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Bioaccumulation of Heavy Metals by Plants in a Closed Industrial Landfill from Bacau, Romania

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ABSTRACT

The heavy metals contents of the soils, the botanical characteristics and the level of heavy metal accumulation of a closed industrial discharge were examined. The study should evaluate the levels of heavy metal contamination and accumulative potential of the site's plants and assess the feasibility of remediation by these plant species. The results showed high levels of heavy metals (Cr, Ni, Cu, Zn, As, Cd, Pb) in the soil. The botanical study at the dump showed a plant community rich in biodiversity (20 species and 6 families), with no obvious toxicity symptoms. Measurements of metal levels in dominant species confirmed that they were very similar to those reported for species growing in polluted environments. Metals were found in the leaves and roots of plants found on the landfill. However, the bioconcentration factors are less than 1 except for the case of *Carduus australis* Pomel in Zn which is 1.04. Positive correlations were noted between heavy metal levels in the leaves. Therefore, for effective site restoration, native species may be well suited to cope with local conditions in a phytoextraction strategy.

Introduction

The industrial revolution was the major source of heavy metals into the environment (Alloway, 1995a). The toxicity caused by heavy metals, found

in many soils contaminated by industrial activities, constitutes a significant environmental risk for humans. Until recently, industrial waste disposed in large open dumps often extended over several hectares. Today, regulation in most European

countries does not allow the disposal of waste in open areas and many old landfills have been abandoned. Over time, these landfills have been colonized by a number of plant species, resulting in the gradual formation of the topsoil (Remon et al., 2005), enriched in various heavy metals. Despite the restoration of vegetation cover, these contaminated sites are potential sources of pollution of the local environment; it is therefore necessary to accurately assess their risks and to propose appropriate recovery methods. In this respect, plants could be of great interest both as indicators of the danger of contaminated soils (Fränzle, 2006), and as effective recovery tools (Tordoff et al., 2000; Senou et al., 2018).

In addition to chemical extraction methods, the study of plant communities in terms of species diversity, toxicity, symptoms and metal concentrations in above-ground tissues must be measured to accurately assess phyto-availability and the ecotoxicity of soil metals. In fact, such an approach has already been carried out in a number of potentially hazardous sites, including tailings (Cobb et al., 2000; Stoltz and Greger, 2002), municipal waste (Gimmmler et al., 2002) or industrially contaminated (Dudka et al., 1996). Moreover, in addition to understanding the factors governing the vertical transfer of heavy metals, the identification and characterization of plant species capable of growing and surviving in polluted areas could be very useful for developing phytostabilization technologies (Olson and Fletcher, 2000). Indeed, for technical and financial reasons, the removal of metallurgical landfills for disposal at special sites is clearly unrealistic. Therefore, the only way to prevent or minimize the hazards of heavy metals is to control and stabilize existing landfills. In this respect, the restoration of an appropriate vegetation cover (Wong, 2003) could be an effective alternative to the treatment of industrial discharges, which could meet the dual objective of sustainable regeneration of sites and visual improvement of highly degraded areas. However, chemical extraction procedures rarely predict the biological accumulation of metals. The

development of complementary methods to evaluate the bioavailability of metals remains necessary. In this perspective, measuring the concentration of metals in the different parts of the selected plants could be an interesting alternative. The polluted soil issue is whether contaminants have an impact on the local ecosystem. In this respect, it is obvious that the study of plant communities living in a polluted environment could be very useful. Indeed, it has long been known that the presence or absence of certain plant species or associations may be a good indicator of edaphic constraints, such as high levels of metals (Brooks, 1983).

In addition to their potential use in bioindication, it is important to have a better understanding of primary plant successions under extreme soil conditions. This should lead to the identification of plant species capable of colonizing heavily polluted soils, which could be used to achieve or accelerate sustainable plant quarrying in ecological restoration strategies (Bradshaw, 1997).

In this article, we have studied the soil and vegetation of an old industrial dump in the city of Bacau (Romania). Our objectives were to evaluate the level of metal contamination of the soils of this landfill and the phytoavailability of heavy metals by the analysis of the vegetation and the accumulative potential of the plants of the site. We have also identified and characterized plant species, which could be used in a phytoextraction strategy for this site.

Materials and methods

Study site

The studied industrial discharge (46 ° 31 '20.04 "N, 26 ° 58' 39.79" E) was located in the south exit of the city of Bacau (Romania). It was an old industrial dump closed since 2010. The entire landfill covered an area of approximately 46.77 ha. This site, which has shown a well-developed vegetation cover with herbaceous species, has been studied in this work.

