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Research Article

Lead phytoremediation potential of sixty-one plant species: An open field survey

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Abstract

Lead poisoning has been documented as a key public health threat, mostly in developing countries. Though several public health and occupational methods have been undertaken in order to control lead exposure, cases of lead poisoning are still reported. Exposure to lead produces various deleterious effects on the hematopoietic, renal, and reproductive and central nervous system, mainly through increased oxidative stress. These alterations play a prominent role in disease manifestations. In the current paper the concentration of lead was analysed in the soil of different sites and plant parts (roots and shoots) in their natural habitat. The concentration of lead in the soil and plant parts; roots and shoots was found in the range of 1-32.3, 22-533.33 and 13.67-432 mg/Kg respectively. Bioconcentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC) of all the analysed plants were calculated. The feasibility of each plant species for the phytoremediation of lead metal was evaluated on the basis of BCF, TF and BAC. The BCFs, TFs and BACs values of the plants for lead metal was found in the range of 1.86-193.33, 0.05-8.3 and 1.79-219 respectively. Most of the plant species showed feasibility for the phytoremediation of lead metal but based on its concentration in shoots and BCFs, TFs and BACs values, *Erigeron canadensis* L., *Stellaria media* (L.) Vill. *Medicago minima* (L.) L., *Delphinium uncinatum* Hook.f. & Thomson and *Verbena officinalis* L. were found the most efficient plants for the phytoextraction of lead while based on its concentration in roots and BCFs, TFs and BACs values, *Nonea edgeworthii* A. DC., *Arabidopsis thaliana* (L.) Heynh., *Sarcococca saligna* (D. Don) Muell.-Arg. in DC., Prodr., *Marrubium vulgare* L. and *Ranunculus arvensis* L. for the phytostabilization of lead metal.

Keywords: Lead; Phytoremediation; Phytoextraction; Phytostabilization

Introduction

One among the serious problems in the ecosphere is the contamination of the ecosystems by heavy metals. The practice of heavy metals for numerous applications has focused the release of these components into the environment. The problem of heavy metal pollution is becoming ever more severe with the industrial growth and disturbance of the usual biogeochemical cycles. Heavy metals are basically non-biodegradable and therefore accumulate in the ecosystem. The accumulation of these contaminants in soil and water poses risks to the health of living organisms and ecosystems. Heavy metals accumulate in the tissues of the living organisms as they pass from the trophic levels and therefore their concentrations increase in them. In soil heavy metals cause poisonous effects on soil microorganisms, which may render their activities and numbers [1]. Heavy metals are characterized as non-essential and essential regarding their role. Essential heavy metals (iron, manganese, copper, zinc, and nickel) are needed by living organisms in small quantities [2] while non-essential heavy metals (cadmium, lead, arsenic, mercury, and chromium) are not required for vital biochemical and physiological functions by living organisms [3]. The concentration of these metals beyond the permitted limits interferes with the normal physiology of the living systems therefore pose harmful effects on health.

Lead is the most significant toxic heavy metal in the environment. Due to its main physico-chemical belongings, its use can be reviewed to historical times. Worldwide it is profusely distributed and is dangerous ecological chemical [4]. Its significant properties like malleability, softness, ductility, resistance to corrosion and poor conductibility seem to make hard to give up its use. Due to its continuous use and non-biodegradable nature, its concentration accumulates in the environment with increasing risks. The exposure of human to lead and its compounds occurs generally in lead related occupations with numerous sources like industrial processes and leaded gasoline such as lead smelting and its combustion, pottery, lead based painting, boat building, lead containing pipes, grids, arm industry, battery recycling, printing of books, pigments etc. Still its widespread use has withdrawn in many countries of the world, it is still used in many industries like battery recycling and manufacturing, car repair, smelting, refining etc. it is a highly toxic metal affecting virtually every organ in the body. Nervous system is the frequently affected target in lead toxicity both in adults and children. In children lead toxicity is however of a greater impact than in adults. This is because their tissues internally and externally are softer than in adults. The exposure adults for longer time can lead in declined performance in some tests of cognitive performance that measure functions of the nervous system. Young children and Infants are more sensitive to even low concentrations of lead, which may contribute to learning deficits, behavioural problems and lowered IQ [5]. Exposure to lead for longer time has been documented to cause an increase in blood pressure along with anaemia, and that primarily in middle and old age people. Severe harm to the kidneys and brain, both in children and adult were found to be connected to exposure to heavy lead concentrations leading in death. High exposure to lead in pregnant women's may cause miscarriage. Long-lasting lead exposure was found to diminish fertility in males [6]. Impairment to the nervous system and blood disorders have a high incidence in lead toxicity.

