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Phytoremediation potential of wild plants collected from heavy metals contaminated soils

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Abstract: ***A field survey of wild plants growing nearby the metal industrial factories was conducted to determine the existence of native plant flora which might be useful in phytoremediation. A total of 24 plants belonging to 7 families were collected from 10 different sites. Soil and plant samples were analyzed for Cr, Cu, Ni, Pb, and Zn. Each soil exhibited a high concentration of one or more metals. Maximum Pb (328 mg kg-1) and Cu (97 mg kg-1) contents were observed in Glebionis coronaria, while the maximum Zn (180 mg kg-1) and Ni (74 mg kg-1) were obtained by Amaranthus sp. Anagallis bavaria, Amaranthus sp., Chenopodium ambrosioides, Malva parviflora, and Lactuca serriola were collected from site 05, 03, 03, 02, and 08 had highest TF values for Pb (7.9), Cu (6.3), Zn (8.3), Ni (8), and Cr (2.5), respectively. While, C. bonariensis, L. serriola, G. coronaria, C. ambrosioides, and C. bonariensis) collected from site 04, 10, 01, 03, and 09 had the highest BF values for Pb (6.2), Cu (3.2), Zn (7.8), Ni (2.2), and Cr (2.6), respectively. Therefore, these wild plant species may have the potential for bioremediation and can be used for phytoremediation of heavy metals contaminated soil.***

Keywords: heavy metals, soil, plant, phytoremediation**.**

1. Introduction

The contamination of soil with heavy metal (HM) is considered as a global environmental issue, posing significant risks to human health as well as to ecosystems (Solgi et al. 2012; Xiao et al. 2017). Heavy metals are serious pollutants due to their toxicity, persistence in natural conditions and ability to be incorporated into food chains (Wang et al. 2006; Achary et al. 2017). Environmental pollution with HM is a global disaster that is related to human activities such as mining, smelting, electroplating, energy and fuel production, power transmission, intensive agriculture, sludge dumping, and melting operations. Remediation of metal contaminated soils is particularly challenging. Unlike organic compounds, metals cannot be degraded to harmless products, but instead persist indefinitely in the environment complicating their remediation (Stephen et al. 2012). Several technologies are available to remediate soils that are contaminated by HMs (Abou-Shanab 2011). However, many of these technologies are costly (e.g. excavation of contaminated material and chemical/physical treatment) or do not achieve a long-term nor aesthetic solution (Lasat 2002; Prasad and Prasad 2012). Compared to the conventional methods, the phytoremediation, using plants to remove metal pollutants from contaminated soils, can provide a cost-effective, long-lasting, aesthetic, and technical advantages over traditional engineering techniques (Chaney et al. 2005). This technology was developed after the identification of certain plants, metal "hyperaccumulators", that are able to accumulate excessively high amounts of metals in their harvestable part which are easy to dispose (Chaney 1983; Baker et al. 2000). According to Baker et al. (2000) metal hyperaccumulator is defined as a plant that can accumulate the metal to a leaf of 0.1% of nickel, cobalt, chromium, copper, and lead, 1% of zinc and 0.01% of cadmium. Over 500 plant species comprising of 101 families have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cunouniaceae, Cyperaceae, Euphobiaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae and Violaceae (Sarma 2011). Metal hyperaccumulation occurs in about 0.2% of all angiosperms and is particularly well appear in the Brassicaceae (Kramer 2010). Many plant species have become metal tolerant due to the adaptive responses of plant species to HMs, as these species are growing in contaminated sites from a long period. According to Yoon et al. (2006), native plants should be preferred for phytoremediation because these plants are often better in terms of survival, growth, and reproduction under environmental stress than plants introduced from other environments. To make phytoremediation environmentally practical, hyperaccumulator adapted to diverse climates and soils must be discovered. Therefore this study was performed 1) to identify the plant species collected from different HM-contaminated sites; 2) to determine the concentration of HMs in plant biomass and soil and 3) to evaluate their phytoremediation ability of wild plants based on their bioaccumulation factor (BF) and translocation factor (TF).

