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HYPERACCUMULATORS OF HEAVY METALS OF INDUSTRIAL AREAS OF ISLAMABAD AND RAWALPINDI

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Abstract

Contamination of heavy metals is one of the major threats to water and soil as well as human health. Phytoremediation has been used to remediate metal-contaminated sites. This study evaluated the potential of 23 plant species growing on contaminated sites in Industrial areas of the Islamabad and Rawalpindi. Plant root, shoot and the soil samples were collected and analyzed for selected metal concentration values. To evaluate the potential of plant species for phytoremediation: Bioconcentration Factor (BCF), Biological Accumulation Coefficient (BAC) and Biological Transfer Coefficient (BCF) were calculated. The concentration of Pb in soils varied from 2-29 mg/kg, Zn from 28.82-172.56 mg/ kg, Cu from 8.88-306 mg/kg, respectively. The concentration of Pb in plant shoots varied from 1.0 to 39 mg/kg, Zn from 17.25 to 194.03 mg/kg, Cu from 0.65 to 171.83 mg/kg. The concentration of Pb in roots of plant varied 1-43 mg/kg, Zn from 3.34-116.16 mg/kg, Cu from 3.35- 416.89 mg/kg. *Brachiaria raptans* and *Malvastrum coromandelianum* were found most suitable for phytostabilization of sites contaminated with Pb and Cu (BCF= 18 and 9.12). Considering the BAC values, 15 species for Pb, two species for Cu, five species for Zn possessed the characteristics of hyperaccumulator, none of the plant species was found as hyperaccumulator; however plants with high BCF (metal concentration ratio of plant root to soil) and low BTC (metal concentration ratio of plants shoots to roots) have the potential for phytostabilization and phytoextraction. The results of this study can be used for management and decontamination of soils with heavy metals using plant species having phytoremediation potential/characteristics.

Introduction

Heavy metals are currently of much environmental concern. They are harmful to humans, animals and tend to bioaccumulate in the food chain. The threat that heavy metals pose to humans is aggravated by their long term persistence in the environment.

Industrial and municipal wastes generate a great deal of particulate emissions and waste slag enriched in heavy metals that contaminate the surrounding-soil, water and air. Such effects are particularly serious and pose a severe ecological and human health risk when smelting works are located in the vicinity of urban environments. Traditionally techniques of soil remediation are costly and may cause the secondary pollution. Phytoremediation is newly evolving field of science and technology to clean up polluted soil, water or air (Meagher, 2000). It may be defined as the using of green plants to remove, destroy or sequester hazardous substances from environment. Phytoremediation can provide a cost-effective, long lasting aesthetic solution for remediation of contaminated sites (Ma *et al*., 2001). One of the strategies of phytoremediation of metal contaminated soil is phytoextraction, i.e., uptake and accumulation of metals into plant shoots, which can then be harvested and removed from the site. Another application of phytoremediation is phytostabilization where plants are used to minimize metal mobility in contaminated soils. Plant metal uptake is influenced by soil factors including pH, organic matter and cation exchange capacity as well as plant species, cultivar and age. The mobility and availability of heavy metals in soil are generally low, especially when soil is high in pH, clay and organic matter (Jung & Thornton, 1996; Rosselli *et al*., 2003).

It is important to use the native plants for phytoremediation because these plants are often better in terms of survival, growth and reproduction under environmental stress than plants introduced from the other environments. There has been a continuing interest in searching for native plants that are tolerant to heavy metals; however, studies have evaluated the phytoremediation potential of native plants under field conditions (Shu *et al*., 2002; McGrath & Zhoa, 2003).

Heavy metals can cause severe phytotoxicity and may act as powerful force for the evolution of tolerant plant populations. Therefore, it is possible to identify metal-tolerant plant species from natural vegetation in the field sites that are contaminated with various heavy metals.

Hyperaccumulators which are often found growing in polluted areas can naturally accumulate higher quantities of heavy metal in their shoots than roots. In view of the fact metal removal from soil can be greatly enhanced by the judicious selection of plant species, the knowledge about the ability of various plant species or tissues to absorb and transport metals, will provide an insight into choosing appropriate plants for phytoremediation (Deng *et al*., 2004; Zhou & Song, 2004). Furthermore, the identification of hyperaccumulators is an imperious and important task as the key to successful implementation of phytoremediation (Zhou, 2002; Zhou & Song, 2004).

The hyperaccumulators characterized at first were members of the *Brassicaceae* and *Fabaceae* families (Salt *et al*., 1998). Presently at least 45 families are known to contain metal accumulating species. To date, more than 400 plant species of metal hyperaccumulator plants have been reported in the literature (Salt *et al*., 1998). Hyperaccumulation of metals have been found in temperate as well as tropical regions throughout the plant kingdom, but is generally restricted to endemic plant species growing on mineralized soil and related rock types (Baker *et al.,* 1989). While hyperaccumulators have been used to identify mineralized rocks and ores, there is more recent interest in their potential used for decontamination for heavy metals polluted soils.

