Environmental Science and Pollution Research (2021) 28:2426–2442
https://doi.org/10.1007/s11356-020-10454-3

RESEARCH ARTICLE

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Bioaccumulation potential of indigenous plants for heavy metal phytoremediation in rural areas of Shaheed Bhagat Singh Nagar, Punjab (India)

Jagdeep Kaur Parihar[1] · Pardeep Kaur Parihar[1] · Yogesh B. Pakade[2] · Jatinder Kaur Katnoria[1]

Received: 3 September 2019 / Accepted: 10 August 2020 / Published online: 4 September 2020

Abstract

The present study was planned to explore the bioaccumulation potential of 23 plant species via bioaccumulation factor (BA*f*), metal accumulation index (MAI), translocation potential (T*f*), and comprehensive bioconcentration index (CBCI) for seven heavy metals (cadmium, chromium, cobalt, copper, iron, manganese, and zinc). The studied plants, in the vicinity of ponds at Sahlon: site 1, Chahal Khurd: site 2, and Karnana: site 3 in Shaheed Bhagat Singh Nagar, Punjab (India), were *Ageratum conyzoides* (L.) L., *Amaranthus spinosus* L., *Amaranthus viridis* L., *Brassica napus* L., *Cannabis sativa* L., *Dalbergia sissoo* DC., *Duranta repens* L., *Dysphania ambrosioides* (L.) Mosyakin & Clemants, *Ficus infectoria* Roxb., *Ficus palmata* Forssk., *Ficus religiosa* L., *Ipomoea carnea* Jacq., *Medicago polymorpha* L., *Melia azedarach* L., *Morus indica* L., *Malva rotundifolia* L., *Panicum virgatum* L., *Parthenium hysterophorus* L., *Dolichos lablab* L., *Ricinus communis* L., *Rumex dentatus* L., *Senna occidentalis* (L.) Link, and *Solanum nigrum* L. BA*f* and T*f* values showed high inter-site deviations for studied metals. MAI values were found to be more substantial in shoots as compared with that of roots of plants. Maximum CBCI values were observed for *M. azedarach* (0.626), *M. indica* (0.572), *D. sissoo* (0.497), and *R. communis* (0.474) for site 1; *F. infectoria* (0.629), *R. communis* (0.541), *D. sissoo* (0.483), *F. palmata* (0.457), and *D. repens* (0.448) for site 2; *D. sissoo* (0.681), *F. religiosa* (0.447), and *R. communis* (0.429) for site 3. Although, high bioaccumulation of individual metals was observed in herbs like *C. sativa*, *M. polymorpha*, and *Amaranthus* spp., cumulatively, trees were found to be the better bioaccumulators of heavy metals.

Keywords Bioaccumulation factor · Comprehensive bioconcentration index · Heavy metal · Metal accumulation index · Phytoremediation · Translocation factor

Introduction

Unsustainable and unorganized developments with rapid pace in rural areas have created substantial pressure on rural environments. Soil, water, and air compositions are dominated steadily by emissions from vehicles, domestic fuel combustion, and unplanned agricultural practices. Apart from these, poor management of water resources and solid waste significantly raised the level of heavy metals in rural areas (Balakrishnan et al. 2011; Ludwig et al. 2003). The degrading condition of environmental health in rural areas has been overlooked for years. Punjab, a state with rural region above 90% of its total geographical area, is known as the "Granary of India" with agriculture as the main occupation of its economy. As agricultural sector has been mainly focused on the practices for commercial farming, there is excessive use of chemicals like pesticides (herbicides, insecticides, weedicides) and inorganic fertilizers, thereby increasing the heavy metal load in the agricultural soils (Khan et al. 2018). Ponds receive wastewater that contains detergents, sewage and sullage, agricultural runoff, and dung-laden water from animal sheds (Vashisht 2008). Owing to the eutrophication, ponds lose the ability to clean up the polluted water at a very rapid rate and readily accumulate great quantities of pollutants. Hence, both soil and water ecosystems of rural regions in Punjab are exposed to a wide range of heavy metals,

Responsible editor: Elena Maestri

✉ Jatinder Kaur Katnoria
jkatnoria824@yahoo.com; jkat08@yahoo.com

[1] Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar 143005, India

[2] CSIR-National Environmental Engineering Research Institute, Nagpur, India

threatening the lives of plants, animals, and human beings. Metals like Cr, Co, Cu, Mn, Fe, and Zn are designated as essential micronutrients for growth and survival of plants while other metals such as As, Cd, Hg, and Pb are harmful even at very low concentrations of exposure (Showqi et al. 2018). The ultimate threat from these harmful metals lies in direct DNA damage via genomic mutations induced by oxidative stress, posing the carcinogenic risk to human beings (Katnoria et al. 2011; Robin and Vig 2015).

In the ecosystem, plants serve as an important component to control or eradicate various pollutants such as heavy metals via bioaccumulation of contaminants in their tissues and act as living filters (Hu et al. 2014; Shannigrahi et al. 2004). Plants, through the phytoremediation process, give a cost-effective approach with minimal environmental safety concerns than other physical or chemical processes for remediation of polluted areas (Lone et al. 2008). However, very limited information is available about the plant species with the heavy metal phytoremediation ability, especially in rural Punjab. Hence, the present study was conducted in rural areas by selecting three villages viz., Sahlon, Chahal Khurd, and Karnana in Shaheed Bhagat Singh Nagar district, Punjab (India). The selection was based on the adjacent land-use practices that depicted the scenario of pollution factors in rural environments. The objective of the present work was to assess the concentration of certain heavy metals (Cd, Cr, Co, Cu, Fe, Mn, and Zn) in the soil, water, sediment, and indigenous plants with an exploration of the plant species capable of accumulating particular heavy metal via bioaccumulation factor (BA*f*). The work plan also included the analysis of metal(s) mobility from roots to shoots by evaluating translocation factor (T*f*) along with the assessment of total accumulation capability of metal(s) for selected plant species using metal accumulation index (MAI) and comprehensive bioconcentration index (CBCI).

Materials and Methods

Site description

Three village ponds viz., Sahlon (latitude 31° 6′ 0.0792″ N, longitude 76° 2′ 8.0318″ E), Chahal Khurd (latitude 31° 7′ 18.0599″ N, longitude 76° 1′ 41.9207″ E) and Karnana (latitude 31° 8′ 15.7492″ N, longitude 76° 0′ 52.3051″ E) of Shaheed Bhagat Singh Nagar district, Punjab (India) were selected for the present study. The ponds were surrounded by terrestrial plant species of different families growing under the same natural conditions. The selection was based on the adjacent land-use practices. The ponds were adjacent to the residential area, a cluster of brick kilns, agricultural fields, road traffic, and vehicle maintenance workshops. The annual rainfall of the district is 924 cm and an average 36 rainy days in a year with the maximum relative humidity of 30% or less.

Collection of soil and sediment samples

Soil samples were collected in three batches around the surveyed plant species. Each sample was collected up to the depth of 20 cm in triplicate and homogenized to form a single composite batch. As the ultimate fate of heavy metals from the water body is either accumulation in the sediments or outflow of metal contaminants to nearby soils, the study was also planned further to estimate the content of heavy metals in sediment samples of all the ponds. Sediment samples were collected in three batches. Samples from 4–5 locations alongside the littoral zone were pooled together to constitute a single composite batch sample for each pond. Both soil and sediment samples were collected in clean polythene bags and were brought to the laboratory. The samples were dried at 50 °C for 48 h. After drying, the samples were mechanically grounded. Furthermore, the grounded material was passed through the sieve of 150-μm mesh size to get homogenized soil and sediment samples for further analysis.

Collection of water samples

As the ponds were receiving the untreated domestic effluents on a daily basis and such polluted water bodies act as a source of pollutants to the soil ecosystem, the study was further planned to estimate the heavy metal contents in the pond water samples. The water samples were collected from 4–5 different points out of each pond which represented the composite sample of a particular pond. Water samples were collected in clean polypropylene bottles from three village ponds of Shaheed Bhagat Singh Nagar, Punjab, India. Each sample was preserved for heavy metal analysis by acidification ($pH < 2$) with concentrated HNO_3 (American Public Health Association (APHA), Eaton, A.D., Water Environment Federation (WEF), American Water Works Association (AWWA) 2005). All the samples were stored at 4 °C until further analysis.

pH analysis

Water samples were analyzed on-site using a portable pH meter, whereas soils and sediments were brought to the laboratory, and sample suspensions were prepared in distilled water in the ratio 1:5 (w/v). The pH values of pond water samples and all filtered suspensions were observed and recorded using a HM digital meter-PH-200 (New Delhi, India).

Collection of plant samples and their preparation

Both abundance and prevalence as the criteria, a total of 23 plant species including trees, shrubs, and herbs were selected from each sampling site. For better comparison, three replicates of plant samples (shoots and roots) were collected. Three individual plants of similar height and age were selected for shoot and root samples. Herbaceous plants were uprooted to collect the root samples while shoot samples were collected randomly from the height of 0.2 to 3 m (depending on plant height) in different directions. These samples were mixed to form a homogenous sample. All the analyses were conducted in triplicate. The plant species viz., *Ageratum conyzoides* (L.) L., *Amaranthus spinosus* L., *Amaranthus viridis* L., *Brassica napus* L., *Cannabis sativa* L., *Dalbergia sissoo* DC., *Duranta repens* L., *Dysphania ambrosioides* (L.) Mosyakin & Clemants, *Ficus infectoria* Roxb., *Ficus palmata* Forssk., *Ficus religiosa* L., *Ipomoea carnea* Jacq., *Medicago polymorpha* L., *Melia azedarach* L., *Morus indica* L., *Malva rotundifolia* L., *Panicum virgatum* L., *Parthenium hysterophorus* L., *Dolichos lablab* L., *Ricinus communis* L., *Rumex dentatus* L., *Senna occidentalis* (L.) Link, and *Solanum nigrum* L., growing around the selected pond sites, were collected and brought to the laboratory. The plant samples were thoroughly rinsed with tap water to remove dust, soil, and any other unwanted particle attached. After several washings with tap water, the plant tissues were rinsed with distilled water. The moisture and water droplets were removed by blotting paper. The samples were air-dried and then kept in the oven to aid in the process of further drying so that a constant weight was achieved. The process was followed by the mechanical grinding of the dried plant samples, which was done with utmost care to avoid any contamination. Each finely powdered sample was preserved in the properly labeled small polythene bags to avoid intermixing of samples.