2. Materials and Methods

Soil and plant samples were collected from sites chosen based on their industrial activities. Sampling was conducted at ten locations nearby these industrial factories (Lead Co., Site 01; Egyptian Copper Co., Site 02; Amon for Iron Steel Industry, Site 03; Sarhan factory for iron and steel, Site 04; Vectoria factory, Site 05; Makka Co. for packing and plastic systems, Site 06; Egyptian Company for Ni, Site 7; TEFANO, Site 08; UNITEL for manufacturing materials handling systems (Site 09), and Tuborco steel pipes and greenhouse Co. (Site 10) representing industrial metal contaminated sites at Alexandria, Egypt. These locations were heavily exposed to metal industrial emissions.

Five soil samples were collected from each location, generally around the roots of collected plant species. Soil samples were mixed in a large container, air-dried and sieved through a 4 mm stainless steel sieve to remove rocks and un-decomposed organic materials. Soil mechanical analysis was carried out by the pipette method according to Black et al. (1982). Soil pH and electrical conductivity (EC) were determined after mixing a soil and water (1:2) for 1 h. Organic matter was measured by the Walkley-Black titration method (Walkley and Black 1934). Total metals in soil were determined by digesting 500 mg of soil in a mixture of concentrated $HNO_3/HClO_4$ (10:7, v/v) (Huang et al. 1997) and measured using flame atomic absorption spectrophotometry (Perkin-Elmer 2380).

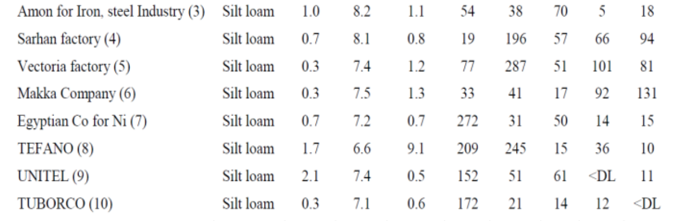
Three plants for each species were randomly collected. The collected plant species were identified according to Täkholm (1974) and Boulos (1995) using herbarium plant reference species held in the Faculty of Science, University of Alexandria (Egypt). A whole plant was excavated and divided into root and shoot and both carefully washed several times in distilled water. Washed plant material was dried at 60°C for 72h and ground to pass a 2-mm mesh sieve. Dry plant tissue (~500 mg) were digested in a mixture of $HNO_3/HClO_4$ (10:7, v/v) (Huang et al. 1997) and then brought to a constant volume with de-ionized water. Digests were analyzed for HM by flame atomic absorption spectrophotometry (Perkin-Elmer 2380).

Bioaccumulation factor (BF) is defined as the ratio of total metal concentration in shoots to that in soil (DM), which is a measure of the ability of a plant uptake and transport metals to the shoots (Caille et al. 2004). Bioaccumulation factor (BF) was determined by using the equation adopted from Rashed (2010): $BF = C_{[HM\ in\ plant]}/C_{[HM\ in\ soil]}$. The translocation factor (TF) is defined as the ratio of total metal concentration in the plants shoot to that in the roots (Zu et al. 2005): $TF = C_{[HM\ in\ shoot]}/C_{[HM\ in\ root]}$.

3. Result and discussion

The physicochemical properties of soils are presented in Table 1. Soil pH, EC, and organic matter (OM) ranged from 6.6 to 8.2, 0.5 to 9.1mS/cm and 0.34 to 2.1%, respectively. Abou-Shanab et al. (2007) reported that most of the Egyptian soil pHs were generally in the alkaline range (7.7-8.3). Soil pH is one of the most important factors controlling the conversion of metals from insoluble solid-phase to more soluble and/or bioavailable solution-phase (Chlopecka et al. 1996). Sanders 1983 reported that the solubility of metals is generally higher as pH decreases within the pH range of normal agricultural soils (approximately pH 5.0 to 7.0). The high pH values of soils could have accounted for a low transfer of metals from soil to plant. Site 3, 8 and 9 had higher pH (8.2), EC (9.1 mS/cm), and OM (2.1%) of soil, respectively than other sites. All soils were found to be silt loam in texture (Table 1).