Heavy metals contamination of the soil and plants has become serious and continuous problem of the world, which has attracted a great deal of attraction from government and regulatory authorities in the past few decades to prevent further heavy metals addition and in return soil deterioration and to implement possible methods of remediation (Ahmad *et al.*, 2011).

The overall objectives of this research are: 1) to determine total concentration of heavy metals in plant biomass growing in contaminated sites; 2) to compare the metal concentration in the above ground biomass to those in roots and in the soils; 3) to identify plant species which have the potential for phytoremediation.

Material and Methods

Site description: The plants and soil samples used in this study were collected from known metal contaminated sites located in Industrial areas of Islamabad and Rawalpindi that lies between $33^{o} – 28^{/}$ and $33^{o} – 48^{/}$ north latitude and $72^{o}–48^{/}$ and $73^{o}–22^{/}$ east longitude (Fig. 1). The land is gradually rising in elevation from 480–500 meters from the sea level and slopes towards the south, mainly composed of sandy loam, loamy sand, sand clay loam and sand. The area has distinct seasons marked by wide variation in temperature. The mean maximum temperature in winter is 17.7^{o}C and mean minimum temperature is 2.6^{o}C. In summer the mean maximum temperature is near 40^{o}C and mean minimum temperature is 24^{o}C. Throughout the year, the winds blow predominantly from the north or south-east, but in summer there are short spells of wind. The area has distinct rainfall season, the summer season from July to September and the winter season from December to March.

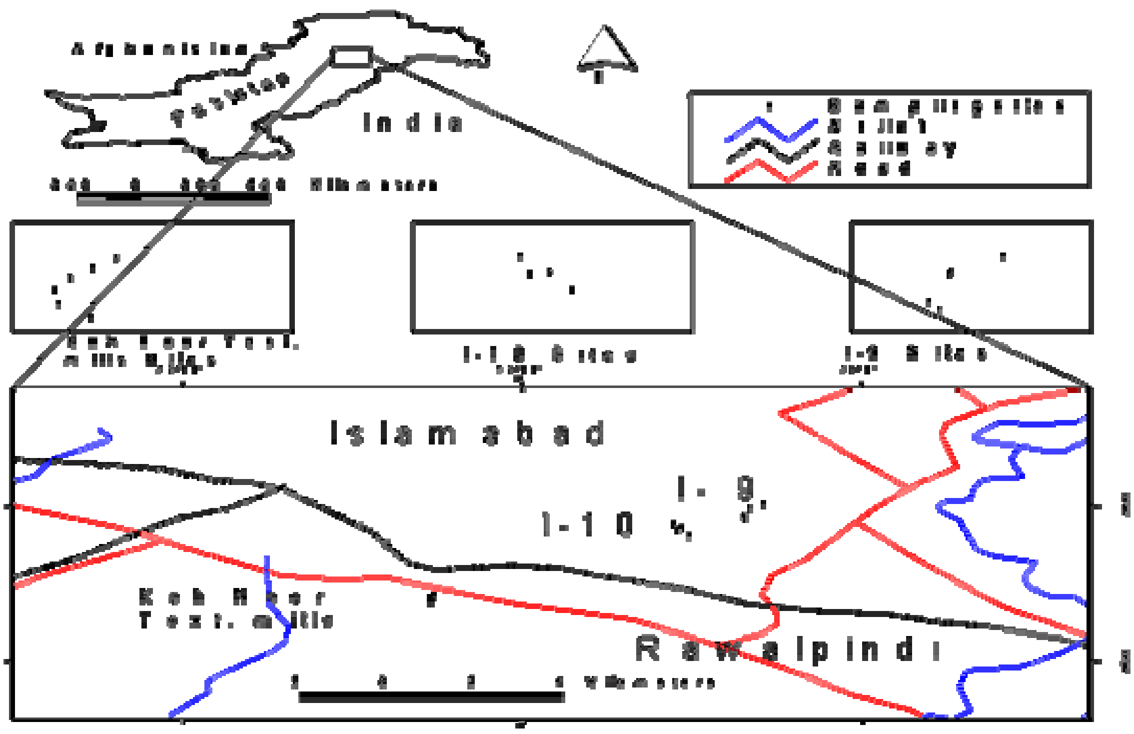

Fig. 1. Location of the study area.

Industrial Estate Islamabad (IEI) was established in 1963. It houses more than 200 industries. IEI is spread over 625 acres of land on the border of cities of Rawalpindi and Islamabad. Industries at IEI have been categorized into nine segments i.e., steel melting furnaces, re-rolling mills, flour mills, oil and ghee, marble cutting and polishing, pharmaceuticals, soap, auto body shops and recycling of lead storage batteries etc. Textile mill named Koh-i-Noor Textile Mills located in Rawalpindi along the G.T. Road. The waste water drains originating from industrial unit are disposed to natural drains within the industrial estate. The natural drains eventually lead to a single main drain in the area known as Nallah Lye. The metals discharged from these industries include Pb, Zn, Cu, Co, Ni, Cr, and Cd etc.