Types of waste and conditions of the discharge

The landfill was part of the heating network infrastructure of the city of Bacau (Romania). Due to the restructuring of the city heating system, the deposit of slag and ash has been closed. According to HG.349 / 2005 (Municipality of Bacau, Romania, 2015), ash and slag dumps are hazardous industrial waste. The landfill has an area of 46.77 ha with a volume of 3370000 m³ divided into three compartments. The landfill was covered with a 40-60 cm soil layer and was included in the zonal landscape (Municipality of Bacau, Romania, 2015).

Sampling and soil analysis

Systematic sampling has been designed (because polluted sites are generally heterogeneous). The study area was divided into three transects (A, B and C) at 10 m intervals. Soil samples (0-20 cm deep) were taken every meter along each transect, yielding 15 sampling points. The samples were dried in the shade for 48 h, screened to 2 mm and milled to pass a 250 µm mesh screen.

The analysis of the metallic trace elements (Cr, Ni, Cu, Zn, As, Cd, Pb) was carried out by spectrometry with the easyWAVE software or easyCONTROL HPR1000 / 10S high pressure segmented rotor (Milestone ETHOS station, Bacau, Romania). This method allows acid digestion of the sludge sample in a closed cell device using temperature controlled microwave heating for the determination of the metal by spectroscopic methods.

The concentrations of heavy metals in various extracts were measured by inductively coupled optical emission spectrometry (ICP-OES). The wavelengths were chosen by "profile function" to give the greatest sensitivity to each element, without interference. Quantitative analyzes were performed using calibration curves at appropriate concentration levels with PlasmaCal certified single-element standard solutions (SCP Science - Canada). All calibration standards were prepared in the same matrix used for the extracts. The detection

limits were 0.042; 0.124; 0.055; 1.32; 0.035; 0.01; 0.027 respectively for Cr, Ni, Cu, Zn, As, Cd and Pb. To verify the analytical accuracy, randomly selected samples (approximately 20% of the total number) were measured in triplicate. The relative standard deviation was systematically between 1 and 8% and never higher than 10%. During the overall sample preparation and analysis process, particular care was taken to minimize contaminants from air, glass and reagents, all of which were analytical grade.

Vegetation study and plant analysis

Vegetation cover was studied in 1 m × 1 m quadrants around each of the 15 soil sampling points. Taxa were identified with standard botanical procedures and then named. In each quadrant, the number of individuals of each species and / or the percentage of coverage estimates were recorded. This made it possible to identify the most abundant species.

The accumulation of metals in plant tissues was assessed from the most abundant species. The plant samples were thoroughly washed in tap water and rinsed three times with distilled water. The samples were then separated into leaves, stems and roots, dried at 40°C to constant weight. In the metal testing laboratory, the samples were crushed to a 2 mm sieve. Digestion of the plant samples was performed using 8 ml of 65% HNO₃, 0.5 ml of 40% HF. The concentration of metals in various extracts was measured by ICP-OES as described above.

Statistical analyzes

The Pearson coefficient is used to evaluate the linear correlation between two metal levels in the leaves and stems of the different species analyzed. Indeed, this type of coefficient makes it possible to establish the existence of a link between 2 variables X and Y in order to measure the strength or the intensity of this link. A positive sign indicates that the relationship is proportional, a negative sign that it is inversely proportional. By convention we say that the relation between X and Y is perfect if $r = 1$;

very strong if $r > 0.8$; strong if r is between 0.5 and 0.8; average if r is between 0.2 and 0.5; low if r is between 0 and 0.2 and zero if $r = 0$. This was calculated using the SYSTAT statistical software (SYSTAT In., Evanston, IL, USA).

Results

Plant community

Botanical examination at the dump level yielded 20 species and 6 families (Table 1). Most of these species were herbaceous (18 species) belonging to *Asteraceae* and *Chenopodiaceae*. *Arthrocnemum fruticosum* (L.) Moq. and *Chenopodium murale* L. were the only shrub species recorded in the study. No trees were noted in the study area. Despite this taxonomic diversity, the vegetation cover was not uniform and, within each quadrant, the area covered, the number of taxa and the type of dominant species were rather variable.