Table 1. Physico-chemical properties of soil samples



Site	Texture	OM[a]	pH	EC[b]	Pb	Cu	Zn	Ni	Cr
				ms/cm	mg/kg dry soil				
Lead Company (1)	Silt loam	1.0	7.5	6.9	127	126	10	<DL	10
Egyptian copper Co. (2)	Silt loam	1.4	7.9	0.8	388	230	58	7	45
Amon for Iron, steel Industry (3)	Silt loam	1.0	8.2	1.1	54	38	70	5	18
Sarhan factory (4)	Silt loam	0.7	8.1	0.8	19	196	57	66	94
Vectoria factory (5)	Silt loam	0.3	7.4	1.2	77	287	51	101	81
Makka Company (6)	Silt loam	0.3	7.5	1.3	33	41	17	92	131
Egyptian Co for Ni (7)	Silt loam	0.7	7.2	0.7	272	31	50	14	15
TEFANO (8)	Silt loam	1.7	6.6	9.1	209	245	15	36	10
UNITEL (9)	Silt loam	2.1	7.4	0.5	152	51	61	<DL	11
TUBORCO (10)	Silt loam	0.3	7.1	0.6	172	21	14	12	<DL

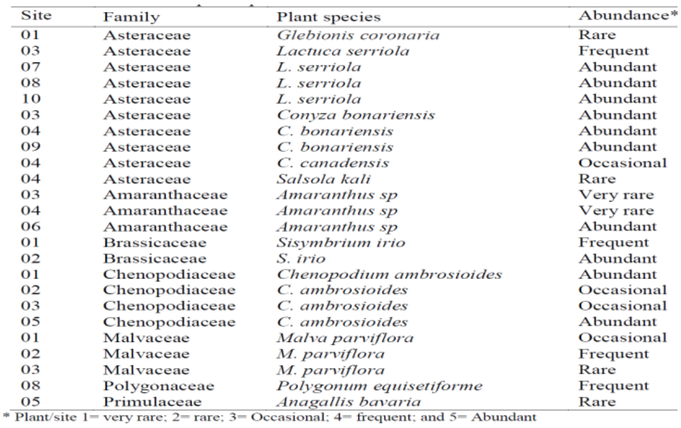
Number in parenthesis represent the site number; [a]Organic matter; [b]Electrical conductivity; DL= below detection limit

The heavy metal pollution of an agricultural ecosystem is often caused by wastewater irrigation, solid waste disposal, vehicular exhaust, fertilization, industrial activities, etc. (Cheng 2003; Khan et al. 2008; Liu et al. 2012). Among these pollution sources, industrial activities are the dominant sources of heavy metals near factories. Kabala and Singh (2001) reported that, in the vicinity of a copper smelter in Poland, the concentrations of Cu, Pb, and Zn in the surface soils were significantly higher than their concentrations in the subsurface soils. It was reported that industrial waste can lead to heavy metal pollution of the surrounding soils (Gowd et al. 2010). Total metal content is important because it determines the size of the metal pool in the soil and thus available for metal uptake (Ibekwe et al. 1995). Therefore, soil samples were analyzed for total concentration of Pb, Cu, Zn, Ni and Cr. Results showed that each site exhibited a high concentration of one or more metals. This variation in metal concentration can be attributed to the behavior of trace metals in soils that depend not only on the level of contamination, as expressed by the total content, but also on the form and origin of the metal and the properties of the soils themselves (Tessier and Campbell 1988; Chlopecka et al. 1996). The concentrations of metals vary from site to site. Such heavy metal pollution on these sites was connected with the industries. Total Pb content in soils varied between 19 and 388 mg kg^{-1} dry soil and the highest value was recorded in soil collected nearby the Egyptian Copper Co. (Site 2). Copper concentration in soils was also high and varied between 21 and 287 mg kg^{-1}dry soil. The relatively high content of Cu (287 mg kg^{-1}dry soil) was detected in soil collected from site 5. Total Cr concentrations in the soil samples collected from the sites were variable with the highest concentration (131 mg Cr kg^{-1}) detected in soil collected from site 6 compared to other sites as a result of industrial activities. The concentrations of these metals were high compared to the values generally observed in agricultural soils and considered to be toxic according to Kabata-Pendias and Pendias (2001).