Sampling: Sampling was carried out between 15^{th} and 30^{th} September 2006. Twenty three plant species were collected from the 15 sites, selecting 6 from Kohi-i-Noor Textile Mills, 5 from I-9 Sector and 4 from I-10 Sector. The plants were carefully dug from the substrate and most of the bulk soil was manually removed from the roots. At least three individual plants from each species were randomly collected, mixed to form a composite whole plant sample. In total, 43 plant samples of 23 species belonging to 12 families were collected (Table 1). Plant samples were placed loosely in labeled bag and were transported to the laboratory as quickly as possible. The soil in which the plants grew were representative of the surface horizon, maximum sampling depth was about 20 cm. Prior to the analysis of plant material, shoots and roots of plants were separated and carefully washed with tap and deionized water in order to remove any surface soil or dust deposits. After washing, plant samples were air dried at room temperature for two weeks and then ground into fine powder.

Table 1. Plant species identified and used in the study.

S. #	Family	Name of species	Habit
1.	Amaranthaceae	*Amaranthus viridis* L.	Annual herb
2.	Amaranthaceae	*Alternanthera pungens* Kunth	Annual herb
3.	Amaranthaceae	*Achyranthes aspera*	Annual herb
4.	Poaceae	*Brachiaria reptans* (L.) Gardner & Hubb.	Annual grass
5.	Poaceae	*Cenchrus pennisetiformis* Hochst & Steud ex Steud	Annual grass
6.	Cannabaceae	*Cannabis sativa* L.	Perennial herb
7.	Poaceae	*Cynodon dactylon* (L.) Pers.	Perennial grass
8.	Chenopodiaceae	*Chenopodium album* L.	Annual herb
9.	Cyperaceae	*Cyperus rotundus* L.	Perennial sedge
10.	Poaceae	*Dactyloctenium aegypticum* L.	Annual grass
11.	Asteraceae	*Eclipta alba* (L.) Hassk.	Annual herb
12.	Poaceae	*Eleusine indica* (L.) Gaertn.	Annual grass
13.	Asteraceae	*Erigeron conyzanthus* L.	Annual herb
14.	Convolvolaceae	*Ipomoea hederacea* Jacq.	Annual herb
15.	Malvaceae	*Malvastrum coromandelianum* (L.)Garcke	Perennial herb
16.	Asteraceae	*Parthenium hysterophorus* L.	Annual herb
17.	Portulaceae	*Portulaca oleracea* L.	Annual herb
18.	Polygonaceae	*Persicaria barbata* (L.) Hara	Annual herb
19.	Polygonaceae	*Rumex nepalensis* Sprenge.	Annual herb
20.	Euphorbiaceae	*Ricinus communis* L.	Perennial shrub
21.	Poaceae	*Sorghum halepense* (L.) Pers.	Annual grass
22.	Solanaceae	*Solanum nigrum* L.	Annual herb
23.	Asteraceae	*Xanthium strumarium* L.	Annual shrub

Plant analysis: For metal analysis, 0.5 g of shoots along with leaves and roots sample were taken. 5 ml of nitric acid (65%) and 1 ml of perchloric acid (70-72%) was added (Wang & Zhou, 2003). The digestion was allowed to proceed in microwave digester (CEM 2000 MARS XPress) at 80 C^{o} for 15 minutes. It was cooled and transferred to 50 ml calibrated flask. The volume was raised up to the mark with distilled water (Price, 1979), digestion followed by the measurement of total concentrations of Pb, Zn, Cu using Atomic Absorption Spectrophotometer (VARIAN, AA240FS).

Soil analysis: The composite soil samples, after collecting from the field were brought to the laboratory in polythene bags. The samples were spread on the paper sheets, air dried, ground and sieved in 2 mm mesh size. Soil pH, EC and TDS were measured in a solution of 1:9 soils: water ratio with Milwaukee SM/802 smart combined meter. For measuring pH, it was calibrated with buffer solutions of pH 4, 7 and 9 while for measuring EC, it was calibrated with 1413 µS/cm at 25^{o}C/ 77^{o}F calibrating solution. Soil texture was determined by Bouyoucos hydrometer method. On the basis of percentage of sand, silt and clay, textural class of each sample was determined with the help of standard textural class triangular (Brady, 1990).

For selected heavy metals in soil samples, 0.5 g of air dried, ground and sieved soil, was digested with 5:1 v/v of nitric acid (65%) and perchloric acid (70-72%) (Wang & Zhou, 2003). The digestion was proceeded in microwave digester (CEM 2000 MARS XPress) at 220^{o}C for 30 minutes. Digested samples were cooled and volume was raised up to the 50 ml mark with distilled water, These extracts were used for total concentration of heavy metals, Pb, Zn and Cu,. Total concentration of heavy metal in soil samples were analyzed by using flame Atomic Absorption Spectrophotometer (VARIAN, AA240FS).

Biological accumulation coefficient (BAC), biological transfer coefficient (BTC) and bioconcentation factor (BCF): Biological Accumulation Coefficient was defined as the concentration of heavy metals in plant shoots divided by the heavy metal concentration in soil (Zu *et al*., 2005) and is given in equation 1.