Heavy metal content

Different heavy metals viz., cadmium (Cd), copper (Cu), chromium (Cr), cobalt (Co), iron (Fe), manganese (Mn), and zinc (Zn) in soils, water, sediments, and plant samples were analyzed using a flame atomic absorption spectrophotometer (FAAS), Model: 240 FS 200 series AA, Make: Agilent Technologies; placed at the Central Instrumentation Facility in the Emerging Life Sciences Block, Guru Nanak Dev University, Amritsar (India).

Preparation of samples

Pond water sample The pond water samples were filtered using a Whatman No. 1 filter paper before analysis.

Soil and sediment samples Samples were digested using an aqua-regia digestion mixture (3:1; $HCl:HNO_3$). A total of 5 mL of distilled water was added to digested samples and stirred thoroughly with the glass rod. The final volume was made to 20 mL after the filtration of digested samples. The samples were further diluted 10 times before analysis of heavy metals using an atomic absorption spectrophotometer.

Plant samples A total of 0.5 g of the powdered plant material was mixed with a triacid mixture ($HNO_3:H_2SO_4:HClO_4$; 5:1:1) and digested until and unless a crystal clear transparent solution was obtained. Digested samples were filtered and the final volume was made to 100 mL for further analysis.

Estimation of heavy metal content

An atomic absorption spectrophotometer works on the principle of Beer-Lambert law, i.e., linear relationship between light absorption and analyte concentration. The estimation of different heavy metals viz., Cd, Cu, Cr, Co, Fe, Mn, and Zn, was carried out using a flame unit of the atomic absorption spectrophotometer (FAAS). FAAS determines the metals at part per million (ppm) concentration level. The instrument was equipped with UltrAA lamps, the SpectrAA software, and a double-beam monochromator system. The software setting and operational conditions of the instrument were adjusted according to the directions given by the manufacturer. In order to check the accuracy of instrument, the standards for each metal were prepared by diluting 10,000 mg/L single element standard solutions (Agilent Technologies) with double distilled water and analyzed after every 50 samples. The standards of known concentration for the different metals viz., Cd (0.5 ppm, 1 ppm, 1.5 ppm), Co (5 ppm, 10 ppm, 15 ppm), Cu (1 ppm, 3 ppm, 5 ppm), Cr (5 ppm, 10 ppm, 15 ppm), Fe (5 ppm, 10 ppm, 15 ppm), Mn (2 ppm, 4 ppm, 6 ppm), and Zn (0.5 ppm, 1 ppm, 1.5 ppm) were made from the prepared stock solutions. Analytical grade reagents purchased from Sigma-Aldrich, Bangalore, were used for the analysis. The calibration curve was used to determine the unknown concentration of a particular metal in the sample to be analyzed. Over-range readings were diluted to appropriate concentration and the dilution factor was calculated.

Calculation of bioaccumulation factor and translocation factor

BA*f* and T*f* of metals in plant samples were calculated using Eqs. 1 and 2 as follows (Usman et al. 2012):

$$\mathrm{BA}f = \frac{[\mathrm{Metal}]_{\text{shoot or root}}}{[\mathrm{Metal}]_{\text{soil}}} \quad (1)$$

where $[\mathrm{metal}]_{\text{shoot or root}}$ is the concentration of respective metal (mg/kg) either in shoot or root of the plant; $[\mathrm{Metal}]_{\text{soil}}$ is the concentration of metal (mg/kg) in the soil.

$$\mathrm{T}f = \frac{[\mathrm{Metal}]_{shoot}}{[\mathrm{Metal}]_{root}} \quad (2)$$

where $[Metal]_{shoot}$ is the concentration of respective metal (mg/kg) in the shoot of plant; and $[Metal]_{root}$ is the concentration of metal (mg/kg) in the roots.

Metal accumulation index

MAI was calculated according to the method developed by Liu et al. (2007). MAI was calculated using Eq. 3 as follows:

$$\mathrm{MAI} = \left(\frac{1}{N}\right) \sum_{j=1}^{N} I_j \tag{3}$$

where N = total number of metals analyzed and I_j = sub-index for variable j. I_j was obtained by the division of mean concentration value (x) of each metal to its standard deviation (Δx) as shown below:

$$\mathrm{I_j} = \frac{x}{\Delta x}$$

Comprehensive bioconcentration index

CBCI is the assessment of plant species for their ability to accumulate heavy metals comprehensively. The following steps were taken into consideration for calculation of CBCI as proposed by Zhao et al. (2014).

1 At first, the fuzzy set/factor set (U) was established as

$$U = (u_1, u_2, u_3 \ldots\ldots u_i)$$

where U indicates the comprehensive accumulation capability of plant species, and u_i corresponds to the different heavy metal influence factors (Cd, Cu, Cr, Co, Fe, Mn, and Zn).

2. Secondly, the fuzzy membership function was estimated as follows:

$$\mu\ (x) = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

where x is the BAf of a specific metal. Minimum and maximum BAf values were represented by $x_{\min}$ and $x_{\max}$ for the given metal among the observed plant species. The fuzzy membership quotient, i.e., μ (x) ranges between 1 and 0 signifying the highest and lowest comprehensive accumulation potential of plant species to different metals.

3. Lastly, CBCI was evaluated using Eq. 4:

$$\mathrm{CBCI} = \left(\frac{1}{N}\right) \sum_{i=1}^{N} \mu_i \tag{4}$$

where N = total number of metals analyzed and $\mu_i = \mu\ (x)$ of metal i.

Statistical analysis

Data were expressed as mean ± standard error (SE) of three replicates. Two-way analysis of variance (ANOVA) was used to determine the differences and interactions among sites (1, 2, and 3) and matrices (soil, sediment, and water) with the help of IBM SPSS® Statistics version 21. The p values ≤ 0.05 were considered to be significant. Furthermore, Principal Component Analysis (PCA) was applied on the multivariable resultant data of CBCI values of plant roots and shoots for seven heavy metals (Cd, Cr, Co, Cu, Fe, Mn, and Zn) at sites 1, 2, and 3. The Paleontological Statistics (PAST) software version 3.24 was used for PCA (Hammer et al. 2001).

Results and discussion

Heavy metals

The inter-site variability of different heavy metals (mg/kg) in soils, ponds, and sediments at three sites is presented in Table 1. The mean concentration of each metal in soil samples was compared with the target values (Agarwal 2009). Target values are specified to indicate the environmental quality of soil with the assumption that there is a negligible risk to the ecosystem. Similarly, in water samples, the metal concentration was compared with the guideline/acceptable values (World Health Organization (WHO) 2017). In the present study, cadmium content in soil samples of all selected sites, i.e., site 1 (0.703 mg/kg), site 2 (0.424 mg/kg), and site 3 (3.644 mg/kg) was found to be above the target limit (0.06 mg/kg). Overall, site 3 revealed the highest cadmium content in the soil. In pond water, mean cadmium concentration ranging from 0.006 mg/L (site 3) to 0.012 mg/L (sites 2) was observed to be above the permissible value, whereas the range of Cd concentration in sediments was found to be highest (0.773 to 4.227 mg/kg) in comparison with that of other matrices (soil and water). In the present case, cadmium contamination in soil, sediment, and water is correlated with the use of agro-chemicals such as phosphate-based commercial fertilizers, release of metal particulates from brick kilns, e-waste, plastic waste, electroplating, and the atmospheric deposition from vehicular exhaust (Kaur et al. 2018; Zhao et al. 2014). Chromium content was recorded to be maximum at site 3 (19.08 mg/kg) followed by site 2 (15.59 mg/kg) and site 1 (13.28 mg/kg) in soil samples showing its concentrations below the target value. However, mean chromium concentration

Table 1 Heavy metal content (mean ± SE) in the soil, water, and sediment samples collected from the vicinity of village ponds in Sahlon (site 1), Chahal Khurd (site 2), and Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab, India

Sample (units)	Sites/Parameters	Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Zinc
Soil (mg/kg)	Site 1	0.703 ± 0.021	13.28 ± 0.057	20.42 ± 0.313	5.372 ± 0.012	889.7 ± 6.093	82.60 ± 7.819	166.3 ± 0.433
	Site 2	0.424 ± 0.024	15.59 ± 0.150	21.05 ± 0.162	6.104 ± 0.024	344.1 ± 5.563	151.1 ± 1.471	34.87 ± 2.877
	Site 3	3.644 ± 0.033	19.08 ± 0.114	24.04 ± 0.376	15.42 ± 0.073	749.6 ± 4.015	184.2 ± 7.778	80.16 ± 0.764
	Target value*	0.06	100	8	20	38,000	850	50
Water (mg/L)	Site 1	0.010 ± 0.001	0.084 ± 0.004	0.163 ± 0.000	0.015 ± 0.001	0.849 ± 0.161	0.207 ± 0.036	0.086 ± 0.047
	Site 2	0.012 ± 0.001	0.062 ± 0.006	0.156 ± 0.001	0.016 ± 0.002	0.687 ± 0.081	0.148 ± 0.031	0.033 ± 0.003
	Site 3	0.006 ± 0.000	0.073 ± 0.006	0.165 ± 0.001	0.015 ± 0.001	0.641 ± 0.030	0.134 ± 0.035	0.059 ± 0.003
	Guideline/acceptable value**	0.003	0.05	-	2	2	0.4	3
Sediment (mg/kg)	Site 1	0.773 ± 0.004	15.14 ± 0.056	22.21 ± 0.266	20.25 ± 0.060	915.5 ± 1.419	431.3 ± 10.94	239.9 ± 3.475
	Site 2	0.920 ± 0.006	20.70 ± 0.046	23.08 ± 0.259	19.75 ± 0.052	929.2 ± 41.97	302.1 ± 12.04	160.8 ± 10.30
	Site 3	4.227 ± 0.017	26.92 ± 0.227	26.25 ± 0.406	38.64 ± 0.074	916.3 ± 0.833	197.7 ± 4.365	85.85 ± 1.732

*Agarwal (2009)