The ten investigated sites had been naturally colonized by native plant species. A flora survey showed a total of 24 plant species, belonging to 11 genera and representing 7 families, inhabiting these sites (Table 2). It was observed that more than one plant species were frequently represented on different sites. Meanwhile, several plant communities composed of combinations or single dominant species were frequently recorded (Table 2).

There were great variations of metal concentrations among plant species collected from different sites. The heavy metal (Pb, Cu, Zn, Ni, and Cr) concentrations in roots and shoots of the 24 plant species were presented in Table 3. Metals uptake by plant roots from soil occurs either passively with the mass flow of water or through active transport processes of the plasma membrane of root epidermal cells (Alloway et al. 1995). Under normal growing conditions, plants can potentially accumulate certain metal ions an order of magnitude greater than the surrounding medium (Kim et al. 2003). Metal concentration in plants growing in uncontaminated soils were 0.1-10 mg Pb kg^{-1}; 4-15 mg Cu kg^{-1}; 8-400 mg Zn kg^{-1}; 0.02-5 mg Ni kg^{-1}; and 0.03-15 mg Cr kg^{-1}(Swaine 1955; Allaway 1968; Kabata- Pendias and Pendias 2001). The higher soil pHs may have played a role in the limited plant availability of heavy metals in the soil, resulting in low plant uptake of these metals (Rosselli et al. 2003).

Table 2: Abundance of plant species collected from different sites

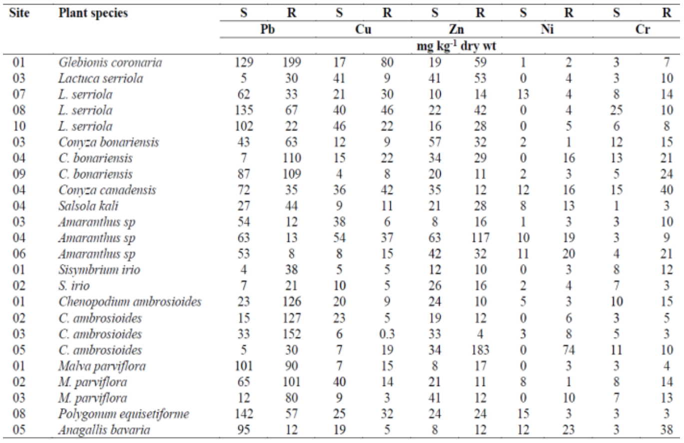


Site	Family	Plant species	Abundance*
01	Asteraceae	*Glebionis coronaria*	Rare
03	Asteraceae	*Lactuca serriola*	Frequent
07	Asteraceae	*L. serriola*	Abundant
08	Asteraceae	*L. serriola*	Abundant
10	Asteraceae	*L. serriola*	Abundant
03	Asteraceae	*Conyza bonariensis*	Abundant
04	Asteraceae	*C. bonariensis*	Abundant
09	Asteraceae	*C. bonariensis*	Abundant
04	Asteraceae	*C. canadensis*	Occasional
04	Asteraceae	*Salsola kali*	Rare
03	Amaranthaceae	*Amaranthus sp*	Very rare
04	Amaranthaceae	*Amaranthus sp*	Very rare
06	Amaranthaceae	*Amaranthus sp*	Abundant
01	Brassicaceae	*Sisymbrium irio*	Frequent
02	Brassicaceae	*S. irio*	Abundant
01	Chenopodiaceae	*Chenopodium ambrosioides*	Abundant
02	Chenopodiaceae	*C. ambrosioides*	Occasional
03	Chenopodiaceae	*C. ambrosioides*	Occasional
05	Chenopodiaceae	*C. ambrosioides*	Abundant
01	Malvaceae	*Malva parviflora*	Occasional
02	Malvaceae	*M. parviflora*	Frequent
03	Malvaceae	*M. parviflora*	Rare
08	Polygonaceae	*Polygonum equisetiforme*	Frequent
05	Primulaceae	*Anagallis bavaria*	Rare

