K.O., HOPKE P.K., OLISE F.S., OGUNDELE L.T., FAWOLE O.G., OLANIYI B.H., JEGEDE O.O., AYOOLA M.A., BASHIRU M.I. Chemical compositions and source identification of particulate matter ($PM_{2.5}$ and $PM_{2.5\text{-}10}$) from a scrap iron and steel smelting industry along the Ife-Ibadan highway, Nigeria. Atm. Pollut. Res. **6** (1), 107, **2015**.
14. RODRIGUEZ L., GOMEZ R., SANCHEZ V., VILLASENOR J., ALONSO-AZCARATE J. Performance of waste-based amendments to reduce metal release from mine tailings: One-year leaching behaviour. J. Environ. Manag. **209**, 1, **2018**.
15. JENSEN D.L., HOLM P.E., CHRISTENSEN T.H. Leachability of heavy metals from scrap dirt sampled at two scrap iron and metal recycling facilities. Waste Manag. Res. **18** (4), 367, **2000a**.
16. LIN Y.C., LEE W.J., SHIH Y.J., JHANG S.R., CHIEN S.K. Levels and sources of heavy metals in soil, sediment, and food crop in the vicinity of electric arc furnace (EAF) steelmaking plant: a case study from Taiwan. J. Soils Sedim. **18** (7), 2562, **2018**.
17. PINTO P.X., AL-ABED S.R. Assessing metal mobilization from industrially lead-contaminated soils located at an urban site. Appl. Geochem. **83**, 31, **2017**.
18. RUDNIK E., WLOCH G., SZATAN L. Comparative studies on acid leaching of zinc waste materials. Metall. Res. Technol **115**, Article No: 110., **2018**.
19. SAKULTUNG S., PRUKSATHORN K., HUNSOM M. Simultaneous recovery of Ni and Co from scrap mobile phone battery by acid leaching process. Asia-Pac. J. Chem. Eng. **3**, 374, **2008**.
20. KOLENCIK M., URIK M., CERNANSKY S., MOLNAROVA M., MATUS P. Leaching of zinc, cadmium, lead and copper from electronic scrap using organic acids and the Aspergillus niger strain. Fres. Environ. Bull. **22** (12a), 3673, **2013**.
21. SZÁKOVÁ J., KRÝCHOVÁ M., TLUSTOŠ, P. The risk element contamination level in soil and vegetation at the former deposit of galvanic sludges. J. Soils Sedim. **16** (3), 924, **2016**.
22. RACHIERU M.S., FACIU M.E., IFRIM I., STEFANESCU I., KAMARI A., STAMATE M., LAZAR I. Heavy metals and gamma radioactivity bioaccumulation in *Artemisia absinthium* L. grown on a waste dump. Environ. Eng. Manag. J. **16** (4), 859, **2017**.
23. GOMEZ-ARROYO S., BARBA-GARCIA A., ARENAS-HUERTERO F., CORTES-ESLAVA J., DE LA MORA M.G., GARCIA-MARTINEZ R. Indicators of environmental contamination by heavy metals in leaves of *Taraxacumofficinale* in two zones of the metropolitan area of Mexico City. Environ. Sci. Pollut. Res. **25** (5), 4739, **2018**.
24. FRÖHLICHOVÁ A., SZÁKOVÁ J., NAJMANOVÁ J., TLUSTOŠ P. An assessment of the risk of element contamination of urbanand industrial areas using *Taraxacum* sect. *Ruderalia*as a bioindicator. Environ. Monit. Assess. **190** (3), 150, **2018**.
25. KROLAK E., MARCINIUK J., POPIJANTUS K., WASILCZUK P., KASPRZYKOWSKI Z. Environmental factors determining the accumulation of metals: Cu, Zn, Mn and Fe in tissues of Taraxacumsp sect. Taraxacum. Bull. Environ. Contam. Toxicol. **101** (1), 68, **2018**.
26. ISO 11260. Standard of soil quality - Determination of effective cation exchange capacity and base saturation level using barium chloride solution. International Organization for Standardization, Geneve, **1994**.
27. QUEVAUVILLER P., URE A., MUNTAU H., GRIEPINK B. Improvement of analytical measurements within the BCR– program – Single and sequential extraction procedures applied to soil and sediment analysis. Int. J. Environ. Anal. Chem. **51** (1-4), 129, **1993**.
28. MELOUN M., MILITKÝ J. Statistical analysis of the experimental data. (in Czech) Academia, Praha, **2004.**
29. MARRUGO-NEGRETE J., PINEDO-HERNÁNDEZ J., DÍEZ S. Assessment of heavy metal pollution, spatial

distribution and origin in agricultural soils along the Sinú River Basin, Colombia. Environ. Res. **154**, 380, **2017**.