A suitable in situ technique which is cost-effective and environmentally sustainable for removing metals like lead from soils is represented by phytoremediation (the use of higher plants to clean up soils). One phytoremediation strategy consists of phytoextraction, employing hyper accumulator plants to concentrate metals at the shoot level [7, 8]. Care should be taken in choosing the right hyper accumulator species for the application of phytoremediation techniques, because the introduction of alien plants may alter and disrupt indigenous ecosystems [9] and because well-known hyper accumulator species may be unsuitable for local climatic conditions [10].

In the present research work sixty one plant species belongs to thirty families were collected and analysed for the concentration of lead metal. It was analysed in the soil of the root zone, in root and shoot of each plant. Phytoremediation potential of the analysed plants grown in their natural habitats was evaluated by the calculation of Bioconcentration Factor (BCF), Translocation Factor (TF) and Biological Accumulation Coefficient (BAC).

Materials and methods

Research area

Lower Dir is one of the 26 districts of the Khyber Pakhtunkhwa province of Pakistan. The district was formed in 1996, when the district of Dir was divided into Upper Dir and Lower Dir. Timergara city is the district headquarters and largest city. It mainly comprises the terrain drained by the Panjkora River and its affluents. Dir takes its name from the name of a village, Dir, which served as the capital of the state during the Nawabs era Dir (princely state). It has District Swat in the East, Afghanistan on the West, Upper Dir on North-West and Malakand on the south. Pashto is the main spoken language of the population, followed by Kohistani and Gujri.

Collection of plants and soil from the research area

Sixty one plant species were collected from different locations of the research area. Soil was also collected from the root zone of each collected plant. Soil was analyzed for the background concentrations of lead. Collected plants were identified with the help of Flora of Pakistan or by matching with the already preserved specimens at the Herbarium of Islamia College University Peshawar. After identification, each plant was separated into roots and shoots. These plant parts were dried in the shade for a week and then fully dried in an oven at 75°C for 24 hours. Plant parts were grinded with the help of pestle and mortar. The powdered samples were digested using HNO_3 and $HClO_4$ and analyzed for the concentrations of lead using Atomic Absorption Spectroscopy (AAS). Bioconcentration factor (BCF) as well as a translocation factor (TF) of the collected plants were determined and their overall feasibility for the phytoextraction and phytostabilization was evaluated **[11-13]**.

Analysis of heavy metals in soil

The collected soil of the root zone of each plant was analyzed for the background concentrations of lead. Heavy metals in the soil were determined according to Sharidah **[14]** 5g sample of the soil was taken in a 100 mL beaker. 3 mL of 30% H_2O_2 was added to it. This was left undisturbed for 1 hour until the vigorous reaction ceased. Then 75 mL of 0.5 M HCl solution was added to it and heated on hot plate for 2 hours. The digest was filtered through a Whatman filter paper. The filtrate was used for the determination of lead by atomic absorption spectrometry. The analysis was conducted in triplicate. Results were shown as mean.

Analysis of accumulated heavy metals in plant samples

For this purpose, each plant part was thoroughly washed with tape water and then with distilled water in order to remove dusts and soil particles. The clean plant parts were dried in an oven at 105ºC for 24 hours. Then the plant samples were grinded with the help of pestle and mortar. The powder was digested according to Awofolu **[15]**. 0.5 g sample of the plant part was taken into a 100 mL beaker. 5 mL concentrated (65%) HNO_3 and 2 mL $HClO_4$ were added to it and heated on hot plate until the digest became clear. The digest was allowed to cool and then filtered through a Whatman filter paper. The filtrate was collected in a 50 mL volumetric flask and diluted to the mark with distilled water. The filtrate was used for the analysis of lead by AAS. As mentioned previously, each experiment was run in triplicate. Results were shown as mean.

Evaluation of plants for the phytoextraction of lead

Bioconcentration factor (BCF) indicates the efficiency of a plant in up-taking heavy metals from soil and accumulating them into its tissues. "It is a ratio of the concentration of lead in the plant tissue (root, stem or leaves) to that in soil." It is calculated as follows **[13]**.

$$Bioconcentration\ Factor\ (BCF) = \frac{C\ Pb_{\ harvested\ tissue}}{C\ Pb_{\ soil}} \ldots (1)$$

where $C_{harvested\ tissue}$ is the concentration of the metal in the plant harvested tissue (roots) and C_{soil} is the concentration of the same metal in soil.