* Plant/site 1= very rare; 2= rare; 3= Occasional; 4= frequent; and 5= Abundant

Plant hyperaccumulators are species capable of accumulating metals at levels 100-fold greater than those typically determined in shoots of non-metal hyperaccumulator plants. Thus, an accumulator will concentrate more than 10 mg/kg^{-1} Hg, 100 mg kg^{-1} Cd, 1000 mg kg^{-1} Co, Cr, Cu and Pb, 10000 mg kg^{-1} Zn, and Ni (Baker et al. 2000). Results show that Pb in collected plants was relatively high and ranged from 4 to 142 mg kg^{-1} in shoots and from 8 to 199 mg kg^{-1} in roots, with the maximum being in the shoot of *Polygonum equisetiforme* and root of *Glebionis coronaria* (Table 3). The highest Pb concentration (328 mg kg^{-1}) was detected in plant tissues of *G. coronaria* collected from soil nearby lead company (Site 01). The Pb concentrations in approximately 58% of collected plant roots were much higher than those of the shoots Pb contents, indicating low mobility of Pb from the plant roots to shoots as a result of Pb phytoestabilization in soil adhering to the plant roots. Copper content in plants was low in most species except for *G. coronarina* (80 mg kg^{-1}) root, *Amrranthus sp* (54 mg kg^{-1}) shoot, and *Lactuca serriola* (46 mg kg^{-1}) shoot were collected from Lead company (Site 01), Sarhan factory (Site 04), and TUBORCO (Site 10), respectively. Zinc contents in plant were ranged from 8 to 183 mg kg^{-1} with maximum Zn contents were detected in the roots of *Chenopodium ambrosioides* (183 mg kg^{-1}) and *Amaranthus* sp. (117 mg kg^{-1}). Nickel and Chromium contents in plants were low in most species, with maximum Ni and Cr concentration (74 and 40 mg kg^{-1}) was detected in the roots of *C. ambrosioides* and *Conyza Canadensis*, respectively. *Amaranthus* sp. had more potential to uptake and concentrate Pb and Cd from the soil in pH 6.3-6.5 with translocation factor higher than one which indicates that metal concentrations in shoots were higher than roots and this plant is suitable for phytoremediation (Ziarati and Alaedini 2014).

Table 3. Concentration of heavy metals in shoot (S) and root (R) of plant species collected from different sites



Site	Plant species	S	R	S	R	S	R	S	R	S	R
		Pb		Cu		Zn		Ni		Cr	
		mg kg^{-1} dry wt									
01	*Glebionis coronaria*	129	199	17	80	19	59	1	2	3	7
03	*Lactuca serriola*	5	30	41	9	41	53	0	4	3	10
07	*L. serriola*	62	33	21	30	10	14	13	4	8	14
08	*L. serriola*	135	67	40	46	22	42	0	4	25	10
10	*L. serriola*	102	22	46	22	16	28	0	5	6	8
03	*Conyza bonariensis*	43	63	12	9	57	32	2	1	12	15
04	*C. bonariensis*	7	110	15	22	34	29	0	16	13	21
09	*C. bonariensis*	87	109	4	8	20	11	2	3	5	24
04	*Conyza canadensis*	72	35	36	42	35	12	12	16	15	40
04	*Salsola kali*	27	44	9	11	21	28	8	13	1	3
03	*Amaranthus sp*	54	12	38	6	8	16	1	3	3	10
04	*Amaranthus sp*	63	13	54	37	63	117	10	19	3	9
06	*Amaranthus sp*	53	8	8	15	42	32	11	20	4	21
01	*Sisymbrium irio*	4	38	5	5	12	10	0	3	8	12
02	*S. irio*	7	21	10	5	26	16	2	4	7	3
01	*Chenopodium ambrosioides*	23	126	20	9	24	10	5	3	10	15
02	*C. ambrosioides*	15	127	23	5	19	12	0	6	3	5
03	*C. ambrosioides*	33	152	6	0.3	33	4	3	8	5	3
05	*C. ambrosioides*	5	30	7	19	34	183	0	74	11	10
01	*Malva parviflora*	101	90	7	15	8	17	0	3	3	4
02	*M. parviflora*	65	101	40	14	21	11	8	1	8	14
03	*M. parviflora*	12	80	9	3	41	12	0	10	7	13
08	*Polygonum equisetiforme*	142	57	25	32	24	24	15	3	3	3
05	*Anagallis bavaria*	95	12	19	5	8	12	12	23	3	38

The value of translocation factor (TF) and bioaccumulation factor (BF) > 1 had been used to assess the potential of plant species for phytoextraction and phytostabilization of metals (Yoon et al. 2006; Lorestani et al. 2011). The results indicated that TF and BF for all the tested metals by different plant species varied from one metal to another (Table 4).