**World Health Organization (WHO) (2017)

in water was observed to be 0.073 mg/L at site 3 and 0.062 mg/L at site 2 with the highest being at site 1 (0.084 mg/L) revealing its concentrations slightly above the recommended WHO guideline value, whereas the range of chromium content in sediments was 15.14–26.92 mg/kg. The chromium toxicity in water at all three sites could be due to its hexavalent form which is relatively mobile and soluble as compared with immobile and less soluble Cr (III) form (World Health Organization (WHO) 2003). The alloys, solders, pesticides, herbicides, and fertilizers have been the possible sources of chromium contamination in water samples at all three sites. Cobalt concentration was extremely high in the soil samples ranging from 20.42 to 24.04 mg/kg at all sites in comparison with the target value of 8 mg/kg. Less variation in the cobalt content was seen among the studied sites. Among all three sites, cobalt content was observed to be highest at site 3 (24.04 mg/kg). Generally, Co is more mobile than metals like Cr and Zn but less mobile than Cd as soil pH accounts for high variability (84 to 95%) in Co sorption (Kim et al. 2006). An increase in pH facilitates the formation of insoluble hydroxides and carbonates thereby reducing Co mobility. Moreover, lower pH facilitates the leaching of Co with increased mobility (Kim et al. 2006). Additionally, site 3 was reported to have maximum cobalt content (0.165 mg/L) in water followed by site 1 and site 2. A similar trend was observed in sediments presenting the highest concentration of cobalt at site 3. The high content of cobalt in soil and water was due to the use of phosphate fertilizers in agrarian soils and agricultural runoff towards ponds. In the case of copper, iron, and manganese, the concentration of metals in soil and water was found to be within target and guideline values at all sites. The inter-site range of copper, iron, and manganese in sediments was found to be 19.75–38.64 mg/kg, 915.5–929.2 mg/kg, 197.7–431.3 mg/kg, respectively. The present study exhibited variability in the content of zinc at all three sampling sites. The concentration of zinc in soil was seen to be maximum at site 1 (166.3 mg/kg) which was closest to brick kilns followed by site 3 (80.16 mg/kg) and site 2 (34.87 mg/kg). Zinc in site 2 was reported to be within safe limits, whereas those in site 1 and site 3 were above permissible limits. Zinc contamination has been associated with the combustion activities in brick kilns with Zn as the main constituent of ash (Achakzai et al. 2015). The average zinc content in water ranged from 0.033 to 0.086 mg/L. These values were observed to be below the guideline value, whereas the range of Zn concentration in sediments was found to be 85.85–239.9 mg/kg.

Overall, the concentrations of chromium, copper, iron, and manganese in soils were found to be below the target values at all sampling sites. Cd, Cr, Co, Cu, Fe, Mn, and Zn are the major heavy metals of the roadside pollution and are also released from brick kilns combustion, motor oil additives, tires, brake liners, metal corrosion, pavement, and road surface materials. It was found that the soil samples were mainly contaminated with cadmium (0.424 to 3.644 mg/kg) and cobalt (20.42 to 24.04 mg/kg) at all three sites along with zinc (34.87 to 166.3 mg/kg) at sites 1 and 3. Moreover, the concentration of each metal was found to be the highest in sediments as compared with that in the soil and water samples at their respective sites. As shown in Table 2, the pH of sediment samples was also found to be highly acidic in comparison with that of soil and water samples. The sorption of metal contaminants increases with a decrease in pH of environmental matrices (soil, sediment, water, and plant tissues) (Caporale and Violante 2016). However, soil/sediment is a heterogeneous and dynamic system with complex soil solution and solid phase interactions. The sorption of heavy metal is highly influenced by the soil solution properties (index cation, pH, ionic strength, other heavy metal cations, organic ligands, inorganic anions, and metal loading rate) as well as soil solid phase properties (organic and inorganic constituents) (Singh et al. 2006; Loganathan et al. 2012). Humic substances strongly influence the sorption, diffusion, migration, complexation, and speciation of Cd, Co, Zn, and other metals in the environment (Li et al. 2009). In all sites, soil and sediments are in direct contact with the heavy metal pollution load and facilitate the high sorption of metals causing contamination to nearby soils. Two-way analysis of variance was applied to evaluate the significance and interactions among sites (1, 2, and 3) and matrices (soil, sediment, and water) (Table 3). For each metal, a statistically significant difference was observed among different sites and matrices at a 5% level of significance. Moreover, the high statistical interactions were seen between site and matrix for each metal at $p \leq 0.05$ (Fig. 1). The analysis revealed that at each site (1, 2, and 3), the individual metal content was found to be highly dependent on the type of matrix (soil, sediment, and water). The higher range of metal concentration in sediments as compared with that in soil clearly states that all the studied heavy metals are accumulating in the sediments through leaching from nearby metal pollutants.

Furthermore, the indigenous plants were also analyzed for their metal-accumulating potential. The heavy metal contents in shoots and roots of different plant samples were analyzed as displayed in Table 4 and Table 5. Three different sites showed

Table 2 pH (mean ± SE) of the soil, water, and sediment samples collected from the vicinity of village ponds in Sahlon (site 1), Chahal Khurd (site 2), and Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab, India

Sampling sites	pH		
	Soil	Water	Sediment
Site 1	5.53 ± 0.27	6.54 ± 0.19	4.77 ± 0.19
Site 2	5.64 ± 0.32	6.57 ± 0.24	4.96 ± 0.30
Site 3	5.74 ± 0.29	6.83 ± 0.16	4.60 ± 0.22

the mean concentration of cadmium in the range from 0.030 to 9.535 mg/kg for all studied plant species. The maximum content of cadmium was observed in the shoot of *D. sissoo* at all three sites, i.e., 9.535 mg/kg (site 3), 8.800 mg/kg (site 2), and 7.333 mg/kg (site 1). In the present study, cadmium concentration in all plant species was found to be below 10 mg/kg, which is in agreement with the standard concentration of Cd in plants (Alahabadi et al. 2017). The content of chromium in plant species was in the range 10.17–102.9 mg/kg. Chromium at a concentration of 100 μM/kg (or 5.19 mg/kg) dry weight has high toxicity towards most of the higher plant species with detrimental outcomes on plant growth and development (Shanker et al. 2005). However, some plants have low to high levels of tolerance against chromium toxicity, and the plants with an accumulation tendency of > 1000 mg/kg are known as chromium hyperaccumulators (Singh et al. 2013). The present study indicated that roots of *R. dentatus* contained maximum chromium concentration (102.9 mg/kg) at site 3 followed by roots of *M. rotundifolia* (97.77 mg/kg) at site 1 and shoots of *F. infectoria* (90.64 mg/kg) at site 2. The high content of chromium in majority of plant roots is in agreement with the previous report suggesting that chromium bioconcentration is usually high in roots as compared with the shoots (Kabata-Pendias 2000). However, plant species viz., *A. viridis*, *B. napus*, *C. sativa*, and *P. virgatum* at site 1; *A. spinosus* at site 2; and *I. carnea* and *P. hysterophorus* at site 3, showed Cr translocation from roots to shoots. These results reveal that all studied plants are chromium-tolerant with varying ability to accumulate chromium. The mean concentration of cobalt in plants among three sites showed less inter-site deviation which ranged between 5.950 and 21.20 mg/kg. The present study displayed the highest concentration (21.20 mg/kg) of cobalt in *F. religiosa* shoot (site 3). Shoots of *M. azedarach* (site 1) and *M. indica* (site 2) also showed high cobalt concentrations at their respective sites with 14.25 mg/kg and 17.22 mg/kg concentration, respectively. These results are due to the fact that cobalt can be easily taken up by the plant leaves through their cuticles (Kabata-Pendias 2000). The range of copper concentration in plants exhibited high variability between 5.373 and 95.07 mg/kg at all three surveyed sites. The highest copper concentration (95.07 mg/kg) was found in *C. sativa* shoots (site 3) followed by *M. polymorpha* shoots (94.62 mg/kg) at site 1 and shoots of *C. sativa* (51.06 mg/kg) at site 2. Moreover, the roots of *C. sativa* at site 3 also showed a notable mean concentration value of 87.09 mg/kg. The present study revealed that most of the species showed copper concentration beyond toxic range, i.e., 20–30 mg/kg (Zhao et al. 2014). Iron is an essential micronutrient for the ideal growth and development of plant species (U.S. Environmental Protection Agency (USEPA) 2003). The mean concentration values of iron in different plant species were in the range of 112.6–853.8 mg/kg at all three sites. The present study revealed that the maximum content of Fe was present in

Table 3 Two-way analysis of variance for each metal among site (Sahlon: 1, Chahal Khurd: 2, and Karnana: 3) and matrix (soil, sediment, and water)

Two-way ANOVA	Degrees of freedom (df)	*F* ratio						
		Cadmium (Cd)	Chromium (Cr)	Cobalt (Co)	Copper (Cu)	Iron (Fe)	Manganese (Mn)	Zinc (Zn)
Difference between sites (1, 2, and 3)	2	17699.585*	147.556*	227.974*	8707.324*	481.429*	127.181*	1568.352*
Difference between matrices (soil, sediment, and water)	2	12427.194*	2037.266*	21415.928*	51953.961*	12797.692*	6330.009*	5448.951*
Interaction between site and matrix	4	4519.216*	49.849*	57.233*	2838.873*	521.556*	651.738*	640.700*

Error df = 72

$*p \leq 0.05$

the shoots of *M. polymorpha* (853.8 mg/kg) at site 3 followed by shoots of *A. conyzoides* (560.2 mg/kg) at site 2 and *S. nigrum* (534.4 mg/kg) at site 1. Moreover, the roots of *M. polymorpha* at site 3 also represented exceptionally high content (739 mg/kg) of iron. The mean concentration of manganese was in the range of 15.64–98.69 mg/kg in different plant species at all three sites. The highest content of manganese was observed in *A. viridis* (site 1) with 98.69 mg/kg concentration. *R. communis* also showed high manganese content with 79.49 mg/kg and 71.29 mg/kg concentration at site 2 and site 3, respectively. The permissible concentration of zinc in plants is 60 mg/kg as recommended by WHO/FAO (2007), whereas 50 mg/kg by Bhatnagar and Awasthi (2000). Similarly, the conventional zinc concentration range is prescribed as 10 to 150 mg/kg (Hu et al. 2014; Padmavathiamma and Li 2007). The studied plants showed zinc in the range of 16.04–113.8 mg/kg for all the surveyed sites with the maximum being in shoots of *F. infectoria* (site 2). *M. indica* and *D. sissoo* also revealed a high concentration of 70.39 mg/kg at site 1 and 66.75 mg/kg at site 3. By analyzing these data, the indigenous phytoremediating plant species were explored to reveal the underlying mechanisms of the complex bioaccumulation and translocation processes.