Translocation factor (TF) shows the efficiency of the plant in translocating lead from roots to shoots. "It is a ratio of the concentration of lead in shoots to that in its roots." It is calculated as follows [11, 12].

$$Translocation\ Factor\ (TF) = \frac{C\ Pb_{shoots}}{C\ Pb_{roots}} \ldots (2)$$

Whereas $C\ Pb_{shoots}$ is the concentration of lead in shoots and C Pb $_{roots}$ is the concentration of the metal in roots.

Bioaccumulation Coefficient (BAC) is the ratio of the concentration of lead in plant shoot to that in the soil and was calculated for all the studied plants according to the equation given below [16-18].

$$Bioaccumulation\ Coefficient(BAC) = \frac{C\ Pb_{shoots}}{C\ Pb\ Soil} \ldots\ldots (3)$$

Where C Pb $_{shoots}$ is the concentration of lead in the shoots and C Pb $_{Soil}$ is the concentration of metal in soil. BCFs, TFs and BACs of the studied plants for lead were calculated according to the mentioned formulas. From these calculations, the feasibility of the plants for the phytoextraction and phytostabilization of the lead was evaluated.

Statistical analysis

Each experiment was conducted in triplicate (n = 3). Results are shown as mean ± standard Deviation. Experimental data were analysed using Excel

Results and discussion

Concentration of lead in the analysed plants

The family, botanical name, number of site and name of the site of collection as well as the concentration of lead in the soil and plant parts (root and shoot) are shown in (Table 1). The concentration of lead in the soil of different sites and plant parts (roots and shoots) was found in the range of 1-32.3, 22-533.33 and 13.67-432 mg/Kg respectively.

Evaluation of the analysed plants for the phytoremediation of lead

Bioconcentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC) of all the analysed plants were calculated. The feasibility of each plant species for the phytoremediation; phytoextraction and phytostabilization of lead metal was evaluated. The BCFs, TFs and BACs values of the plants for lead metal was found in the range of 1.86-193.33, 0.05-8.3 and 1.79-219 respectively (Table 2).

Concentration of lead in the soil of the analysed sites

It is clear from the data of (Table 1) that the concentration of lead in the soil of sixty one sites varies in the range of 1- 32.3 mg/Kg. The concentration of lead in the soil of the studied sites in mg/Kg was found in the order: Site 30 (32.3) > Site 39 (30.5) > Site 50 (28.8) > Site 4 (28.63) > Site 43 (25.6) > Site 10 (24.6) > Site 54 (21.93) > Site 12 (21.1) > Site 29 (19.9) > Site 60 (18.93) > Site 27 (18.63) > Site 9 (17.8) > Site 22 (17) > Site 24 (16.6) > Site 20 (16.33) > Site 13 (14.73) > Site 11 (14.7) ≥ Site 28 (14.7) > Site 44 (12.73) > Site 32 (11.53) > Site 31 (11.17) > Site 45 (10.23) > Site 59 (9.83) > Site 35 (9.17) > Site 37 (8.13) > Site 33 (8.07) > Site 25 (7.97) > Site 1 (7.93) > Site 17 (7.7) > Site 52 (7.6) > Site 61 (6.8) > Site 21 (6.76) > Site 53 (5.83)> Site 26 (5.7) > Site 19 (5.47) > Site 23 (5.33) > Site 3 (5.07) > Site 51 (4.9) > Site 18 (4.8) > Site 8 (3.93) > Site 16 (3.9) > Site 48 (3.27) > Site 14 (2.9) > Site 5 (2.67) > Site 42 (2.57) > Site 34 (2.33) > Site 49 (2.27) > Site 6 (2.2) > Site 58 (1.9) > Site 57 (1.87) > Site 56 (1.8) > Site 15 (1.73) > Site 55 (1.63) > Site 38 (1.6) > Site 7 (1.53) ≥ Site 40 (1.53) > Site 41 (1.47) > Site 47 (1.4) > Site 26 (1.17) > Site 2 (1.1) > Site 36 (1). The permissible limit of lead in soil is 32 mg/Kg [19]. Results indicate that the concentration of lead in the soil of site 30 is higher (32.3) than the allowable limit while in the rest of the sites is less than the permissible limit.