Heavy metal content of soils

The most obvious feature of the study area was its high level of contamination with various heavy metals (Table 2). This polymetallic pollution was mainly due to Cr, Ni, As and Pb, whose average concentration values were 56.27 mg kg^{-1} , 15.51 mg kg^{-1} and 17.87 mg kg^{-1} and 5.95 , respectively mg kg^{-1} , but As has also been detected at relatively high levels (respectively 17.87 mg kg^{-1} for the mean value). As a general rule, the distribution of heavy metals was homogeneous over the whole surface with the exception of a few points, such as A2, B1 and C3.

Heavy metal content of plants

Heavy metal accumulation by vegetation at the site was verified by measuring the metal concentrations in the leaves and roots of the 5 dominant species in various quadrants. The results are shown in Table 3.

In the leaves, the average metal levels were 21.12 mg kg^{-1} for Cr, 1.86 mg kg^{-1} for Ni, 7.19 mg kg^{-1} for Cu, 20.23 mg kg^{-1} for Zn, 8.65 mg kg^{-1} for As,

0.04 mg kg^{-1} for Cd and 1.40 mg kg^{-1} for Pb. In general, root metal concentrations were slightly lower for all metals. On average, they were 19.83 mg kg^{-1} for zinc, 8.71 mg kg^{-1} for copper, 2.44 mg kg^{-1} for nickel, 2.43 mg kg^{-1} for Pb, and $0, 1 \text{ mg kg}^{-1}$ for Pb. Only Cr and As have a high concentration (respectively 28 mg kg^{-1} for Cr and 9.16 mg kg^{-1} for As). However, differences in root and leaf metal levels were not significant (Turkey test, $P > 0.05$ for all metals). This indicates that in this plant community, metal concentrations were in equilibrium between roots and leaves. However, our results also suggest that, regardless of the soil metal content, the different plant species present at the site have varying capacities to absorb and accumulate metals. For example, at *Carduus australis* Pomel., the Zn contents in the leaves were 2 times higher than in *Atriplex halimus* L., regardless of the soil metal content. It is the same with *Erodium laciniatum* (Cav.) Willd. where the levels in the roots are 3 to 4 times higher than in other species.

Bioconcentration factors (concentration in leaves / concentration in soil)

Bioconcentration factors for heavy metals in leaves (Table 4) are quite heterogeneous regardless of plant species and type of metal. They range from 0.05 (*Erodium laciniatum* (Cav.) Willd. in Cd) to 1.04 (*Carduus australis* Pomel. in Zn). Bioconcentration factors are generally weak to talk about the accumulation of these metals by the plant species found on the site. Regardless of the plant species, the bioconcentration factors are greater than 0.5 only for Cu and Zn. However, we can observe a significant heterogeneity between plant species.

Correlations between heavy metal content in the roots and in the leaves of the species

Correlation coefficients (Pearson correlation) were calculated for each metal combination in leaves and roots (Tables 5, 6).

In the sheets, the correlation coefficient for the Cd-Zn and Zn-Pb pair is very high ($r > 0.8$), those for the Cd-Pb and Ni-Cr pairs are strong ($0.5 < r < 0.8$).

The other correlation coefficients between metals are medium or low. In the roots, the correlation coefficient for the Cd-Zn pair is very strong. That of the Cd-Pb couple is strong. The other correlation coefficients between metals are medium or low. We

found significant differences between correlation coefficients $P < 0.01$ and $P < 0.05$ in leaves and roots respectively for Cd-Zn and Cd-Pb pairs. In the roots, a significant difference in correlations is also found for Ni-Cr ($P < 0.05$).

Table 1. List of plants in the study area with their respective families.

Family	Genus	Species	Herbs	Shrubs	Trees
<i>Arteraceae</i>	<i>Astragalus</i>	<i>curaganae</i> Fisch. Mey.	+		
	<i>Carduus</i>	<i>australis</i> Pomel.	+		
	<i>Centaurea</i>	<i>calcitrapa</i> L.	+		
		<i>sinaica</i> DC.	+		
<i>Brassicaceae</i>	<i>Onopordum</i>	<i>palaestinum</i> Eig.	+		
	<i>Arthocnemum</i>	<i>fruticosum</i> (L.) Moq.		+	
	<i>Atriplex</i>	<i>halimus</i> L.	+		
<i>Chenopodiaceae</i>		<i>stylosa</i> Viv.	+		
	<i>Chenopodium</i>	<i>murale</i> L.		+	
		<i>vulvaria</i> L.		+	
	<i>Herniaria</i>	<i>glabra</i> L.	+		
	<i>Kochia</i>	<i>indica</i> Wight.	+		
<i>Geraniaceae</i>	<i>Salsola</i>	<i>tetrandra</i> Forssk.	+		
	<i>Erodium</i>	<i>laciniatum</i> (Cav.) Willd.	+		
		<i>chium</i> (L.) Willd.	+		
<i>Lamiaceae</i>	<i>Glechoma</i>	<i>hederacea</i> L.	+		
	<i>Marrubium</i>	<i>vulgare</i> L.	+		
<i>Poaceae</i>	<i>Bromus</i>	<i>alopecuroides</i> Poir.	+		
	<i>Dactylis</i>	<i>glomerata</i> L.	+		
	<i>Hordeum</i>	<i>glaucum</i> Steud.	+		