Bioaccumulation and translocation factor

The bioaccumulation factor (BA*f*) is known to be the most significant facet in phytoremediation that reflects the potential of plants to regulate the uptake and mobility of heavy metal in their tissues leading to its bioaccumulation in aerial parts (Zhuang et al. 2007). The bioaccumulation factor ≤ 1 signifies that plants can only uptake the metal and do not have the capacity for metal bioaccumulation. The bioaccumulation factor > 1 implies that plants exhibit bioaccumulation potential (Bashir et al. 2014). The translocation factor (T*f*) principally assesses the phytoextractive ability of plant species. The nutrient transportation from plant roots to shoots is considered highly efficient if T*f* > 1, revealing the existence of a well-organized and better transportation system for metals (Usman et al. 2019). Phytoextractors are the plants that have the potential to be used as phytoaccumulators (BA*f* > 1) and phytotranslocators (T*f* > 1) (Lorestani et al. 2011). The exploration of indigenous plant species with the most advantageous situation-specific phytoremediating ability without any physiological/morphological effects has been in constant consideration to achieve efficient detoxification of metals from soil. Factors like the presence of chelating agents, variations in pH and cellular redox reactions assist in the solubilization of micronutrients facilitating their uptake even at extremely low concentrations. The uptake of toxic elements in plants simulates the mechanisms involving translocation and storage of micronutrients. Consequently, these mechanisms are of high importance in phytoremediation (Tangahu et al. 2011).

Bioaccumulation factor The bioaccumulation factors are represented in Figs. 2, 3, and 4. The range of BA*f* value for cadmium among all three sites was from 0.042 to 20.75. In the present study, *D. sissoo* appeared to be a prominent cadmium accumulator showing high BA*f* values which were recorded as 20.75 (site 2), 10.43 (site 1), and 2.617 (site 3). *A. spinosus* also showed high cadmium BA*f* value of 10.38 (site 2). Cadmium is a very mobile metal and demonstrates high BA*f* value as compared with other metals like Cu, Zn, and Mn (Zhai et al. 2016; Zhan et al. 2014). Although soil was found to be contaminated with cadmium at all three sites, however, in the present study, majority of plants displayed high BA*f* values for chromium and copper in comparison with that for cadmium. In soil, the bioavailability of cadmium depends on pH, redox potential, temperature, and concentration with respect to the presence of other elements (Hasan et al. 2009). The variations in electrochemical potential of cytosolic Cd^{+2} and root apoplast are the main mechanisms that control the absorption of Cd across the root cell plasma membrane (Hasan et al. 2009). Additionally, high negative potential alone can also provide sufficient energy for Cd absorption. The absorption of Cd could also occur via inorganic or metal-phytometallophore complexes but have limited pieces of evidences (Hasan et al. 2009). The range of BA*f* values for chromium varied between 0.766 and 7.362. Almost all observed plant parts appeared to be chromium

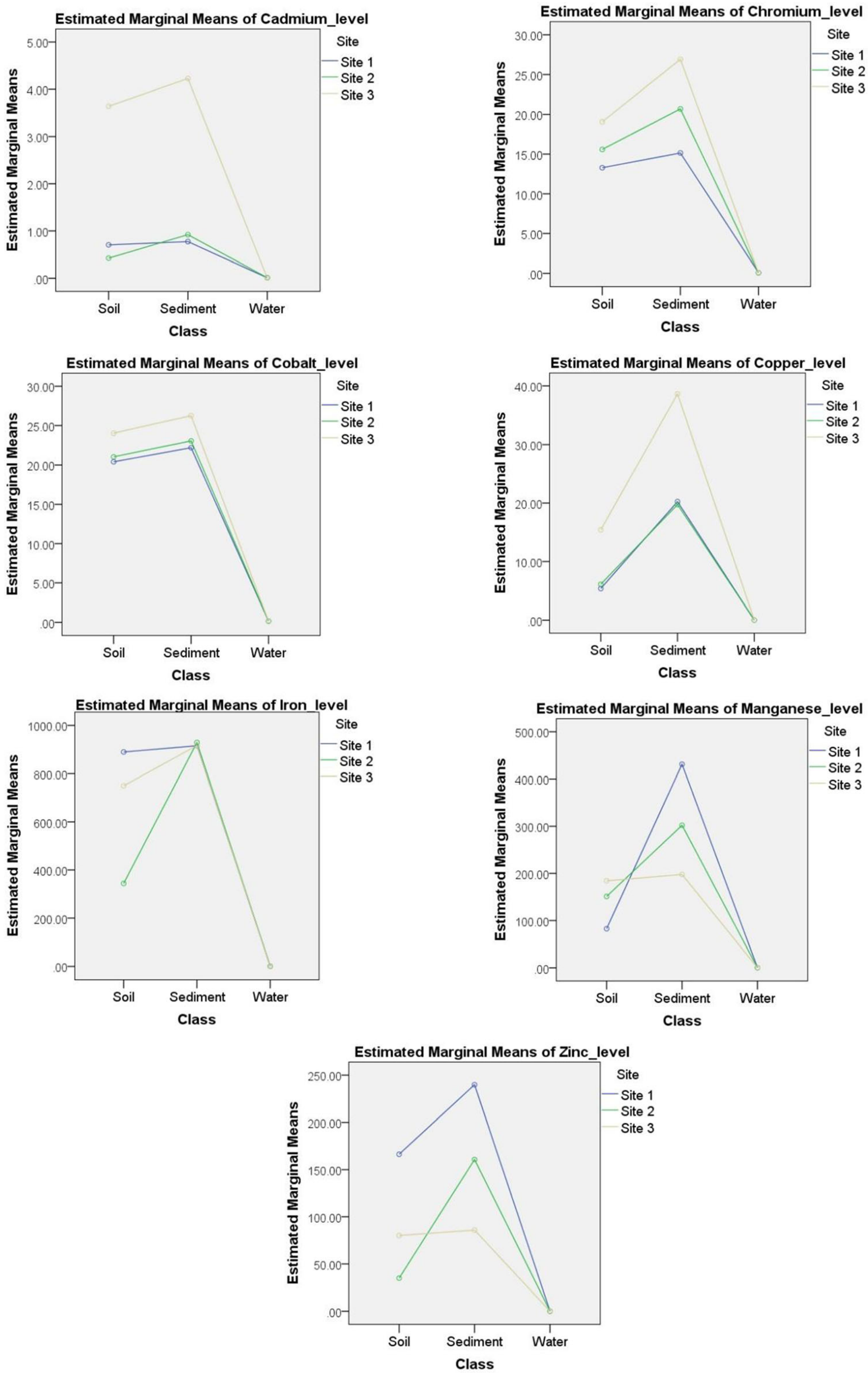

Fig. 1 Interaction between different sites (1, 2, and 3) and matrix (soil, sediment, and water)

phytoaccumulators. Roots of *M. rotundifolia* showed highest chromium BA*f* value of 7.362 at site 1. For chromium metal, BA*f* values of 5.814 (site 2) and 5.393 (site 3) were observed in *F. infectoria* and *R. dentatus* roots which were maximum among their respective sites. BA*f* values for cobalt were in the range of 0.279 to 0.882, among all three sites. None of the studied plants showed BA*f* > 1 for cobalt. The maximum BA*f* value of 0.882 (site 3) was shown by *F. religiosa*. The large surface area of *F. religiosa* leaves may facilitate the easy uptake of cobalt metal through the cuticle (Kabata-Pendias 2000;

Shahid et al. 2017). *F. religiosa* has high dust-capturing ability due to its dense canopy and leaves with a rough exterior and large surface area. The foliar uptake of hydrophobic and hydrophilic metals can occur via two pathways. The diffusion of lipophilic metals could perpetrate through the cuticle, whereas diffusion of hydrophilic metals may take place via aqueous stomatal pores along with cuticle (Shahid et al. 2017). Moreover, all the three sites showed a very high content of cobalt in soil with the maximum concentration at site 3. *M. indica* and *M. azedarach* displayed the high BA*f* values for cobalt as 0.818 (site 2) and 0.698 (site 1), respectively. Wide variations in BA*f* values were observed for copper ranging from 0.893 to 17.61. The highest BA*f* value of 17.61 (site 1) was related to the shoots of *M. polymorpha*. Roots of *M. polymorpha* also showed a considerable BA*f* value of 12.22 (site 1). However, *M. polymorpha* roots and shoots showed relatively low BA*f* values for copper at site 3 even in the presence of significant copper concentration in soil at same site. This variation in same plant at different sites might be due to the availability of variable forms (water soluble, exchangeable, inorganically bound, organically bound, oxide-bound, and residual) of copper to the plant species for their intake (Sharma et al. 2015). Almost all studied plants acted as phytoaccumulators for the reason that they illustrated BA*f* values greater than one. At sites 2 and 3, *C. sativa* shoots showed high BA*f* values of 8.375 and 6.615 for copper respectively. Iron occurs predominantly as Fe^{+3} oxides in soil (U.S. Environmental Protection Agency (USEPA) 2003). Ferrous (Fe^{+2}) form is more soluble and bioavailable to plants than ferric ions. Ferrous ions are required for the chlorophyll synthesis and are essential for the proper functioning of respiratory enzymes consequently, facilitating the optimal uptake of metal in plants. Bioaccumulation factors of different plant species for iron varied from 0.127 to 1.628 among three surveyed sites. At site 1, BA*f* values for iron were found to be < 1 in all plants. BA*f* values of shoots of *F. infectoria*, *F. palmata*, *A. conyzoides*, and shoots and roots of *A. spinosus* for iron were observed to be > 1 at site 2, while site 3 displayed maximum BA*f* value (1.139) in the shoots of *M. polymorpha*. BA*f* values of plants among all sites were in the range 0.085 to 1.195 for manganese. *A. viridis* (shoots) with BA*f* value of 1.195 at site 1 was reported to be the accumulator of manganese out of all studied plant species among three sites. All the plant samples were seen as the excluders of zinc at site 1 and site 3. The plant species including shoots (1.045) and roots (1.060) of *A. conyzoides*, roots of *C. sativa* (1.603), shoots of *D. repens* (1.511), *F. infectoria* (3.262), *F. palmata* (1.054), *M. indica* (1.217), shoots (1.498) and roots (1.106) of *D. lablab*, shoots of *R. communis* (1.498), and roots of *S. nigrum* (1.227) were found to be the accumulators of Zn. The bioaccumulation of heavy metals in plants increases as the pH of soil/sediments decreases (Caporale and Violante 2016). In the present study, all soil and sediment samples were found to be acidic in nature facilitating the accumulation of heavy metal contaminants in plant tissues.