Concentration of lead in the roots and shoots of the analysed plants

Data of the (Table 1) shows that the concentration of lead was found in the roots of the plants in the range of 22-533.33 mg/Kg. Its concentration in the roots of all the analyzed plants in mg/Kg was found in the order: *Arabidopsis thaliana* (L.) Heynh. (533.33) > *Ranunculus arvensis* L. (501.33) > *Nonea edgeworthii* A. DC. (392.66) > *Sarcococca saligna* (D.Don) Muell.-Arg. in DC. Prodr. (392) > *Marrubium vulgare* L. (309.33) > *Urtica pilulifera* L. (304.66) > *Medicago minima* (L.) L. (303.33) > *Calendula arvensis Boiss.* (290.66) > *Stellaria media* (L.) Vill. (260) > *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson (246.66) > *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (232.33) > *Duchesnea indica* (Jacks.) Focke (221.66) > *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger (220) ≥ *Rosa macrophylla* Lindl. (220) > *Cannabis sativa* L. (194) > *Artemisia japonica* Thunb. (188.33) > *Delphinium suave* Huth (177) > *Xanthium strumarium* L. (176) > *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. (167.66) > *Lactuca dissecta* D.Don (129) > *Iris germanica L.* (127.66) > *Onosma hispida* Wall. ex G. Don (119.33) > *Plantago lanceolata* L. (116.33) ≥ *Delphinium uncinatum Hook.f. & Thomson* (116.33) > *Emex spinosa* (L.) Campd. (112.33) > *Salvia moorcroftiana Wall. ex Benth.* (112) > *Filago hurdwarica* (Wall. ex DC.) Wagenitz (110.66) > *Silybum marianum (L.) Gaertn.* (108) > *Verbascum thapsus* L. (101.66) > *Sanguisorba minor* Scop. (96.33) > *Rydingia limbata* (Benth.) Scheen & V.A.Albert (91.67) > *Cousinia buphthalmoides* Regel (90) > *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (88.33) > *Daphne mucronata* Royle (88) > *Teucrium stocksianum* Boiss. (86.33) > *Persicaria glabra* (Willd.) M. Gómez (79) > *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (76) > *Verbena officinalis* L. (65.67) > *Polygala abyssinica* R.Br. ex Fresen. (64.33) > *Astragalus pyrrhotrichus* Boiss. (60.67) > *Ajuga integrifolia* Buch.-Ham. (60.53) > *Isatis tinctoria* L. (58.67) > *Asplenium dalhousiae* Hook. (58.33) > *Torilis leptophylla* (L.) Rchb.f. (56.67) > *Sisymbrium irio* L. (53) > *Euphorbia helioscopia* L. (50.33) > *Vicia sativa* L. (48) ≥ *Geranium rotundifolium* L. (48) > *Himalaiella heteromalla* (D.Don) Raab-Straube (47.33) > *Erigeron canadensis* L. (45.67) > *Cerastium glomeratum* Thuill. (44.67) > *Medicago lupulina* L. (42.67) > *Artemisia vulgaris* L. (35) > *Argyrolobium stenophyllum* Boiss (32) > *Pteris cretica* L. (31.67) > *Catharanthus roseus* (L.) G. Don (31.33) > *Cirsium vulgare* (Savi) Ten. (30) > *Cheilanthes pteridoides C. Chr.* (28.67) > *Allium griffithianum* Boiss. (27.33) > *Solanum nigrum* L., Sp. Pl. (26) > *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (22).The permissible limit of Lead in plants recommended by WHO is 2 mg/Kg **[20]**. Results showed that the concentration of Lead in the roots of all the plants is higher than that of this permissible limit.