BAC = [Metal] shoot / [Metal] soil ----------- Eq. 1

Biological Transfer Coefficient was described as the ratio of heavy metal concentration in plant shoot to that in plant root (Zu *et al*., 2005) and is given in equation 2.

BTC = [Metal] shoot / [Metal] root ----------- Eq. 2

Bioconcentation Factor was calculated as ratio of concentration of heavy metal in plant roots to that of soil (Yoon *et al*., 2006) and is given in equation 3.

BCF = [Metal] root / [Metal] soil -----------Eq. 3

Results

The soil and plant samples collected from 15 sites were analyzed for their metal contents. It appears that metal concentration in different samples varies to a great extent from sample to sample.

The concentration of lead (Pb) varied from site to site and minimum concentration of Pb was found 2 mg kg $^{-1}$at I – 9 sector (site 10) and maximum concentration of Pb was found 29 mg kg $^{-1}$ at site 2 on G.T. Road (near Kohi-i-Noor Textile Mills). In soil samples minimum total concentration of Zn was 28.82 mg kg $^{-1}$at I-10 Sector (site 12) and maximum concentration was 172.56 mg kg^{-1}near Kohi-i-Noor Textile Mills (site 4). The total concentration of Cu was maximum (357.39 mg kg $^{-1}$) in samples collected near Kohi-i-Noor Textile Mills, site 2 and the minimum (8.88 mg kg $^{-1}$) at site 3.

Pb concentrations in plant species is presented in Table 2. The lowest and highest Pb concentrations in shoots were found in *R. communis* (5 mg kg^{-1}) and *P. oleraceae* (51 mg kg^{-1}) respectively. *P. oleraceae*, *C. dactylon* and *A. pungens* contained higher Pb concentration in shoots. The lowest and highest Pb concentration in roots (1 mg kg $^{-1}$) was found in *P. hysterophorus*, *C. dactylon* and (56 mg kg $^{-1}$) *D. aegypticum* respectively (Table 2). *P.hysterophorus* from another site and *A. viridis* also contained higher concentrations of Pb. The Cu concentration in plant shoots varied from 0.65 mg kg^{-1} in *A. viridis* to 171.83 mg kg $^{-1}$ in *P. oleraceae* (Table 3). *P. barbatum* and *P. hysterphorus* also has higher concentration in its shoots. The highest and lowest concentration in roots was 416.89 mg kg $^{-1}$in *C. pennisetiformis and* 2.35 mg kg $^{-1}$ in *A. viridis* respectively (Table 3). *P. oleraceae* also has higher concentration in roots. The range of Zn concentration in shoots of plants varied from 17.25 mg kg^{-1} in *M. coromandialinum* to 194.03 mg kg $^{-1}$ in *X.strumarium* (Table 4). *B. reptans* also has higher concentration (135.34 mg kg $^{-1}$) in its shoots. The concentration in roots varied from 3.34 mg kg $^{-1}$ in *A. aspera* to 135.13 mg kg $^{-1}$ in *B. reptans. S. nigrum* (134.43 mg kg $^{-1}$), *E. indica* (117.86 mg kg $^{-1}$) and *C. dactylon* (116.16 mg kg $^{-1}$) also accumulated higher concentration in their roots.

Table 2. Lead concentration in soil and plant samples (mg kg $^{-1}$) from industrial areas of Rawalpindi and Islamabad.

Scientific name	Site #	Roots	Shoots	Soil
Amaranthus viridis L.	1	43	15	21
	2	8	39	29
	13	5	16	15
	7	28	33	10
Alternanthera pungens Kunth.	5	19	39	19
Achyranthes aspera L.	6	30	9	28
Brachiaria reptans (L.) Gardner & Hubb.	10	37	28	2
Cenchrus pennisetiformis Hochst. and Steud.ex Steud.	1	23	28	21
	2	38	16	29
Cannabis sativa L.	1	29	30	21
Cynodon dactylon (L.) Pers.	2	1	1	29
	4	18	41	9
Chenopodium album L.	2	32	32	29
Cyperus rotundus L.	14	33	20	13
Dactyloctenium aegypticum L.	1	29	20	21
	8	56	29	20
Eclipta alba (L.) Hassk.	11	20	10	5
Eleusine indica (L.) Gaertn.	14	42	18	13
Erigeron conyzanthus L.	15	8	18	8
Ipomoea hederacea Jacq.	3	9	15	12
Malvastrum coromandelianum (L.) Garcke	1	37	16	21
	2	32	27	29
	3	9	28	12
Parthenium hysterophorus L.	1	13	36	21
	2	1	23	29
	4	5	20	9
	9	48	43	7
Portulaca oleracea L.	2	10	11	29
	3	8	19	12
	7	12	28	10
	13	16	51	15
Persicaria barbata (L.) Hara	8	31	38	20
	9	38	32	7
	12	27	20	21
Rumex nepalensis Sprenge.	15	33	27	8
Ricinus communis L.	2	19	20	29
	4	21	5	9
	12	8	29	21
	15	3	29	8
Sorghum halepense (L.) Pers.	5	16	25	19

Solanum nigrum L.	3	20	11	12
Xanthium strumarium L.	3	8	21	12
	11	9	27	5

Table 3. Copper concentration in soil and plant samples (mg kg $^{-1}$) from industrial areas of Rawalpindi and Islamabad.