Translocation factor The translocation factor values are presented in Table 6. The present study displayed the range of transfer factor for cadmium, chromium, cobalt, copper, iron, manganese, and zinc from 0.311 to 11.97, 0.36 to 2.483, 0.535 to 1.789, 0.215 to 7.624, 0.57 to 2.886, 0.628 to 2.653, and 0.457 to 2.429, respectively. The highest transfer values were observed for cadmium at all three sites as compared with those of other metals. Translocation factor of *P. hysterophorus* for cadmium was found to be high at all three sites demonstrating a maximum value of 11.97 at site 3 followed by 7.463 at site 2. *P. hysterophorus* can be utilized as a phytoextractor of cadmium as the BA*f* value of its shoot was observed to be greater than one at both these sites. *R. dentatus* also indicated a very high cadmium transfer value of 11.06 (site 1). In the current study, *B. napus* revealed the highest value of chromium transfer factor (2.483) at site 1. Previous studies have also reported that members of the *Brassicaceae* family can be used as phytoaccumulators or phytoremediators (Kabata-pendias 2000; Salt et al. 1995; Schmidt 2003; Singh et al. 2010). Results of the present study also suggest that *B. napus* has the potential to be used as a phytoextractor of chromium as both BA*f* and T*f* values were seen to be > 1. Similarly, *A. spinosus* and *P. hysterophorus* also showed high T*f* value for chromium at site 2 (1.146) and site 3 (2.059) and were observed to be potential phytoextractors. Likewise, *P. hysterophorus* with a high T*f* value of 7.624 (site 1), 2.353 (site 3) and *A. spinosus* 1.259 (site 2) make them suitable for copper phytoextraction. *B. napus* with T*f* value of 1.789 (site 1) along with *P. hysterophorus* 1.427 (site 2) and *C. sativa* 1.229 (site 3) illustrated some phytotranslocation capacity for cobalt. *S. nigrum* with T*f* value 2.886 (site 1), *A. conyzoides* 2.537 (site 2), and *P. hysterophorus* 2.641 (site 3) were on top of their respective sites with translocation factor greater than one, thus making them potential phytotranslocators for iron. Additionally, *A. conyzoides* also has a possible phytoextractive ability as the BA*f* value for iron was greater than one in its shoots. *S. nigrum*, *D. lablab*, and *P. hysterophorus* displayed T*f* values of 2.276 (site 1), 1.019 (site 2), and 2.653 (site 3) for manganese respectively which make them probable phytotranslocators. Among investigated plant species at all sampling sites, only *A. viridis* shoot displayed the BA*f* value above one for manganese. Moreover, T*f* value for this plant was also calculated to be greater than one at site 1 (1.197). Thus, *A. viridis* could be considered a suitable candidate for phytoextraction of manganese. Among all species, high values of T*f* for zinc were seen to be 2.429 (site 1), 1.355 (site 2), and 1.217 (site 3) for *S. occidentalis*, *D. lablab*, and *P. hysterophorus*, respectively. However, out of these three species, only *D. lablab* can be used for phytoextraction of zinc.

Table 4 Heavy metal content (mean ± SD) in shoots of different plant species grown around the ponds of villages Sahlon (site 1), Chahal Khurd (site 2), and Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab

S. no.	Plant species	Site	Heavy metal content (mg/kg)							MAI	CBCI
			Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Zinc		
1.	*Ageratum conyzoides* (L.) L.	1	0.339 ± 0.159	52.60 ± 2.445	10.02 ± 1.311	14.13 ± 3.951	202.4 ± 8.873	34.04 ± 2.373	48.36 ± 6.916	11.29	0.300
		2	0.350 ± 0.217	43.00 ± 3.377	9.070 ± 0.736	18.93 ± 1.851	560.2 ± 8.956	55.08 ± 5.978	36.45 ± 5.428	16.48	0.345
2.	*Amaranthus viridis* L.	1	0.245 ± 0.091	61.77 ± 4.077	9.040 ± 1.035	12.63 ± 0.289	276.6 ± 9.789	98.69 ± 5.120	62.73 ± 2.994	19.82	0.474
3.	*Amaranthus spinosus* L.	2	4.400 ± 0.459	82.57 ± 3.032	7.040 ± 0.510	21.17 ± 2.930	344.6 ± 20.35	41.91 ± 4.935	30.47 ± 6.908	12.53	0.379
4.	*Brassica napus* L.	1	0.367 ± 0.044	54.64 ± 2.835	10.67 ± 1.976	15.24 ± 2.031	224.0 ± 14.29	23.48 ± 1.573	16.04 ± 3.010	10.92	0.221
5.	*Cannabis sativa* L.	1	3.006 ± 0.438	84.68 ± 3.363	9.312 ± 0.727	14.77 ± 1.757	340.8 ± 18.67	40.31 ± 2.874	27.00 ± 1.730	14.45	0.396
		2	0.341 ± 0.047	50.60 ± 1.898	14.19 ± 3.932	51.06 ± 2.131	163.6 ± 4.812	33.48 ± 3.946	25.55 ± 4.955	15.60	0.333
		3	0.818 ± 0.453	41.37 ± 2.329	12.36 ± 2.886	95.07 ± 5.659	139.3 ± 6.063	28.49 ± 3.310	36.12 ± 4.370	11.50	0.280
6.	*Dalbergia sissoo* DC.	1	7.333 ± 1.299	93.20 ± 1.832	9.688 ± 0.387	37.53 ± 2.132	224.4 ± 3.751	38.31 ± 5.010	28.35 ± 4.310	24.74	0.497
		2	8.800 ± 0.766	85.24 ± 5.846	13.72 ± 1.033	33.20 ± 3.236	230.7 ± 2.538	18.71 ± 4.251	25.86 ± 5.957	21.32	0.483
		3	9.535 ± 2.718	80.80 ± 6.540	20.21 ± 4.336	87.96 ± 5.202	201.3 ± 2.401	25.82 ± 2.103	66.75 ± 4.929	21.02	0.681
7.	*Dolichos lablab* L.	2	0.250 ± 0.033	60.24 ± 5.494	13.65 ± 1.989	18.53 ± 2.009	237.2 ± 17.43	43.51 ± 7.422	52.23 ± 11.40	8.379	0.325
8.	*Duranta repens* L.	2	0.117 ± 0.065	86.11 ± 4.489	15.38 ± 2.083	25.26 ± 1.758	217.0 ± 5.147	51.03 ± 9.984	52.70 ± 4.522	14.53	0.448
9.	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	3	0.900 ± 0.706	76.97 ± 11.31	11.38 ± 3.078	61.77 ± 7.411	409.9 ± 8.754	35.03 ± 4.208	52.48 ± 4.785	12.32	0.422
10.	*Ficus infectoria* Roxb.	2	0.242 ± 0.026	90.64 ± 5.213	15.40 ± 1.093	21.43 ± 2.802	492.9 ± 8.648	46.42 ± 7.643	113.8 ± 17.93	16.80	0.629
11.	*Ficus palmata* Forssk.	2	1.241 ± 0.148	85.77 ± 4.982	13.06 ± 2.398	23.23 ± 2.175	448.4 ± 8.624	38.09 ± 11.46	36.76 ± 5.855	14.76	0.457
12.	*Ficus religiosa* L.	3	0.584 ± 0.216	74.48 ± 8.198	21.20 ± 0.940	54.62 ± 1.952	142.2 ± 2.458	53.84 ± 3.166	39.77 ± 2.969	21.51	0.447
13.	*Ipomoea carnea* Jacq.	1	0.093 ± 0.033	62.80 ± 1.700	8.690 ± 1.178	11.50 ± 1.165	189.6 ± 6.636	48.11 ± 1.279	20.34 ± 1.114	20.21	0.233
		3	0.883 ± 0.156	64.00 ± 5.153	12.01 ± 1.453	64.07 ± 6.644	191.8 ± 7.976	58.36 ± 2.858	32.59 ± 3.156	12.97	0.351
14.	*Malva rotundifolia* L.	1	1.167 ± 0.196	52.80 ± 7.786	9.440 ± 1.484	66.83 ± 2.939	280.6 ± 4.431	32.49 ± 1.227	35.87 ± 3.292	20.36	0.382
15.	*Medicago polymorpha* L.	1	0.233 ± 0.061	10.17 ± 0.529	10.07 ± 1.952	94.62 ± 2.032	168.2 ± 11.14	35.92 ± 4.674	39.76 ± 7.068	14.74	0.328
		3	0.284 ± 0.150	43.43 ± 14.12	11.61 ± 2.784	13.77 ± 0.537	853.8 ± 34.06	40.40 ± 2.986	36.60 ± 1.159	14.99	0.299
16.	*Melia azedarach* L.	1	0.333 ± 0.097	83.64 ± 2.925	14.25 ± 0.231	28.67 ± 3.819	531.4 ± 11.15	57.00 ± 6.504	58.26 ± 4.403	24.40	0.626
17.	*Morus indica* L.	1	0.679 ± 0.021	59.60 ± 1.854	10.52 ± 2.009	40.17 ± 1.040	396.2 ± 9.134	78.12 ± 6.380	70.39 ± 2.882	26.86	0.572
		2	1.000 ± 0.463	66.00 ± 2.444	17.22 ± 0.587	17.97 ± 1.164	326.9 ± 3.175	42.60 ± 3.674	42.45 ± 5.747	27.99	0.411
18.	*Panicum virgatum* L.	1	0.228 ± 0.061	60.24 ± 3.076	7.953 ± 1.234	11.34 ± 0.890	199.5 ± 8.163	27.71 ± 2.695	29.19 ± 3.204	12.33	0.208
19.	*Parthenium hysterophorus* L.	1	0.500 ± 0.199	79.80 ± 3.612	8.460 ± 1.617	56.17 ± 2.880	373.7 ± 16.02	41.11 ± 4.463	48.23 ± 4.517	13.22	0.459
		2	0.697 ± 0.148	35.95 ± 4.992	8.490 ± 1.076	10.69 ± 2.621	318.8 ± 20.09	38.11 ± 3.917	30.90 ± 6.492	7.749	0.160
		3	6.185 ± 1.697	91.40 ± 5.244	6.700 ± 1.240	57.48 ± 3.409	336.4 ± 9.718	41.49 ± 2.981	30.57 ± 3.873	14.25	0.410