Concentration of lead in the shoots of the analysed plants

It is evident from the data of (Table 1) that the concentration of lead in the shoots of the analyzed plant in mg/Kg was found in the order: *Arabidopsis thaliana* (L.) Heynh. (432) > *Medicago minima* (L.) L. (394) > *Erigeron canadensis* L. (379) > *Stellaria media* (L.) Vill. (298.33) > *Verbena officinalis* L. (269.33) > *Delphinium uncinatum* Hook.f. & Thomson (251.66) > *Ranunculus arvensis* L. (249) > *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (240.33) > *Salvia moorcroftiana Wall. ex Benth.* (239.66) > *Onosma hispida* Wall. ex G. Don (228.33) > *Marrubium vulgare* L. (221.66) > *Delphinium suave* Huth (219.33) > *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (219) > *Cerastium glomeratum* Thuill. (218.33) > *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson (194) > *Isatis tinctoria* L. (189.66) > *Lactuca dissecta* D.Don (188.66) > *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (179) > *Himalaiella heteromalla* (D.Don) Raab-Straube (170.33)> *Daphne mucronata* Royle (169.33)> *Bryophyllum* *daigremontianum* (Raym.-Hamet & Perrier) A. Berger (162.66) > *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. (160) > *Cirsium vulgare* (Savi) Ten. (150.33) > *Sanguisorba minor* Scop. (149) > *Allium griffithianum* Boiss. (147.33) > *Sarcococca saligna* (D.Don) Muell.-Arg. in DC. Prodr. (144.66) > *Cannabis sativa* L. (139) > *Astragalus pyrrhotrichus* Boiss. (138.33) > *Asplenium dalhousiae Hook.* (119.33) > *Filago hurdwarica* (Wall. ex DC.) Wagenitz (109.66) > *Duchesnea indica* (Jacks.) Focke (108.66) > *Rydingia limbata* (Benth.) Scheen & V.A.Albert (99) > *Pteris cretica* L. (98.67) > *Euphorbia helioscopia* L. (98.33) > *Solanum nigrum* L., Sp. Pl. (97.67) > *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (97.33) > *Emex spinosa* (L.) Campd. (88.33) > *Nonea edgeworthii* A. DC. (82.33) > *Vicia sativa* L. (80) > *Silybum marianum* (L.) Gaertn. (79.67) > *Plantago lanceolata* L. (70.67) > *Verbascum thapsus* L. (69.67) > *Artemisia japonica* Thunb. (69.33) > *Iris germanica* L. (67.67) ≥ *Rosa macrophylla* Lindl. (67.67) > *Medicago lupulina* L. (61.67) > *Catharanthus roseus* (L.) G. Don (61.33) > *Polygala abyssinica* R.Br. ex Fresen. (56.33) > *Persicaria glabra* (Willd.) M. Gómez (54.33) > *Xanthium strumarium* L. (51.33) > *Cousinia buphthalmoides* Regel (50) > *Silybum marianum* (L.) Gaertn. (49.33) > *Urtica pilulifera* L. (40) > *Artemisia vulgaris* L. (39.67) > *Argyrolobium stenophyllum* Boiss (32.67) > *Ajuga integrifolia* Buch.-Ham. (31) > *Cheilanthes pteridoides* C. Chr. (28.67) > *Torilis leptophylla* (L.) Rchb.f. (26.33) > *Teucrium stocksianum* Boiss. (24.67) > *Geranium rotundifolium* L. (20.67) > *Calendula arvensis* Boiss. (13.67).The permissible limit of Lead in plants recommended by WHO is 2 mg/Kg [20]. Results showed that the concentration of Lead in the shoots of all the plants is higher than this permissible limit.

Bioconcentration factor (BCF) of the analysed plants for lead

It is clear from the data of (Table 2) that the Bioconcentration factor (BCF) was calculated as lead concentration ratio of plant roots to soil [18, 21, 22]. The calculated bioconcentration factor (BCF) of all the plants was in the order: *Marrubium vulgare* L. (193.33) > *Calendula arvensis* Boiss. (189.97) > *Rosa macrophylla* Lindl. (134.97) > *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (124.91) > *Arabidopsis thaliana* (L.) Heynh. (111.11) > *Xanthium strumarium* L. (101.73) > *Nonea edgeworthii* A. DC. (100.68) > *Emex spinosa* (L.) Campd. (96.01) > *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (88.33) > *Salvia moorcroftiana* Wall. ex Benth. (73.2) > *Artemisia japonica* Thunb. (70.54) > *Ranunculus arvensis* L. (65.97) > *Teucrium stocksianum* Boiss. (58.73) > *Verbascum thapsus* L. (56.48) > *Persicaria glabra* (Willd.) M. Gómez (56.43) > *Torilis leptophylla* (L.) Rchb. f. (51.52) > *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson (43.27) > *Duchesnea indica* (Jacks.) Focke (38.02) > *Silybum marianum* (L.) Gaertn. (37.24) > *Cannabis sativa* L. (36.4) > *Delphinium suave* Huth (36.12) > *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (32.62) > *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger (27.6) > *Astragalus pyrrhotrichus* Boiss. (23.61) > *Sarcococca saligna* (D.Don) Muell.-Arg. in DC. Prodr. (23.06) > *Urtica pilulifera* L. (16.09) > *Stellaria media* (L.) Vill. (15.92) > *Artemisia vulgaris* L. (15.91) > *Iris germanica* L. (15.82) > *Onosma hispida* Wall. ex G. Don (15.5) > *Pteris cretica* L. (13.95) > *Solanum nigrum* L., Sp. Pl. (13.68) > *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. (13.17) > *Isatis tinctoria* L. (10.73) > *Verbena officinalis* L. (9.66) > *Medicago minima* (L.) L. (9.39) > *Daphne mucronata* Royle (8.95) > *Cheilanthes pteridoides C. Chr.* (8.77) > *Sisymbrium irio* L. (7.84) > *Cirsium vulgare (*Savi) Ten. (7.63) > *Filago hurdwarica* (Wall. ex DC.) Wagenitz (7.53) > *Ajuga integrifolia*