Table 2. Heavy metals concentrations (mg kg^{-1}) in the studied soil samples.

Transect	Sample	Cr	Ni	Cu	Zn	As	Cd	Pb
A	1	55.19	15.54	8.41	27.11	18.27	0.12	5.95
	2	52	15.78	8.34	26.9	17.66	0.15	6.03
	3	58.45	15.02	9.02	27.34	18.24	0.14	6.08
	4	57	14.92	9.12	28.01	18.45	0.16	5.92
	5	48.34	14.88	8.56	26.56	17.89	0.11	5.66
B	1	62.12	15.8	8.97	28.12	18.36	0.90	6.04
	2	55.64	16.02	9.01	28.32	17.32	0.15	6.32
	3	51	16.12	9.34	27.54	16.99	0.17	6.55
	4	54	15.45	8.88	28.27	16.79	0.19	5.89
	5	49.54	15.77	9.12	26.66	17.87	0.20	5.26
C	1	61.81	16.14	9.04	27.16	18.64	0.18	4.98
	2	56	15.66	8.67	27.22	18.01	0.21	6.45
	3	63.22	15.23	8.45	26.58	18.09	0.18	6.38
	4	59.33	14.99	9.04	28.30	17.6	0.20	5.56
	5	60.44	15.12	9.33	27.14	17.82	0.13	6.12

Table 3. Heavy metal concentrations in leaves and roots from dominant species taken at different points of the study area.

Species	Localization	Metal content in leaves (mg kg ⁻¹)							Metal content in roots (mg kg ⁻¹)						
		Cr	Ni	Cu	Zn	As	Cd	Pb	Cr	Ni	Cu	Zn	As	Cd	Pb
<i>Carduus australis</i> Pomel.	A1	21.43	1.63	7.44	26.87	9.33	0.06	1.24	30.53	2.07	8.17	12.26	8.18	0.05	2.27
	A2	22.4	1.56	7.03	28.22	8.56	0.06	1.33	31.03	2.01	7.44	11.13	10.34	0.07	2.23
	B1	24.01	2.02	6.83	24.77	7.77	0.06	1.29	28.54	1.99	9.34	13.47	11.03	0.08	2.09
	C1	19.77	1.56	6.96	25.03	11.6	0.06	1.30	34.12	2.16	6.12	9.30	6.88	0.12	2.56
<i>Atriplex halimus</i> L.	A1	22.33	2.35	7.10	15.61	8.41	0.04	1.04	28.16	2.66	9.21	11.41	7.75	0.05	1.73
	B2	21.33	2.39	7.23	14.05	9.12	0.04	1.05	26.92	2.04	10.01	13.02	7.02	0.04	1.90
	C1	22.12	2.44	6.24	13.66	10.44	0.04	1.67	31.14	2.38	8.38	8.90	6.30	0.03	2.01
<i>Erodium laciniatum</i> (Cav.) Willd.	C3	19.93	1.92	7.55	20.34	5.63	0.01	1.68	30.46	4.131	10.24	46.92	10.9	0.27	3.46
	B3	20.44	1.86	7.99	21.33	7.03	0.01	1.60	27.94	3.65	11.05	38.42	11.09	0.23	3.04
	C2	18.88	2.06	8.20	22.68	4.73	0.02	1.51	31.58	5.74	10.12	44.08	9.12	0.20	3.67
<i>Bromus alopecuroides</i> Poir.	B3	23.83	1.31	7.88	19.79	9.44	0.08	1.65	25.93	1.62	7.84	17.2	9.37	0.10	2.23
	A1	22.78	1.22	7.56	17.83	11.01	0.08	1.77	23.44	1.55	9.56	20.12	11.49	0.08	2.76
<i>Hordeum glaucum</i> Steud.	A2	18.78	1.21	6.55	16.92	8.03	0.03	1.03	22.12	1.12	8.44	16.55	9.44	0.09	2.04
	C1	17.07	1.13	6.15	15.65	7.09	0.04	1.45	19.89	1.08	6.02	14.91	10.07	0.11	1.99

Table 4. Bioconcentration factors in leaves of different species.