Scientific name	Site #	Roots	Shoots	Soil
Amaranthus viridis L.	1	18.51	13.38	306.27
	2	45.19	8.94	357.39
	13	2.35	0.65	12.93
	7	14.8	9.68	34.1
Alternanthera pungens Kunth.	5	52.12	6.7	75.13
Achyranthes aspera L.	6	10.28	6.66	92.57
Brachiaria reptans (L.) Gardner & Hubb.	10	40.19	8.57	30.42
Cenchrus pennisetiformis Hochst. &Steud.ex Steud.	1	41.76	11.83	306.27
	2	416.89	64.07	357.39
Cannabis sativa L.	1	29.01	18.19	306.27
Cynodon dactylon (L.) Pers.	2	84.05	49.93	357.39
	4	159.41	8.3	223.83
Chenopodium album L.	2	13.87	5.11	357.39
Cyperus rotundus L.	14	23.56	3.39	23.16
Dactyloctenium aegypticum L.	1	7.51	6.7	306.27
	8	32.03	14.61	18.7
Eclipta alba (L.) Hassk.	11	44.23	27.31	50.5
Eleusine indica (L.) Gaertn.	14	37.87	12.89	23.16
Erigeron conyzanthus L.	15	32.91	8.16	22.87
Ipomoea hederacea Jacq.	3	19.78	17.02	8.88
Malvastrum coromandelianum(L.) Garcke	1	23.19	13.58	306.27
	2	23.19	16.09	357.39
	3	80.99	21.01	8.88
Parthenium hysterophorus L.	1	59.34	111.58	306.27
	2	59.34	38.53	357.39
	4	93.17	18.06	223.83
	9	29.23	15.31	17.42
Portulaca oleracea L.	2	190.65	171.83	357.39
	3	225.65	35.52	8.88
	7	265.98	9.96	34.1
	13	6.99	9.06	12.93
Persicaria barbata (L.) Hara	8	29.17	159.04	18.7
	9	15.09	16.59	17.42
	12	18.79	9.2	10.98
Rumex nepalensis Sprenge.	15	3.35	7.68	22.87
Ricinus communis L.	2	171.66	15.67	357.39
	4	15.34	4.94	223.83
	12	11.27	1.74	10.98
	15	8.1	7.27	22.87
Sorghum halepense (L.) Pers.	5	16.67	1.57	75.13
Solanum nigrum L.	3	131.26	22.42	8.88
Xanthium strumarium L.	3	126.3	15.38	8.88
	11	18.75	9.45	50.5

The BAC values for all plant species are given in Table 5. Among 43 plant species screened, BAC for Pb for number of plant samples were greater than 1, *B. reptans* had the highest BAC for Pb (BAC = 14) and the lowest was 0.03 in *C. dactylon*. BAC values for Cu of only two samples were greater than 1, maximum was 1.91 in *I. hyderacea* and minimum was 0.01 in *C. album*. The highest BAC for Zn was 2.18 in *B. reptans* while lowest was 0.38 in *A. pungens*.

About 23 plant samples, BTC for Pb varied from 0.30 in *A. aspera* to 2.76 in *P. hysterophorus*. BTC values of *A. pungens, C. pennisetiformis, C. sativa, E. conyzanthus, I. hyderacea, P. oleraceae* and *P. barbratum* were higher than 1. The range of BTC for Cu in plant samples were from 0.09 in *R. communis* and *S. halepense* to 2.29 in *R. nepalensis*. BTC values of *P. barbatum* and *P. hysterophorus* were higher than 1. BTC values for Zn ranged from 0.37 in *S. nigrum* to 8.23 in *A. aspera*. BTC values of eight species were greater than 1.

The highest BCF for Pb (18.5) was found in *B. repens* while *P. hysterophorus* had the lowest BCF (0.61) for Pb. Though its total Pb concentration was <1000 mg kg $^{-1}$ (Table 5). Though several plant species showed BCF greater than one for Cu. *S. nirgum* had the highest BCF for Cu (14.78) while *A. aspera* had the lowest BCF for Cu i.e., 0.11 (Table 5). The range of BCF for Zn i.e., 0.04 to 2.18 for *A. aspera* and *B. repens* respectively (Table 5). The most of species had BCF lower than one for Zn.

Table 4. Zinc concentration in soil and plant samples (mg kg $^{-1}$) from industrial areas of Rawalpindi and Islamabad.