Buch.-Ham. (6.6) > *Polygala abyssinica* R.Br. ex Fresen. (6.29) > *Catharanthus roseus* (L.) G. Don (6.18) > *Lactuca dissecta* D.Don (6.11) > *Cousinia buphthalmoides* Regel (5.06) > *Plantago lanceolata* L. (4.54) > *Sanguisorba minor* Scop. (4.39) > *Vicia sativa* L. (4.3) > *Geranium rotundifolium* L. (4.16) > *Delphinium uncinatum* Hook.f. & Thomson (4.04) > *Allium griffithianum* Boiss. (3.45) > *Himalaiella heteromalla* (D.Don) Raab-Straube (3.21) > *Rydingia limbata* (Benth.) Scheen & V.A.Albert (3.01) > *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (2.71) > *Euphorbia helioscopia* L. (2.7) > *Cerastium glomeratum* Thuill. (2.69) > *Argyrolobium stenophyllum* Boiss (2.18) > *Medicago lupulina* L. (2.14) > *Asplenium dalhousiae* Hook. (2.04) > *Erigeron canadensis* L. (1.86). Sheoran *et al.* [23] stated that the plants are not feasible for the phytoextraction of metal if bioconcentration factor is less than one. Fitz and Wenzel [24] demonstrated that plants exhibiting BCF value less than one are unsuitable for the phytoextraction of metals. Results showed that the calculated bioconcentration factor of all the plants was greater than one.

Translocation factor (TF) of the analysed plants for lead

Data of (Table 2) indicates that the Translocation Factor (TF) was described as ratio of lead in plant shoot to that in plant root [16-18, 21]. The translocation factor of the plants was found in the order: *Erigeron canadensis* L. (8.3) > *Allium griffithianum* Boiss. (5.39) > *Cirsium vulgare* (Savi) Ten. (5.01) > *Cerastium glomeratum* Thuill. (4.89) > *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (4.42) > *Verbena officinalis* L. (4.1) > *Solanum nigrum* L., Sp. Pl. (3.76) > *Himalaiella heteromalla* (D.Don) Raab-Straube (3.6) > *Isatis tinctoria* L. (3.23) > *Pteris cretica* L. (3.16) > *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (2.48) > *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (2.36) > *Astragalus pyrrhotrichus* Boiss. (2.28) > *Delphinium uncinatum* Hook.f. & Thomson (2.16) > *Salvia moorcroftiana* Wall. ex Benth. (2.14) > *Asplenium dalhousiae* Hook. (2.05) > *Catharanthus roseus* (L.) G. Don (1.96) > *Euphorbia helioscopia* L. (1.95) > *Daphne mucronata* Royle (1.92)> *Onosma hispida* Wall. ex G. Don (1.91)> *Vicia sativa* L. (1.67) > *Sanguisorba minor* Scop. (1.55) > *Sisymbrium irio* L. (1.5) > *Lactuca dissecta* D.Don (1.46) > *Medicago lupulina* L. (1.45) > *Medicago minima* (L.) L. (1.3) > *Delphinium suave* Huth (1.24) > *Stellaria media* (L.) Vill. (1.15) > *Artemisia vulgaris* L. (1.13) > *Rydingia limbata* (Benth.) Scheen & V.A.Albert (1.08) > *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (1.03) > *Argyrolobium stenophyllum* Boiss (1.02) > *Filago hurdwarica* (Wall. ex DC.) Wagenitz (1) ≥ *Cheilanthes pteridoides C. Chr.* (1) > *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. (0.95) > *Polygala abyssinica* R.Br. ex Fresen. (0.88) > *Arabidopsis thaliana* (L.) Heynh. (0.81) > *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson (0.79) ≥ *Emex spinosa* (L.) Campd. (0.79) > *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger (0.74) > *Cannabis sativa* L. (0.72) ≥ *Marrubium vulgare* L. (0.72) > *Persicaria glabra* (Willd.) M. Gómez (0.69) ≥ *Verbascum thapsus* L. (0.69) > *Plantago lanceolata* L. (0.61) > *Cousinia buphthalmoides* Regel (0.56) > *Iris germanica* L. (0.53) > *Ajuga integrifolia* Buch.-Ham. (0.51) > *Ranunculus arvensis* L. (0.5) > *Duchesnea indica* (Jacks.) Focke (0.49) > *Torilis leptophylla* (L.) Rchb.f. (0.47) > *Silybum marianum* (L.) Gaertn. (0.46) > *Geranium rotundifolium* L. (0.43) > *Artemisia japonica* Thunb. (0.37) ≥ *Sarcococca saligna* (D.Don) Muell.-Arg. in DC. Prodr. (0.37) > *Rosa macrophylla* Lindl. (0.31) > *Xanthium strumarium* L. (0.29) ≥ *Teucrium stocksianum* Boiss. (0.29) > *Nonea edgeworthii* A. DC. (0.21)