Species	Localization	Bioconcentration factor						
		Cr	Ni	Cu	Zn	As	Cd	Pb
<i>Carduus australis</i> Pomel.	A1	0.39	0.10	0.88	0.99	0.51	0.50	0.20
	A2	0.43	0.10	0.84	1.04	0.48	0.40	0.22
	B1	0.39	0.12	0.76	0.88	0.42	0.07	0.21
	C1	0.31	0.09	0.76	9.92	0.62	0.33	0.26
<i>Atriplex halimus</i> L.	A1	0.40	0.15	0.84	0.57	0.46	0.33	0.17
	B2	0.39	0.14	0.80	0.49	0.52	0.27	0.16
	C1	0.36	0.15	0.69	0.50	0.56	0.22	0.33
<i>Erodium laciniatum</i> (Cav.) Willd.	C3	0.40	0.12	0.89	0.76	0.31	0.05	0.33
	B3	0.33	0.11	0.85	0.77	0.41	0.06	0.24
	C2	0.31	0.13	0.94	0.83	0.26	0.09	0.23
<i>Bromus alopecuroides</i> Poir.	B3	0.46	0.08	0.84	0.71	0.55	0.47	0.25
	A1	0.41	0.07	0.90	0.65	0.60	0.66	0.30
<i>Hordeum glaucum</i> Steud.	A2	0.36	0.07	0.78	0.62	0.45	0.20	0.17
	C1	0.28	0.07	0.68	0.57	0.38	0.22	0.29

Table 5. Pearson correlations of metal content in leaves of dominants plant species (correlation values r with significant differences marked by a star).

Cr	Ni	Cu	Zn	As	Cd	Leaves
0.054	0.015	-0.003	0.937	0.004	0.658*	Pb
	0.524*	-0.055	0.001	0.034	0.008	Cr
		-0.004	0.443	0.042	-0.002	Ni
			0.002	0.011	0.002	Cu
				0.034	0.962**	Zn
					0.004	As

* The correlation is significant at $P < 0.05$; ** The correlation is significant at $P < 0.01$.

Table 6. Pearson correlations of metal content in roots of dominants plant species (correlation values r with significant differences marked by a star).

Cr	Ni	Cu	Zn	As	Cd	Roots
0.209	0.002	0.034	0.098	-0.004	0.701*	Pb
	0.543*	-0.012	-0.014	0.002	0.006	Cr
		-0.057	-0.011	-0.009	-0.022	Ni
			0.002	0.025	0.001	Cu
				-0.009	0.884**	Zn
					0.056	As

* The correlation is significant at $P < 0.05$; ** The correlation is significant at $P < 0.01$.

Discussion

In this study, we analyzed the level of heavy metal contamination and studied native vegetation on an

abandoned ash and slag dump. This landfill was part of the heating network infrastructure of the city of Bacau (Romania). Our main objective was to evaluate the phytoavailability of heavy metals by

analyzing the native vegetation encountered on this landfill.

Our results show that the site has been colonized by a certain number of plant species despite the presence of total heavy metal contents close to or above those generally recognized for polluted soils (Adriano, 2001). The most obvious characteristic of this soil was the presence of heavy metals such as chromium (up to 63.22 mg kg⁻¹), nickel (up to 16.14 mg kg⁻¹), copper (up to at 9.34 mg kg⁻¹), lead (up to 6.45 mg kg⁻¹), zinc (up to 28.32 mg kg⁻¹), arsenic (up to 17.82 mg / kg) mg kg⁻¹) and cadmium (up to 0.9 mg kg⁻¹). These concentrations were higher than those measured in unpolluted French natural soils (Baize, 2000), confirming a polymetallic pollution of this landfill. Thus, as a number of authors have already pointed out (Mc Laughlin et al., 2000, Remon et al., 2005), these results on heavy metal contamination of the site indicate that neither total soil "Extractable" concentrations are not enough to accurately assess the fate and effects of contaminants. Therefore, there is now a need to develop complementary methods that could be used to monitor soil quality. In this perspective, the study of plant communities living in a polluted environment (Alvarez et al., 2003; Fränzele, 2006) could have several advantages: they are in close and continuous contact with the polluted substrate, they can accumulate metals in their aerial parts at levels proportional to the available soil content (Baker, 1981), their taxonomy is well established and they can be quickly recognized by a qualified botanist. So far, most studies on the ability of plants to monitor metal pollution have focused on the use of one or a few specific species (Madejon et al., 2004). However, the use of a single species to monitor soil quality has been criticized (Mertens et al., 2005), mainly because the availability of a given metal, and hence its leaf concentration, may be species dependent. Therefore, in this study, we analyzed several species, chosen to be representative of the study sites, in order to obtain a complete picture of the availability of metals for all the plants living on the landfill.