Scientific name	Site #	Roots	Shoots	Soil
Amaranthus viridis L.	1	29.21	50.09	125.08
	2	39.71	63.2	118.55
	13	20.67	30.94	39.96
	7	43.8	43.44	41.17
Alternanthera pungens Kunth.	5	68.77	33	86
Achyranthes aspera L.	6	3.34	27.51	76.66
Brachiaria reptans (L.) Gardner & Hubb.	10	135.13	135.34	61.93
Cenchrus pennisetiformis Hochst. & Steud.ex Steud.	1	90.51	54.83	125.08
	2	113.68	95.78	118.55
Cannabis sativa L.	1	27	43.9	125.08
Cynodon dactylon (L.) Pers.	2	116.16	76.08	118.55
	4	52.21	35.45	172.56
Chenopodium album L.	2	24.93	33.5	118.55
Cyperus rotundus L.	14	73.28	36.28	62.09
Dactyloctenium aegypticum L.	1	112.2	93.15	125.08
	8	6.08	60.74	61.18
Eclipta alba (L.) Hassk.	11	67.4	84.93	81.27
Eleusine indica (L.) Gaertn.	14	117.86	74.66	62.09
Erigeron conyzanthus L.	15	25.22	33.85	60.64
Ipomoea hederacea Jacq.	3	61.4	39.61	137.92
Malvastrum coromandelianum (L.) Garcke	1	18.46	17.25	125.08
	2	45.76	38.48	118.55
	3	45.84	36.91	137.92
Parthenium hysterophorus L.	1	29.21	70.93	125.08
	2	21.25	34.57	118.55
	4	25.66	24.14	172.56
	9	33.96	50.14	47.04
Portulaca oleracea L.	2	26.53	26.53	118.55
	3	28.59	28.59	137.92
	7	25.36	25.36	41.17
	13	27.65	59.29	39.96
Persicaria barbata (L.) Hara	8	108.81	65.73	61.18
	9	21.89	38.56	47.04
	12	49.44	65.74	28.82
Rumex nepalensis Sprenge.	15	31.02	67.64	60.64
Ricinus communis L.	2	109.77	47.94	118.55
	4	35.55	32.71	172.56
	12	44.58	52.37	28.82
	15	46.01	60.36	60.64
Sorghum halepense (L.) Pers.	5	55.26	46.69	86
Solanum nigrum L.	3	134.43	50.59	137.92
Xanthium strumarium L.	3	66.22	28.25	137.92
	11	35.22	194.03	81.27

Discussion

The present study was planned to assess the status of metal contamination in industrial areas of Islamabad and Rawalpindi. The overall situation of metal pollution in different industrial areas indicated that water channels running through these sites are used for disposal of effluents from industries and urban activities. The study area was predominantly contaminated with Cu and Zn. It also showed elevated concentrations of Pb. The maximum concentration of Cu (357.39 mg kg $^{-1}$) at site 2, Zn (137.92 mg kg $^{-1}$) was found in the soil of site 1. Maximum concentration of Pb (29 mg kg $^{-1}$) was recorded at site 3. The results indicated that plants species differ greatly in their capacity of heavy metal accumulation in roots and shoots. The concentration of Pb varied greatly in roots and above ground parts. Out of 43 plant species, 24 plant species have concentration greater in shoots than roots. Total Pb concentrations in the plants ranged from 1 mg kg $^{-1}$ to as high as 56 mg kg $^{-1}$ in the roots of *D. aegypticum* at site 8 (Table 2). In addition, roots of *P. hyesterophorus*, *A. viridis*, *E. indica* and *C.*

pennisetiformis also contained significant amount of Pb (38-48 mg kg $^{-1}$). None of the plant species accumulated Pb above 1000 mg kg $^{-1}$ in the shoots, the criteria for a hyperaccumulator as given by Baker & Brooks (1989). The greater concentration of Pb in shoots was found in *P. oleracea* (51 mg kg $^{-1}$) from site 13 (Table 2). In 55 % of the plant samples, the Pb concentrations in shoot were greater than those in roots, indicating high mobility of Pb from roots to the shoots and mobilization of heavy metals in roots.

Table 5. The biological accumulating coefficient (BAC), biological transfer coefficient (BTC) and bioconcentration factor (BCF) in selected plants.