> *Urtica pilulifera* L. (0.13) > *Calendula arvensis* Boiss. (0.05). Translocation factor value > than one indicates translocation of metal from root to above ground part [25]. Results showed that the TF value of *Erigeron canadensis* L. (8.3), *Allium griffithianum* Boiss. (5.39), *Cirsium vulgare* (Savi) Ten. (5.01), *Cerastium glomeratum* Thuill. (4.89), *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (4.42), *Verbena officinalis* L. (4.1), *Solanum nigrum* L., Sp. Pl. (3.76), *Himalaiella heteromalla* (D.Don) Raab-Straube (3.6), *Isatis tinctoria* L. (3.23), *Pteris cretica* L. (3.16), *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (2.48), *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (2.36), *Astragalus pyrrhotrichus* Boiss. (2.28), *Delphinium uncinatum* Hook.f. & Thomson (2.16), *Salvia moorcroftiana* Wall. ex Benth. (2.14), *Asplenium dalhousiae* Hook. (2.05), *Catharanthus roseus* (L.) G. Don (1.96), *Euphorbia helioscopia* L. (1.95), *Daphne mucronata* Royle (1.92), *Onosma hispida* Wall. ex G. Don (1.91), *Vicia sativa* L. (1.67), *Sanguisorba minor* Scop. (1.55), *Sisymbrium irio* L. (1.5), *Lactuca dissecta* D.Don (1.46), *Medicago lupulina* L. (1.45), *Medicago minima* (L.) L. (1.3), *Delphinium suave* Huth (1.24), *Stellaria media* (L.) Vill. (1.15), *Artemisia vulgaris* L. (1.13), *Rydingia limbata* (Benth.) Scheen & V.A.Albert (1.08), *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (1.03), *Argyrolobium stenophyllum* Boiss (1.02), *Filago hurdwarica* (Wall. ex DC.) Wagenitz (1) and *Cheilanthes pteridoides* C. Chr. (1) is greater than one.

Bioaccumulation coefficient (BAC) of the analysed plants

It is clear from that data of (Table 2) that the Bioaccumulation (BAC) was calculated as ratio of lead metal in shoots to that in soil [16-18, 21]. The calculated bioaccumulation coefficient of each plant species was found in the order: *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. (219) > *Salvia moorcroftiana* Wall. ex Benth. (156.64) > *Marrubium vulgare* L. (138.54) > *Wulfeniopsis amherstiana* (Wall. ex Benth.) D.Y. Hong (129.21) > *Arabidopsis thaliana* (L.) Heynh. (90) > *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. (76.82) > *Emex spinosa* (L.) Campd. (75.5) > *Astragalus pyrrhotrichus* Boiss. (53.83) > *Solanum nigrum* L., Sp. Pl. (51.41) > *Delphinium suave* Huth (44.76) > *Pteris cretica* L. (43.47) > *Rosa macrophylla* Lindl. (41.52) > *Verbena officinalis* L. (39.61) > *Persicaria glabra* (Willd.) M. Gómez (38.81) > *Verbascum thapsus* L. (38.71) > *Cirsium vulgare* (Savi) Ten. (38.25) > *Isatis tinctoria* L. (34.67) > *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson (34.04) > *Ranunculus arvensis* L. (32.76) > *Xanthium strumarium* L. (29.67) > *Onosma hispida* Wall. ex G. Don (29.65) > *Cannabis sativa* L. (26.08) > *Artemisia japonica* Thunb. (25.97) > *Torilis leptophylla* (L.) Rchb.f. (23.94) > *Nonea edgeworthii* A. DC. (21.11) > *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger (20.41) > *Duchesnea indica* (Jacks.) Focke (18.64) > *Allium griffithianum* Boiss. (18.58) > *Stellaria media* (L.) Vill. (18.27) > *Artemisia vulgaris* L. (18.03) > *Daphne mucronata* Royle (17.22) > *Silybum marianum* (L.) Gaertn. (17.01) > *Teucrium stocksianum* Boiss. (16.78) > *Erigeron canadensis* L. (15.41) > *Cerastium glomeratum* Thuill. (13.15) > *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. (12.57) > *Medicago minima* (L.) L. (12.2) > *Catharanthus roseus* (L.) G. Don (12.1) > *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. (11.97) > *Sisymbrium irio* L. (11.79) > *Himalaiella heteromalla* (D.Don) Raab-Straube (11.56) > *Calendula arvensis* Boiss. (8.94) ≥ *Lactuca dissecta* D.Don (8.94) > *Cheilanthes pteridoides* C. Chr. (8.77) > *Delphinium uncinatum* Hook.f. & Thomson (8.74) > *Sarcococca saligna* (D.Don) Muell.-Arg. in DC. Prodr. (8.51) > *Iris germanica* L. (8.39) > *Filago hurdwarica* (Wall. ex DC.) Wagenitz (7.46) > *Vicia sativa* L. (7.16) > *Sanguisorba* *minor* Scop. (6.79) > *Polygala abyssinica* R.Br. ex Fresen. (5.51) > *Euphorbia helioscopia* L. (5.28) > *Asplenium dalhousiae* Hook. (4.17) > *Ajuga integrifolia* Buch.-Ham. (3.38) > *Rydingia limbata* (Benth.) Scheen & V.A.Albert (3.25) > *Medicago lupulina* L. (3.1) > *Cousinia buphthalmoides* Regel (2.81) > *Plantago lanceolata* L. (2.76) > *Argyrolobium stenophyllum* Boiss (2.22) > *Urtica pilulifera* L. (2.11) > *Geranium rotundifolium* L. (1.79). Only plant species with BCF, BAC and TF > than one have the potential for the remediation process [21]. Results showed that the BAC value of all the plants is greater than one.