In this study, the metal content was measured in the leaves and roots of plants. The different species studied do not behave in the same way in the face of metallic pollution. The content varies among species but, regardless of species, the maximum accumulation was 24.01 mg kg⁻¹ Cr, 2.44 mg kg⁻¹ Ni, 2.20 mg kg⁻¹ Cu, 28, 22 mg kg⁻¹ Zn, 11.01 mg kg⁻¹ As, 0.8 mg kg⁻¹ Cd and 1.68 mg kg⁻¹ Pb in the leaves. Without roots, the maximum accumulation was 34.12 mg kg⁻¹ Cr, 5.74 mg kg⁻¹ Ni, 11.05 mg kg⁻¹ Cu, 46.92 mg kg⁻¹ Zn, 11.01 mg kg⁻¹ As, 0.27 mg kg⁻¹ Cd and 3.67 mg kg⁻¹ Pb. However, a comparison of these values with known baseline levels of micronutrients (Harada and Hatanaka, 2000) in plants growing in the wild indicates that the species of the dump had concentrations quite normal. The low Pb content could be explained by the low mobility of this metal in soils. The work of Orłowska et al. (2002) showed that lead has low mobility in soil (less mobile than Zn). Most of the Cd or Pb taken by the plant is stored in the cuticle and cell walls in insoluble form and therefore does not penetrate the plant further (Tremel-Schaub and Feix, 2005). High levels of Zn and Cu can be justified by the fact that these metals are trace elements that are naturally taken by plants. However, the process of metal phytoextraction depends on the bioavailability of the metal in the soil (Brown et al., 1995), but this bioavailability can be influenced by multiple factors (abiotic and biotic) in the contaminated environment.

Considering the bioconcentration factors, the dominant species found on the landfill cannot be considered as accumulators of the heavy metals assayed in this study. A species is known as an accumulator if its bioconcentration factor is greater than 1, which means that the concentrations measured in the plant are higher than those in the soil. The strongest factor we measured is for *Carduus australis* Pomel and is 1.04 for Zn. This result corroborates that of Hammer et al. (2003) for Zn, where the most important bioconcentration factor (1.71) was observed on *Salix viminalis* clone 78198 on soil containing 1160 mg Zn kg MS⁻¹. A positive correlation between Zn and Cd concentrations in leaves and roots has been

demonstrated suggesting a common transport of both metals. Cd is able to use Zn transporters, which are present in the plant to absorb the essential element Zn. It has been known for many years that Zn is a competitor ion of Cd (Hawf and Schmid, 1967) and that it decreases Cd uptake (Mengel and Kirkby, 2001). Cd uptake depends on the amount of Zn in the soil and plants generally absorb more Cd if the soil Zn content is low (Kirkham, 2006).

Conclusion

Awareness of poor soil health obviously leads to the question of what are the risks to public health and ecosystems in each pollution situation. Indeed, it is widely recognized that natural or anthropogenic sites contaminated by heavy metals can accommodate plant associations strictly subservient to this type of environment, original and singular, sometimes referred to as "metallic groups". The determination of heavy metals in the plants of these sites highlights the degree of transfer of metals and their bioaccessibility for humans.

In the framework of this study, measurements made at the closed industrial discharge site of the city of Bacau (Romania) showed higher or lower metal levels in the soil samples taken. Despite this polymetallic pollution, botanical surveys revealed a floristic diversity, with 20 listed plant species distributed among six botanical families. The analysis of Cr, Ni, Cu, Zn, As, Cd, Pb content in the leaves and roots of the dominant species showed higher or lower concentrations. However, bioconcentration factors are generally less than 1.

In order to be able to make the best use of the natural plant species found on the site studied, in phytoremediation programs, it is necessary to clearly characterize the tolerance and accumulation capacity of the dominant species identified on the site with respect to the different toxic elements.

Conflict of interest statement

Authors declare that there is no conflict of interest.

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