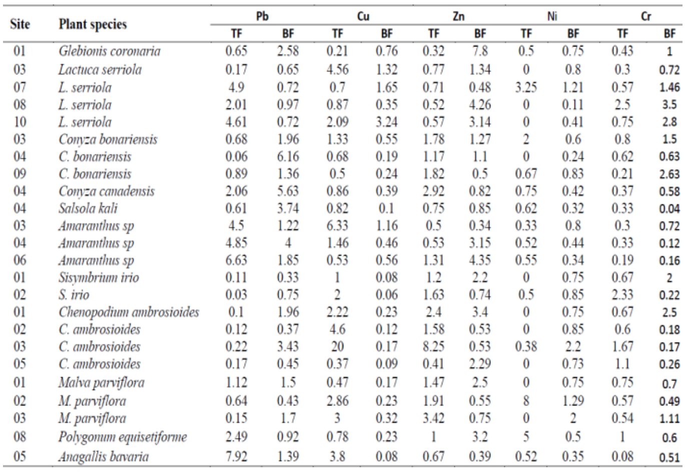
The results showed *Anagallis Bavaria*, *Amaranthus* sp., *C. ambrosioides*, *Malva parviflora*, and *L. serriola* had highest TF values for Pb (7.9), Cu (6.3), Zn (8.3), Ni (8), and Cr (2.5), respectively. High root to shoot translocation of these metals indicated that these plants have vital characteristics to be used in phytoextraction of these metals as indicated by Ghosh and Singh (2005) and La´zaro et al. (2006). Plant species with slow growth, superficial root system and little biomass production are not generally preferred for phytoremediation. These species had high biomass and based on high TF values could have enormous potential to be used for phytoextraction of Pb, Cu, Zn, Ni, and Cr than other species which also showed TF>1 for different metals. High heavy metal accumulation may be related to well develop detoxification mechanism based on retention of metal ions in vacuoles, by binding them on suitable ligands such as organic acids, proteins and peptides in the presence of enzymes that can function at greater level of metalicions (Cui et al. 2013) and metal exclusion strategies of plant species (Ghosh and Singh 2005). Plant species with greater TF values were considered good candidate for phytoextraction of metal from soils and translocate into the shoots (Yoon et al. 2006). According to Ghosh and Singh (2005) phytoextraction is a process to remove the contamination from soil without destroying soil structure and fertility. Phytostabilisation is a process which depends on roots ability to limit the heavy metals mobility and bioavailability in the soils which occurs through the sorption, precipitation, complexation or metal valance reduction (Ghosh and Singh 2005).

Heavy metals tolerant species with high BF and low TF can be used for phytostabilisation of heavy metal contaminated soils.

Plant species (such as *C. bonariensis*, *L. serriola*, *Glebionis coronaria*, *C. ambrosioides*, *C. bonariensis*) had the highest BF values for Pb (6.2), Cu (3.2), Zn (7.8), Ni (2.2), and Cr (2.6), respectively, indicating that these plant species limit metal mobility from roots to shoots once absorbed by plant roots. The elevated concentration of heavy metals in roots and low translocation in above ground parts indicated their suitability of these plant species for phytostabilisation. These species included 33%, 4%, 25%, 8%, and 33% with BCF >1 and 58%, 46%, 42%, 83%, and 79% with TF<1 for Pb, Cu, Zn, Ni, and Cr, respectively. In conclusion, the results indicated that none of these plant species were identified as hyperaccumulator because all species accumulated Pb, Cu, Zn, Ni, and Cr less than 1000 mg/kg (Baker and Brooks 1989).