30. HU B.F., JIA X.L., HU J., XU D.Y., XIA F., LI, Y. Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze river delta, China. Int. J. Environ. Res. Public Health **14** (9), Article No. 1042, **2017**.
31. ANONYMOUS Public notice No. 153/2016 about the conditions for the protection of the agricultural soil quality. Legal code of The Czech Republic, (in Czech), 2692, **2016b**.
32. DENTON G.R.W., EMBORSKI C.A., HACHERO A.A.B., MASGA R.S., STARMER J.A. Impact of WWII dumpsites on Saipan (CNMI): heavy metal status of soils and sediments. Environ. Sci. Pollut. Res. **23** (11), 11339, **2016**.
33. HUFFMAN G.P., HUGGINS F.E., SHAH N., ZHAO J. Speciation of arsenic and chromium in coal and combustion ash by XAFS spectroscopy. Fuel Proc. Technol. **39** (1-3), 47, **1994**.
34. SHAH A.N., TANVEER M., HUSSAIN S. Beryllium in the environment: Whether fatal for plant growth? Rev. Environ. Sci. Bio. **15** (4), 549, **2016**.
35. CHANEY R.L. Zinc phytotoxicity. In: ROBSON A.D. (Ed.) Zinc in soil and plants. Kluwer Academic Publishers, Dordrecht, **1993**.
36. MARI M., NADAL M., SCHUHMACHER M., DOMINGO J.L. Exposure to heavy metals and PCDD/Fs by the population living in the vicinity of a hazardous waste landfill in Catalonia, Spain: Health risk assessment. Environ. Int. **35** (7), 1034, **2009**.
37. KASASSI A., RAKIMBEI P., KARAGIANNIDISK A., ZABANIOTOU K., TSIOUVARAS A., NASTIS A., TZAFEITOPOULOU K. Soil contamination by heavy metals: Measurements from a closed unlined landfill. Biores. Technol. **99** (18), 8578, **2008**.
38. GALUŠKOVÁ I., BORŮVKA L., DRÁBEK O. Urban soil contamination by potentially risk elements. Soil Water Res. **6** (2), 55, **2011**.
39. MARTINEZ C.E., MOTTO, H.L. Solubility of lead, zinc and copper added to mineral soils. Environ. Pollut. **107** (1), 153, **2000**.
40. MAKOVNÍKOVÁ J., BARANČÍKOVÁ G., DLAPA P., DERCOVÁ K. Inorganic contaminants in the soil ecosystems. (in Czech). Chem. Listy **100** (6), 424, **2006**.
41. GROPPA M.D., IANUZZO M.P., ROSALES E.P., VAZQUEZ S.C., BENAVIDES M.P. Cadmium modulates NADPH oxidase activity and expression in sunflower leaves. Biol. Plant. **56** (1), 167, **2012**.
42. JENSEN D.L., HOLM P.E., CHRISTENSEN T.H. Soil and groundwater contamination with heavy metals at two scrap iron and metal recycling facilities. Waste Manag. Res. **18** (1), 52, **2000b**.
43. ANONYMOUS Directive No. 2002/32/ES of European Parliament and Council of Europe concerning xenobiotics in feedstuffs, **2002**.
44. SASTRE J., HERNÁNDEZ E., RODRÍGUEZ,R., ALCOBÉ X., VIDAL M., RAURET, G. Use of sorption and extraction tests to predict the dynamics of the interaction of trace elements in agricultural soils contaminated by a mine tailing accident. Sci. Total Environ. **329** (1-3), 261, **2004**.
45. SAUERBECK D. Funktionen, Güte und Belastbarkeit des Bodensausagrikulturchemischer Sicht. Materialienzur Umweltforschung, Kohlhammer Verlag Stuttgart, **1985**.
46. KABATA-PENDIAS A., PENDIAS H. Trace Elements in Soils and Plants. 3. ed., CRC Press, USA, **2001**.
47. ČURLÍK J., KOLESÁR M., DURŽA O., HILLER E. Dandelion (*Taraxacumofficinale*) and agrimony (*Agrimoniaeupatoria*) as indicators of geogenic contamination of flysch soils in Eastern Slovakia. Arch. Environ. Contam. Toxicol. **70** (3), 475, **2016**.
48. AHMED M., MATSUMOTO M., KUROSAWA K. Heavy metal contamination of irrigation water, soil, and vegetables in a multi-industry district of Bangladesh. Int. J. Environ. Res. **12**(4), 531, **2018**.
49. ALLOWAY B.J. Heavy Metals in Soils. Blackie and Son Ltd., Glasgow and London. **1990**.