Table 4 (continued)

S. no.	Plant species	Site	Heavy metal content (mg/kg)							MAI	CBCI
			Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Zinc		
20.	*Ricinus communis* L.	1	0.273 ± 0.092	89.37 ± 3.095	9.240 ± 0.665	51.67 ± 2.045	153.8 ± 16.43	63.80 ± 9.991	60.34 ± 5.062	14.10	0.474
		2	1.550 ± 0.206	77.37 ± 3.044	12.97 ± 2.890	34.16 ± 3.537	287.6 ± 7.230	79.49 ± 6.950	52.25 ± 7.231	15.07	0.541
		3	1.783 ± 0.771	90.97 ± 5.627	12.91 ± 2.734	29.52 ± 5.681	251.3 ± 4.518 Robin et al. 2015	71.29 ± 1.313	35.18 ± 5.652	20.65	0.429
21.	*Rumex dentatus* L.	1	0.327 ± 0.016	67.74 ± 4.858	10.35 ± 0.348	20.21 ± 1.422	145.6 ± 3.516	37.40 ± 4.383	30.52 ± 3.991	19.48	0.281
		3	0.884 ± 0.263	92.57 ± 8.475	12.03 ± 0.792	25.80 ± 4.378	274.5 ± 9.395	23.31 ± 4.799	26.57 ± 3.068	11.16	0.255
22.	*Senna occidentalis* (L.) Link	1	0.167 ± 0.053	60.00 ± 3.878	9.133 ± 0.717	12.33 ± 1.849	143.6 ± 9.750	26.69 ± 2.232	58.03 ± 2.675	12.34	0.283
23.	*Solanum nigrum* L.	1	0.294 ± 0.125	50.04 ± 1.257	7.533 ± 0.759	7.924 ± 0.609	534.4 ± 16.57	45.00 ± 4.346	43.29 ± 2.472	17.89	0.362
		2	1.759 ± 0.612	48.24 ± 3.537	13.05 ± 3.718	12.33 ± 2.099	231.4 ± 23.38	62.48 ± 3.327	19.83 ± 2.596	8.887	0.282

MAI metal accumulation index, *CBCI* comprehensive bioconcentration index

Overall, among all plant species, the translocation factor of *P. hysterophorus* was found to be greater than one for at least each investigated metal when all the three surveyed sites were taken into account. *P. hysterophorus* requires a significant amount of metals in the shoots for the production of seeds which can be up to 100,000 seeds in its lifetime (Asia - Pacific Forest Invasive Species Network (APFISN) 2007). This indicates the reason for high T*f* value for different metals in the present case. Working on transfer factor of various plants, a previous study by Malik et al. (2010) also revealed *P. hysterophorus* as a capable phytoremediating plant.

The plant species with bioaccumulation factor (BA*f*) above one and translocation factor (T*f*) below one for particular metal has the phytostabilization ability (Mirecki et al. 2015). In the present study, some of the plants in response to heavy metals at their respective sampling sites indicated T*f* < 1 revealing their potential utilization as phytostabilizers by restraining the movement of heavy metals in roots. Among all plant species, multi-metal phytostabilization ability was observed in *A. conyzoides* and *C. sativa* for Cd, Cr, Cu, and Zn metals. *D. lablab*, *I. carnea*, *M. polymorpha*, *R. dentatus*, and *S. occidentalis* were seen to be Cr and Cu phytostabilizers. Besides Cr and Cu, *S. nigrum* was also found to be Zn phytostabilizer. Furthermore, single metal phytostabilization efficacy was noticed in *D. ambrosioides*, *M. rotundifolia*, and *P. hysterophorus* for Cr, *A. viridis* and *B. napus* for Cu, and *A. spinosus* for Fe.

Metal accumulation index

MAI values for the shoots and roots are summarized in Table 4 and Table 5. Metal accumulation index presents overall performance of plants to accumulate metals with respect to its deviation in metal uptake. In the present study, considerable variations were presented by different plants in uptake of metals. The results showed high MAI values as compared with that of previous studies (Alahabadi et al. 2017; Hu et al. 2014; Liu et al. 2007; Safari et al. 2018). The native plant species showed high efficiency in metal accumulation which could be due to the sub-humid to semi-arid environment and atmospheric chemistry prevailing in local studied areas. The high temperature of sub-humid to semi-arid environment, and acidic pH facilitates the higher sorption of metal contaminants in plant tissues (Caporale and Violante 2016). The vehicular pollution throughout the year with post-monsoon burning of agricultural crop residues aggravates the particulate matter (PM) and trace gases that severely degrade the atmospheric air quality. Consequently, higher pollution load triggers the alterations in atmospheric chemistry, radiation balance, affecting local climate and air quality index (Jethva et al. 2019). The various other factors like sampling time, season, and plant characteristics also contribute to the mixed results (Hu et al. 2014). Moreover, the present study accounts for the air as well as soil pollution because the shoots and roots of various herbs and trees are in direct contact with soil and air (Dzierżanowski et al. 2011). The minimum value of MAI was found in *P. hysterophorus* roots, i.e., 8.186 (site 3). In comparison with the shoots, majority of roots displayed low MAI values as they are in direct contact with the soil and more susceptible to environmental variations. Among all plants, MAI values were found to be the highest for *M. indica* at site 2 (27.99) and site 1

Table 5 Heavy metal content (mean ± SD) in roots of different plant species grown around the ponds of villages Sahlon (site 1), Chahal Khurd (site 2), and Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab

S. no.	Plant species	Site	Heavy metal content (mg/kg)							MAI	CBCI
			Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Zinc		
1.	*Ageratum conyzoides* (L.) L.	1	0.173 ± 0.025	63.77 ± 9.329	10.35 ± 1.331	34.37 ± 2.380	225.6 ± 13.41	38.31 ± 5.457	59.24 ± 3.167	11.20	0.398
		2	0.441 ± 0.176	47.81 ± 4.877	15.15 ± 2.003	16.03 ± 1.949	220.8 ± 10.60	62.43 ± 8.043	36.96 ± 4.871	9.184	0.322
2.	*Amaranthus viridis* L.	1	0.081 ± 0.069	57.48 ± 2.620	8.660 ± 1.529	14.12 ± 1.964	250.2 ± 8.154	82.44 ± 7.923	37.75 ± 3.545	12.53	0.356
3.	*Amaranthus spinosus* L.	2	1.944 ± 0.600	72.03 ± 2.955	13.16 ± 2.023	16.82 ± 2.209	348.5 ± 11.15	46.97 ± 3.828	29.99 ± 6.996	12.79	0.386
4.	*Brassica napus* L.	1	0.055 ± 0.007	22.00 ± 1.736	5.964 ± 1.125	19.48 ± 1.777	250.8 ± 6.762	22.05 ± 2.439	26.03 ± 4.630	12.72	0.120
5.	*Cannabis sativa* L.	1	2.765 ± 0.692	82.41 ± 3.329	9.059 ± 0.714	16.41 ± 0.901	320.4 ± 16.24	35.53 ± 4.574	23.13 ± 3.455	13.40	0.360
		2	0.801 ± 0.228	58.93 ± 2.894	10.09 ± 0.755	48.17 ± 3.145	173.1 ± 21.47	53.30 ± 2.965	55.89 ± 4.479	13.01	0.396
		3	0.536 ± 0.170	51.29 ± 6.385	10.06 ± 2.151	87.09 ± 7.214	128.5 ± 6.670	26.52 ± 1.930	58.67 ± 6.368	10.02	0.332
6.	*Dolichos lablab* L.	2	0.377 ± 0.115	61.69 ± 4.592	13.37 ± 1.263	35.80 ± 3.962	223.4 ± 10.31	42.68 ± 3.415	38.55 ± 4.761	11.23	0.361
7.	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	3	0.400 ± 0.081	78.24 ± 17.64	12.18 ± 3.378	41.90 ± 4.233	308.0 ± 7.548	33.20 ± 3.056	43.23 ± 5.946	11.69	0.333
8.	*Ipomoea carnea* Jacq.	1	0.300 ± 0.054	68.15 ± 6.353	8.580 ± 1.108	5.373 ± 0.177	295.1 ± 7.674	42.60 ± 3.583	19.68 ± 2.882	15.95	0.258
		3	0.600 ± 0.135	48.37 ± 4.324	12.96 ± 2.392	82.80 ± 5.586	168.6 ± 6.252	44.68 ± 4.373	53.07 ± 3.195	12.81	0.383
9.	*Malva rotundifolia* L.	1	0.267 ± 0.096	97.77 ± 5.143	9.540 ± 1.892	10.77 ± 1.412	237.0 ± 12.47	43.68 ± 6.728	44.59 ± 2.997	10.69	0.378
10.	*Medicago polymorpha* L.	1	0.129 ± 0.029	28.23 ± 7.808	10.28 ± 0.860	65.67 ± 3.231	248.3 ± 7.825	29.72 ± 3.614	58.66 ± 4.967	13.15	0.378
		3	0.503 ± 0.445	44.57 ± 17.44	12.74 ± 1.677	34.00 ± 5.617	739.0 ± 35.95	26.08 ± 1.865	33.23 ± 2.137	9.632	0.281
11.	*Panicum virgatum* L.	3	0.167 ± 0.015	59.40 ± 4.982	7.775 ± 1.360	9.872 ± 2.356	197.7 ± 8.307	34.11 ± 4.002	27.57 ± 1.756	11.57	0.207
12.	*Parthenium hysterophorus* L.	1	0.206 ± 0.025	84.64 ± 3.467	8.520 ± 1.330	7.367 ± 1.071	366.8 ± 16.83	23.60 ± 0.405	32.69 ± 3.050	19.51	0.309
		2	0.093 ± 0.042	78.57 ± 5.005	5.950 ± 1.001	22.86 ± 1.908	172.8 ± 8.445	40.31 ± 8.093	31.97 ± 6.003	9.516	0.227
		3	0.517 ± 0.195	44.40 ± 3.509	12.09 ± 2.808	24.43 ± 6.903	127.4 ± 7.102	15.64 ± 1.418	25.11 ± 4.842	8.186	0.082
13.	*Rumex dentatus* L.	1	0.030 ± 0.005	76.64 ± 5.425	11.03 ± 2.610	25.40 ± 2.420	122.8 ± 3.345	41.89 ± 1.757	35.71 ± 2.464	15.71	0.323
		3	1.805 ± 0.064	102.9 ± 30.54	11.31 ± 0.315	21.27 ± 7.258	388.0 ± 26.15	28.05 ± 2.300	38.78 ± 3.698	15.41	0.355
14.	*Senna occidentalis* (L.) Link	1	0.107 ± 0.032	63.24 ± 2.381	8.685 ± 0.670	35.33 ± 1.620	112.6 ± 3.195	23.08 ± 0.834	23.89 ± 3.835	19.11	0.210
15.	*Solanum nigrum* L.	1	0.139 ± 0.037	90.00 ± 6.616	7.300 ± 1.034	36.82 ± 1.055	185.2 ± 7.108	19.77 ± 1.323	29.01 ± 2.879	15.77	0.264
		2	0.271 ± 0.038	60.04 ± 3.534	13.85 ± 2.501	22.80 ± 2.962	225.1 ± 12.42	77.73 ± 6.628	42.77 ± 5.786	10.65	0.404