Species	Pb			Cu			Zn		
	BAC	**BTC**	**BCF**	**BAC**	**BTC**	**BCF**	**BAC**	**BTC**	**BCF**
Amaranthus viridis	0.71	0.34	2.04	0.04	0.72	0.43	0.40	**1.71**	0.51
Alternanthera pungens	**2.05**	**2.05**	1.00	0.08	0.12	0.69	0.38	0.47	0.79
Achyranthes aspera	0.32	0.30	**1.07**	0.07	0.64	0.11	0.35	8.23	0.04
Brachiaria reptans	**14.0**	0.75	**18.5**	0.28	0.21	**1.32**	**2.18**	1.00	2.08
Cenchrus pennisetiformis	**1.33**	**1.21**	**1.09**	0.03	0.28	0.13	0.43	0.60	0.72
Cannabis sativa	**1.42**	**1.03**	**1.38**	0.05	0.62	0.09	0.35	**1.62**	0.21
Cynodon dactylon	0.03	1.00	2.00	0.13	0.59	0.71	0.64	0.65	0.97
Chenopodium album	**1.10**	1.00	**1.10**	**0.01**	0.36	0.03	0.28	**1.34**	0.21
Cyperus rotundus	**1.53**	0.60	2.53	0.14	0.14	**1.01**	0.58	0.49	1.18
Dactyloctenium aegypticum	0.95	0.68	**1.38**	0.02	0.89	**1.71**	0.74	0.83	0.89
Eclipta alba	**2.00**	0.50	**4.00**	0.54	0.61	0.87	0.74	**1.26**	0.82
Eleusine indica	**1.38**	0.42	**3.23**	0.55	0.34	**1.63**	**1.20**	0.63	**1.89**
Erigeron conyzanthus	**2.25**	**2.25**	1.00	0.35	0.24	**1.43**	0.55	**1.34**	0.41
Ipomoea hederacea	**1.25**	**1.66**	0.75	**1.91**	0.86	**2.22**	0.28	0.64	0.44
Malvestrum coromandelianum	0.76	0.43	0.75	0.04	0.58	**9.12**	0.13	0.93	0.14
Parthenium hysterophorus	**1.71**	**2.76**	0.61	0.36	**1.88**	**1.67**	0.56	**2.42**	0.23
Partulaca oleracea	0.37	**1.10**	0.66	0.48	0.90	0.54	0.22	1.00	0.69
Persicaria barbata	**1.9**	**1.22**	**1.28**	0.95	**1.09**	0.86	**1.07**	0.6	0.46
Rumex nepalensis	**3.37**	0.81	**4.12**	0.33	**2.29**	0.14	**1.11**	**2.18**	0.51
Ricinus communis	0.68	**1.05**	0.65	0.06	0.09	**1.02**	0.40	0.43	0.92
Sorghum halepsnse	**1.31**	**1.56**	0.84	0.02	0.09	0.22	0.54	0.48	0.64
Solanum nigrum	0.91	0.55	**1.66**	**2.54**	0.17	**14.78**	0.36	0.37	0.97
Xanthium strumarium	**1.75**	**2.62**	0.66	**1.73**	**1.02**	0.37	0.20	0.42	0.48

Cu is an essential element to plant growth but can cause toxic effects when shoots or leaves accumulate Cu more than 20 mg kg $^{-1}$ (Borkert *et al.*, 1998). Cu concentrations in the plants ranged from 1.74 mg kg $^{-1}$ to 265.98 mg kg^{-1}, with maximum being in the roots of *P. oleracea* from site 7. In 88% of the plant samples, the root Cu concentrations were greater than those of shoot Cu concentrations, indicating low mobility of Cu from the roots to the shoots and immobilization of heavy metal in roots. Cu concentrations of 6.4-160 mg kg $^{-1}$ in the plant biomass were reported by Stoltz & Greger (2002). Shu *et al*., (2002) reported Cu concentrations from 7-198 mg kg $^{-1}$ in the plant biomass of *Paspalum distichum* and *C. dactylon*.

Zn is an essential element to all plants. Plants predominantly absorb Zn as a divalent cation, which acts either as a metal component or enzymes or as a functional, structural or regulatory co-factor of many enzymes (Alloway, 1990). Like Pb, the maximum values (194.03 mg kg $^{-1}$) for Zn were again found in the shoots of *X. strumarium* from site 11, also the shoots of *B. repens* contained higher amount (135.34 mg kg $^{-1}$) of Zn in its shoots and no plant species accumulated Zn above 1000 mg kg $^{-1}$, this indicates the high mobility of Zn from roots to that of shoots. There are 5 plant species that accumulated high amount of Zn in their roots, among them 3 were grasses.

The standard for hyperaccumulator has not been defined scientifically. In the present study the standard is described as four rules i.e., the concentration of heavy metals in plant shoots reach hyperaccumulating level (Pb and Cu > 1000 mg/kg, Zn > 10,000 mg/kg) (Baker *et al.*, 1994; Brown *et al.*, 1994 and Wei *et al*., 2002; Kakar *et al.*, 2011), the concentration of heavy metals in its above ground part is 10-500 times more than in plants from non polluted environments (Concentration: Pb 5 mg/kg, Zn 100 mg/kg, Cu 10 mg/kg) (Shen & Liu, 1998), the metal concentrations in shoots are invariably greater than that in roots and enrichment coefficient > 1, showing a special ability of the plant to absorb from soils and transport metals and store in their above-ground parts (Baker *et al*., 1989; Baker *et al*., 1994; Brown *et al*., 1994; Wei *et al*., 2002). It is difficult to judge whether a plant species is hyperaccumulator or not if the plant species do not accord with above four rules simultaneously. So, define and use of a scientific standard for hyperaccumulator will be very necessary for hyperaccumulator choice and phytoremediation of soil polluted by heavy metals.