Amaranthus sp., *C. ambrosioides*, and *M. parviflora* and *L. serriola* had highest TF values and could be useful for phytoextraction of Pb, Cu, Zn, and Ni, respectively. While, *C. bonariensis*, *L. serriola*, *G. coronaria*, *C. ambrosioides*, and *C. bonariensis* had the highest BF values and could be used as a best candidate for phytostabilization of Pb, Cu, Zn, Ni, and Cr, respectively.

Table 4. Translocation factor (TF) and bioaccumulation factor (BF) of different plant species collected from different sites



Site	Plant species	Pb		Cu		Zn		Ni		Cr	
		TF	BF	TF	BF	TF	BF	TF	BF	TF	BF
01	*Glebionis coronaria*	0.65	2.58	0.21	0.76	0.32	7.8	0.5	0.75	0.43	1
03	*Lactuca serriola*	0.17	0.65	4.56	1.32	0.77	1.34	0	0.8	0.3	0.72
07	*L. serriola*	4.9	0.72	0.7	1.65	0.71	0.48	3.25	1.21	0.57	1.46
08	*L. serriola*	2.01	0.97	0.87	0.35	0.52	4.26	0	0.11	2.5	3.5
10	*L. serriola*	4.61	0.72	2.09	3.24	0.57	3.14	0	0.41	0.75	2.8
03	*Conyza bonariensis*	0.68	1.96	1.33	0.55	1.78	1.27	2	0.6	0.8	1.5
04	*C. bonariensis*	0.06	6.16	0.68	0.19	1.17	1.1	0	0.24	0.62	0.63
09	*C. bonariensis*	0.89	1.36	0.5	0.24	1.82	0.5	0.67	0.83	0.21	2.63
04	*Conyza canadensis*	2.06	5.63	0.86	0.39	2.92	0.82	0.75	0.42	0.37	0.58
04	*Salsola kali*	0.61	3.74	0.82	0.1	0.75	0.85	0.62	0.32	0.33	0.04
03	*Amaranthus sp*	4.5	1.22	6.33	1.16	0.5	0.34	0.33	0.8	0.3	0.72
04	*Amaranthus sp*	4.85	4	1.46	0.46	0.53	3.15	0.52	0.44	0.33	0.12
06	*Amaranthus sp*	6.63	1.85	0.53	0.56	1.31	4.35	0.55	0.34	0.19	0.16
01	*Sisymbrium irio*	0.11	0.33	1	0.08	1.2	2.2	0	0.75	0.67	2
02	*S. irio*	0.03	0.75	2	0.06	1.63	0.74	0.5	0.85	2.33	0.22
01	*Chenopodium ambrosioides*	0.1	1.96	2.22	0.23	2.4	3.4	0	0.75	0.67	2.5
02	*C. ambrosioides*	0.12	0.37	4.6	0.12	1.58	0.53	0	0.85	0.6	0.18
03	*C. ambrosioides*	0.22	3.43	20	0.17	8.25	0.53	0.38	2.2	1.67	0.17
05	*C. ambrosioides*	0.17	0.45	0.37	0.09	0.41	2.29	0	0.73	1.1	0.26
01	*Malva parviflora*	1.12	1.5	0.47	0.17	1.47	2.5	0	0.75	0.75	0.7
02	*M. parviflora*	0.64	0.43	2.86	0.23	1.91	0.55	8	1.29	0.57	0.49
03	*M. parviflora*	0.15	1.7	3	0.32	3.42	0.75	0	2	0.54	1.11
08	*Polygonum equisetiforme*	2.49	0.92	0.78	0.23	1	3.2	5	0.5	1	0.6
05	*Anagallis bavaria*	7.92	1.39	3.8	0.08	0.67	0.39	0.52	0.35	0.08	0.51

However, based on TFs and BFs values plant species were identified in this study which has the potential for phytoremediation of heavy metal contaminated soils. This study also indicated that there is an increasing need for further research on the mechanisms whereby such plants are able to survive in contaminated soils. Furthermore, studies are needed to determine the growth performance, biomass production and metal accumulation of these species in metal contaminated soils for their better management and conservation.

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