MAI metal accumulation index, *CBCI* comprehensive bioconcentration index

(26.86) while *F. religiosa* showed the maximum value at site 3 (21.51). *Morus* spp. have the ability to accumulate metal contaminants from the atmosphere (Alahabadi et al. 2017). *F. religiosa* is a road verge/roadside and avenue tree in the Middle East countries and the Philippines (Centre for Agriculture and Bioscience International (CABI) 2018). It has a high metal accumulation capability with superior dust-capturing efficiency (Roy et al. 2020). Present work also recommends *M. indica* and *F. religiosa* for the phytoremediation of heavy metal contaminants because of their high MAI values with respect to overall inter-site results.

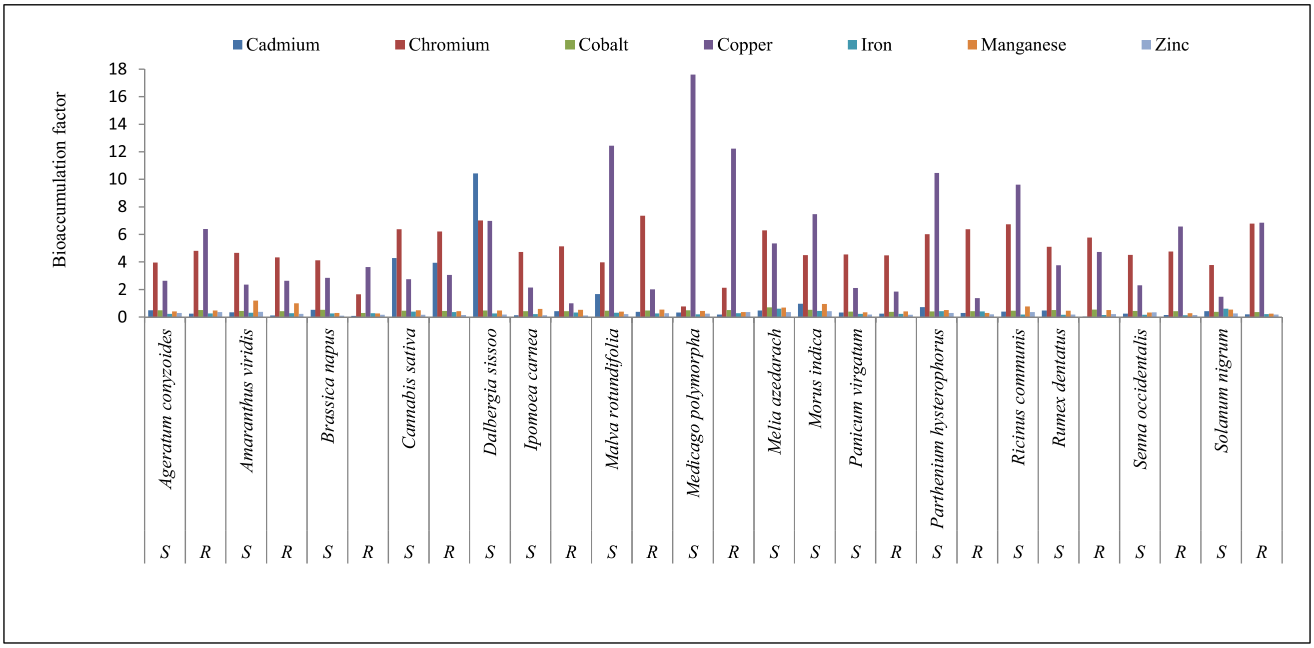

Fig. 2 Bioaccumulation factors of studied metals in different plant species growing around the pond of village Sahlon (site 1) of district Shaheed Bhagat Singh Nagar, Punjab

Comprehensive bioconcentration index

The present study compares plant species at three different sites growing under their indigenous environmental conditions. CBCI reveals the overall performance of plants in terms of bioaccumulation of multiple metals to assess their phytoremediation ability (Zhao et al. 2014). Principal component analysis was applied on the CBCI values of plants at all three sites (Fig. 5). The analysis reduced the variables into two main principal components (PCs) explaining total of 97.876% variability. PC 1 and PC 2 explained 63.54% and 34.34% variability respectively. Component 1 revealed positive association with CBCI values for plant shoots at all three sites along with plant roots at site 1, whereas PC 1 displayed

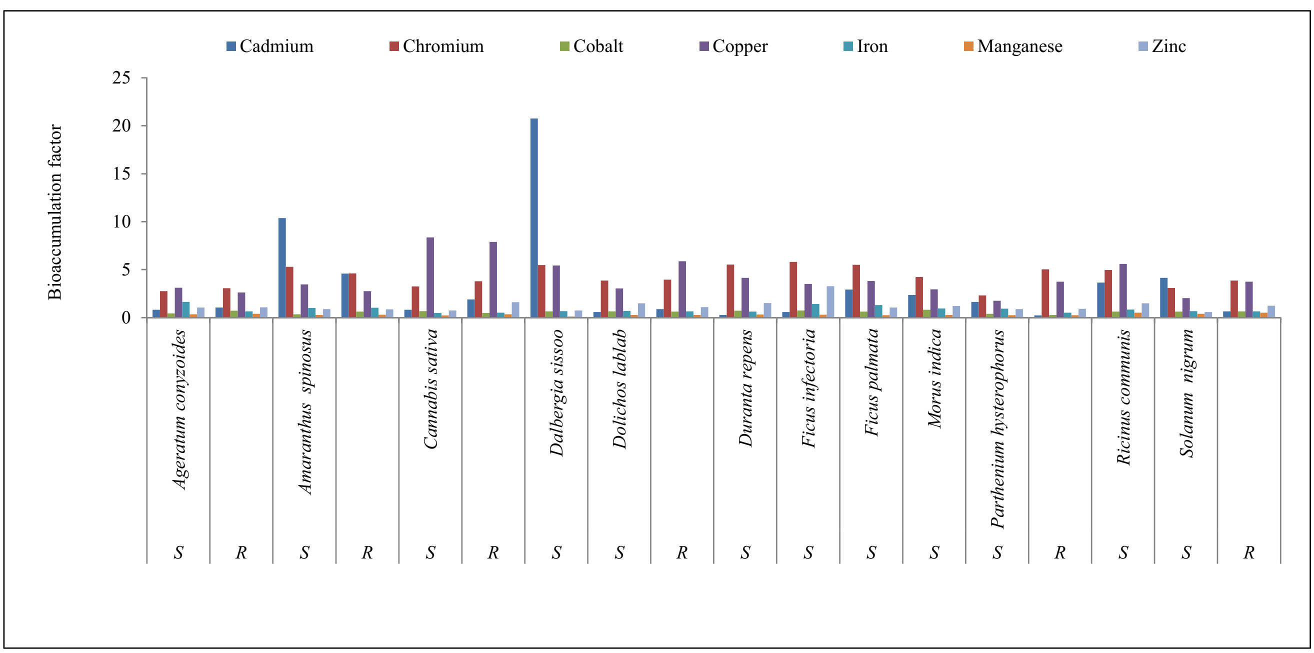

Fig. 3 Bioaccumulation factors of studied metals in different plant species growing around the pond of village Chahal Khurd (site 2) of district Shaheed Bhagat Singh Nagar, Punjab

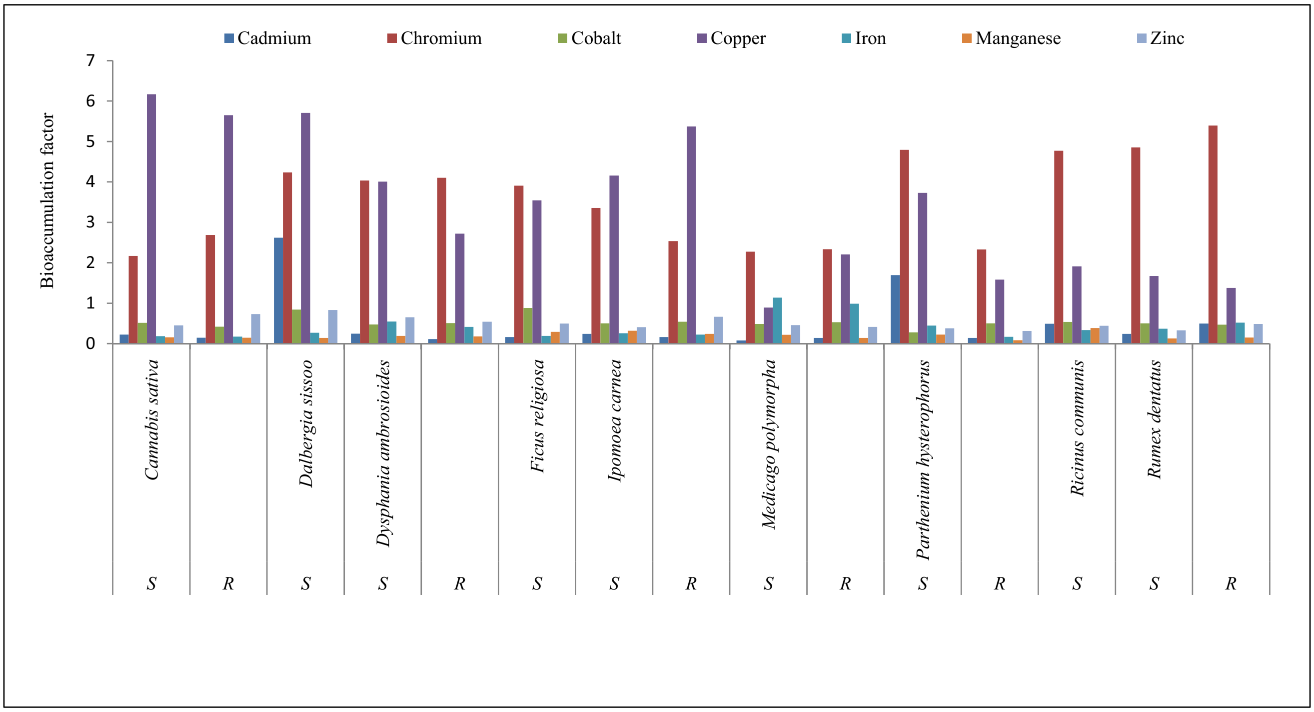

Fig. 4 Bioaccumulation factors of studied metals in different plant species growing around the pond of village Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab

Table 6 Translocation factors of studied metals in different plant species grown around the ponds of villages Sahlon (site 1), Chahal Khurd (site 2), and Karnana (site 3) of district Shaheed Bhagat Singh Nagar, Punjab

S. no.	Plant species	Site	Cadmium	Chromium	Cobalt	Copper	Iron	Manganese	Zinc
1.	*Ageratum conyzoides* (L.) L.	1	1.962	0.825	0.968	0.411	0.897	0.889	0.816
		2	0.793	0.899	0.599	1.181	2.537	0.882	0.986
2.	*Amaranthus viridis* L.	1	3.024	1.075	1.044	0.894	1.106	1.197	1.662
3.	*Amaranthus spinosus* L.	2	2.264	1.146	0.535	1.259	0.989	0.892	1.016
4.	*Brassica napus* L.	1	6.667	2.483	1.789	0.782	0.893	1.065	0.616
5.	*Cannabis sativa* L.	1	1.087	1.028	1.028	0.900	1.064	1.135	1.167
		2	0.426	0.859	1.406	1.060	0.570	0.628	0.457
		3	1.526	0.807	1.229	1.092	1.084	1.074	0.616
6.	*Dolichos lablab* L.	2	0.664	0.976	1.021	0.518	1.062	1.019	1.355
7.	*Dysphania ambrosioides* (L.) Mosyakin & Clemants	3	2.250	0.984	0.934	1.474	1.331	1.055	1.214
8.	*Ipomoea carnea* Jacq.	1	0.311	0.922	1.013	2.140	0.642	1.129	1.034
		3	1.471	1.323	0.927	0.774	1.138	1.306	0.614
9.	*Malva rotundifolia* L.	1	4.375	0.540	0.990	6.205	1.184	0.744	0.804
10.	*Medicago polymorpha* L.	1	1.813	0.360	0.980	1.441	0.677	1.209	0.678
		3	0.564	0.974	0.911	0.405	1.155	1.549	1.101
11.	*Panicum virgatum* L.	1	1.367	1.014	1.023	1.149	1.009	0.812	1.059
12.	*Parthenium hysterophorus* L.	1	2.427	0.943	0.993	7.624	1.019	1.742	1.475
		2	7.463	0.458	1.427	0.468	1.845	0.945	0.967
		3	11.97	2.059	0.554	2.353	2.641	2.653	1.217
13.	*Rumex dentatus* L.	1	11.06	0.884	0.939	0.796	1.186	0.893	0.855
		3	0.490	0.900	1.064	1.213	0.707	0.831	0.685
14.	*Senna occidentalis* (L.) Link	1	1.563	0.949	1.052	0.349	1.275	1.156	2.429
15.	*Solanum nigrum* L.	1	2.120	0.556	1.032	0.215	2.886	2.276	1.492
		2	6.497	0.803	0.942	0.541	1.028	0.804	0.464

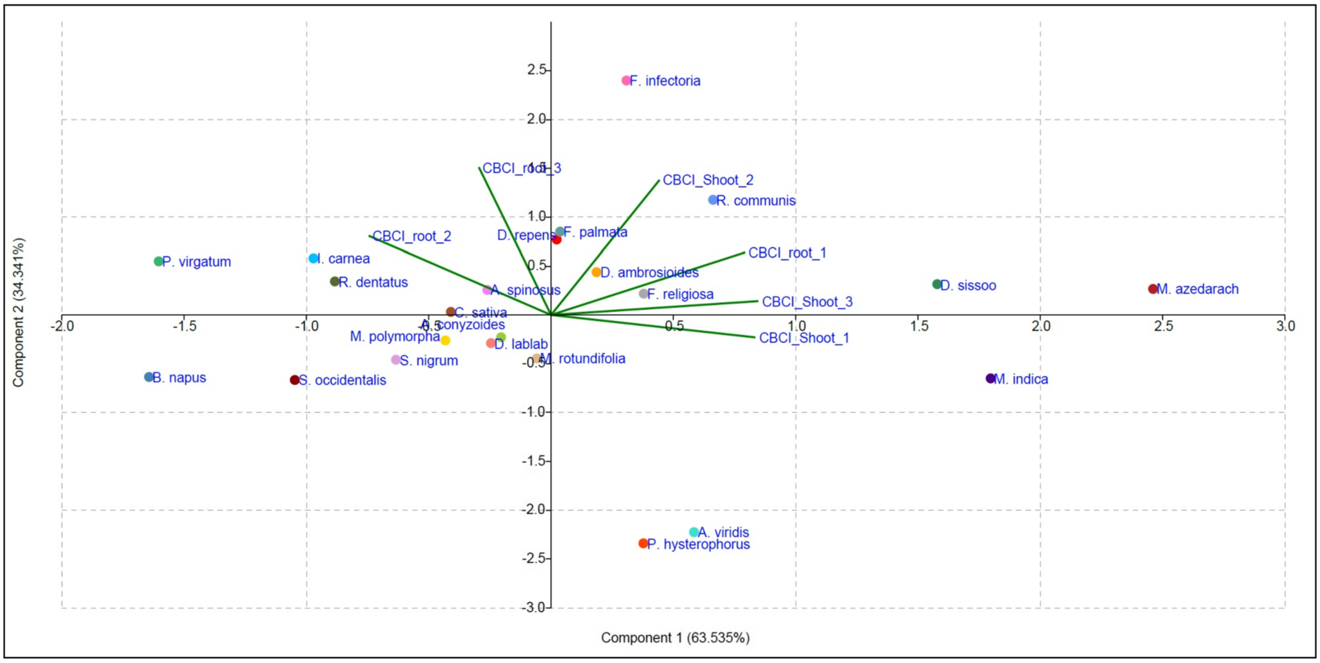

Fig. 5 Reduction of multidimensional variables by Principal Component Analysis (PCA) for plant roots and shoots at three sites [CBCI_Shoot _1, 2, 3; CBCI_root _1, 2, 3 means CBCI values of shoot and root for plants at site 1, 2 and 3]

no association with CBCI values for plant roots at site 2 and site 3 explaining inverse association with low variability by roots at site 3 for first component. Overall, high variability of PC 1 was observed in *M. azedarach*, *M. indica*, *D. sissoo*, *R. communis*, and *F. infectoria*. In case of PC 2, almost all CBCI values were positively associated except the CBCI value of plant shoot at site 1. High variability of PC 2 was observed by *D. repens*, *F. infectoria*, *F. palmata*, and *R. communis*. Also, as shown in Table 4 and Table 5, CBCI results indicated that trees exhibited a strong capacity for accumulation of different metals as compared with shrubs and herbs. *M. azedarach* (0.626), *M. indica* (0.572), *D. sissoo* (0.497), and *R. communis* (0.474) at site 1 showed high CBCI values. At site 2, *F. infectoria* (0.629), *R. communis* (0.541), *D. sissoo* (0.483), *F. palmata* (0.457), and *D. repens* (0.448), and at site 3, *D. sissoo* (0.681), *F. religiosa* (0.447), and *R. communis* (0.429) were the highest CBCI valued plants. Herbs like *C. sativa*, *M. polymorpha*, and *Amaranthus* spp. showed high accumulation of individual heavy metals, but cumulatively trees appeared to be the better accumulators of multiple heavy metals. In previous studies, trees were also found to be efficient air pollutant removers (Beckett et al. 1998, 2000; Fowler et al. 1989; Hu et al. 2014; Mok et al. 2013; Nowak et al. 2006; Serbula et al. 2012; Tomašević et al. 2004; Yang et al. 2005). Along with various soil-polluting factors, trees are prone to air pollution and their leaves can accumulate various metals simultaneously (Liu et al. 2007). Leaves quickly absorb a substantial amount of metals that deposits on their surfaces as dry aerosol particles (Hu et al. 2014; Kleckerová and Dočekalová 2014).

Conclusion

In the present research, detailed information on metals accumulated by plants, soil, sediment, and water revealed deviated results depending upon site-wise conditions. Moreover, the results provided viable information about bioaccumulation capacities of plant species for different heavy metals on individual and combined basis. The highest BA*f* for Cd, Cr, Co, Cu, Fe, Mn, and Zn was shown in *D. sissoo* (shoots), *M. rotundifolia* (roots), *F. religiosa* (shoots), *M. polymorpha* (shoots), *A. conyzoides* (shoots), *A. viridis* (shoots), and *F. infectoria* (shoots) respectively. Considering the combined pollutants at each site, *M. azedarach*, *F. infectoria*, and *D. sissoo* showed the high cumulative bioaccumulation capacity. A suitable mix of herbs, shrubs, and trees in accordance with the present study can be cultivated for remediation of both soil and atmospheric pollution caused by different heavy metals.

Funding information The present study was supported by the University Grants Commission (UGC), New Delhi, under the Maulana Azad National Fellowship scheme to the first author (vide grant no. 201213-MANF-2012-13-SIK-PUN-16486). The authors received the financial assistance granted by the University Grants Commission (UGC), New Delhi, for instrumentation facility under UGC CPEPA and UPE program.

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