In this study, none of the plant species showed metal concentrations>1000 mg/kg in shoots, i.e., none of them are hyperaccumulators (Baker & Brooks, 1989). However, the ability of these plants to tolerate and accumulate heavy metals may be useful for phytostabilization. BAC, BTC and BCF can be used to estimate a potential for phytoremediation purposes. Considering BAC, out of 23 plant species, 15 plant species such as *A. pungens, B. repens , C. pennisetiformis, C. sativa, C. album, C. rotundus, E.alba,, E. indica, E. conyzanthus, I. hederacea, P. hysterophorus, R.. nepalensis, S. halepense* and *X. strumarium* for Pb, three species such as *I. hederacea, S.*

nigrum, and *X. strumarium* for Cu, four species such as *B. raptans, E. indica, P. hysterophorus,* and *R. nepalensis* for Zn may possess the characteristic of hyperaccumulator. Biological accumulation occurs when a contaminant taken up by a plant is not degraded rapidly, resulting in the accumulation in the plant. The process of phytoextraction generally requires the translocation of heavy metals to easily harvestable plant parts i.e., shoots (Khan *et al.*, 2010, 2011).

Considering the BTC values, 11 species (*A. pungens*, *C. pennisetiformis*, *C. sativa, E. conyzanthus*, *I. hederacea*, *P. hysterophorus*, *P. oleracea*, *P. barbata*, *R. communis*, *S. halepense* and *X. strumarium*) for Pb, 2 species (*P. hysterophorus* and *Rumex nepalensis*) for Cu, 8 species (*A. viridis, A. aspera, C. sativa, C. album, E. elba, E. conyzanthus*, *P. hysterophorus* and *R.. nepalensis*) for Zn (Table 5) have values greater than 1. These species possessed the characteristic of hyperaccumulator.

The BCF of Pb in this study was lower than that found by Kim *et al.*, (2003) in *P.redundent* (BCF= 58) and higher than those (BCF=0.004-0.45) reported by Stoltz & Greger, (2002). Shu *et al.*, (2002) reported a BCF of 0.1 for Pb in *P. distichum*. Similar to Pb, no plant species accumulated Cu above 1000 mg kg $^{-1}$ (Table 3). BCF values of 14 species such as *R.. nepalensis*, *A. asper, B. raptans, C. pennisetiformis, C. sativa, C. dactylon, C. album, C. rotundus, D. aegypticum, E. alba, E. indica*, *P. barbata, R. nepalensis* and *S. nigrum* for Pb, 10 species such as *B. rapens*, *C. rotundus*, *D. aegypticum*, *E. indica*, *E. conyzanthus*, *I. hederacea, M. coromandelianum*, *P. hysterophorus*, *R. communis* and *S. nigrum* for Cu, 3 species such as *B. Repens*, *C. rotundus* and *E. indica* for Zn are greater than 1 (Table 5). Plants exhibiting BTC particularly BCF value less than one are unsuitable for phytoextraction (Fitz & Wenzel, 2002). A few species growing at the sites were capable of accumulating heavy metals in the roots and shoots, but most of them had low BAC, BTC and BCF values, which means limited ability of heavy metal accumulation and translocation by the plants.

This study was conducted to screen plants growing on contaminated areas of Industrial state of Islamabad and Rawalpindi to determine their potential for metal accumulation. Only species with BCFs, BACs and BTCs greater than one have the potential for remediation processes (Table 6). Among 43 plant samples of 23 plant species screened. None of them were identified as metal hyperaccumulator. However, several plants had BCFs, BACs or BTCS greater than 1. *B. Reptans, C. sativa, P. hyesterophorous* and *P. barbatum were* most effective in taking up metals. These plant species were considered suitable for growing in industrially polluted regions, as they accumulate considerable quantities of heavy metals from the soil with their root system and can be used as potential plant species for cleaning heavy metals. Phytoremediation potential of these plant species especially needs to be investigated. In order to reduce the present trend of soil contamination, it is suggested that the industries should follow the environmental regulations particularly waste treatment prior to discharge in the environment.

Table 6. Selected properties of soil samples from the contaminated sites at Rawalpindi and Islamabad.

Site #	Soil pH	Soil texture	Total Pb (mg kg $^{-1}$)	Total Zn (mg kg $^{-1}$)	Total Cu (mg kg $^{-1}$)
1.	8.4	Sandy loam	21	125.08	306.27
2.	8.5	Loamy sand	29	118.55	357.39
3.	8.6	Sandy clay loam	12	137.92	8.88
4.	8.3	Sandy clay loam	09	172.56	223.83
5.	8.3	Sandy loam	19	86.00	75.13
6.	8.9	Sandy loam	28	76.66	92.57
7.	8.2	Sandy clay loam	10	41.17	34.1
8.	8.1	Loamy sand	20	61.18	18.7
9.	7.5	Loamy sand	07	47.04	17.42
10.	8.3	Loamy sand	02	61.93	30.42
11.	8.0	Sandy loam	05	81.27	50.5
12.	7.7	Sand	21	28.82	10.98
13.	8.2	Sand	15	39.86	12.93
14.	7.8	Loamy sand	13	62.09	23.16
15.	8.6	Loamy sand	08	60.64	22.87

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