Table 1. Family name, plant name, site number, name of site and concentration of lead in different parts of the plant

S. No	Family	species	S* No	Name of Site	Concentration of Lead (mg/Kg)		
					Soil	Root	Shoot
1.	Amaryllidaceae	*Allium griffithianum* Boiss.	1.	Munjae	7.93 ±0.15	27.33 ±1.53	147.33± 1.53
2.	Apiaceae	*Torilis leptophylla* (L.) Rchb.f.	2.	Thorathiga (Jail)	1.1 ±0.1	56.67 ±3.06	26.33 ±1.53
3.	Apocynaceae	*Catharanthus roseus* (L.) G. Don	3.	Kheima (Kally)	5.07 ±0.31	31.33 ±3.06	61.33 ±1.53
4.	Aspleniaceae	*Asplenium dalhousiae* Hook.	4.	Tissu Neher (Shehzadi)	28.63 ±0.35	58.33 ±1.53	119.33± 2.52
5.	Asteraceae	*Artemisia japonica Thunb.*	5.	Behari (Shorgar)	2.67 ±0.15	188.33 ±1.53	69.33 ±1.53
		Artemisia vulgaris L.	6.	Malakabad	2.2 ±0.2	35 ±1	39.67 ±2.08
		Calendula arvensis Boiss.	7.	Andhera (Khwar)	1.53 ±0.31	290.66 ±1.52	13.67 ±1.53
		Cirsium vulgare (Savi) Ten.	8.	Manzara Thanga (kalle)	3.93 ±0.15	30 ±1	150.33± 2.52
		Cousinia buphthalmoides Regel	9.	Bar Darmal (Ghar)	17.8 ±0.36	90 ±1	50 ±2
		Erigeron canadensis L.	10.	Bar Darmal (Kalle)	24.6 ±0.44	45.67 ±1.53	379 ±1.73
		Filago hurdwarica (Wall. ex DC.) Wagenitz	11.	Malakand (Khwar)	14.7 ±0.36	110.66 ±2.31	109.66± 1.53
		Lactuca dissecta D. Don	12.	Muslim Abad (Nawa Kalle)	21.1 ±0.2	129 ±2	188.66± 2.08
		Himalaiella heteromalla (D. Don) Raab-Straube	13.	Kuz Darmal (Kalle)	14.73 ±0.25	47.33 ±2.08	170.33± 2.52
		Silybum marianum (L.) Gaertn.	14.	Mian Banda (Kalle)	2.9 ±0.2	108 ±2	49.33 ±1.53
		Xanthium strumarium L.	15.	Thoratiga (Kalle)	1.73 ±0.21	176 ±2	51.33 ±2.51
6.	Boraginaceae	*Nonea edgeworthii* A. DC.	16.	Manzara Thanga (Ghar)	3.9 ±0.1	392.66 ±2.31	82.33 ±3.06
		Onosma hispida Wall. ex G. Don	17.	Majar Camp (Kalle)	7.7 ±0.17	119.33 ±1.53	228.33± 2.52

7.	Brassicaceae	*Arabidopsis thaliana* (L.) Heynh.	18.	Manzara Thanga (Shorgar)	4.8 ±0.2	533.33 ±2.31	432 ±2
		Isatis tinctoria L.	19.	Shengrai	5.47 ±0.25	58.67 ±1.15	189.66± 1.53
		Stellaria media (L.) Vill.	20.	Koz Kally (Timergara)	16.33 ±0.42	260 ±2	298.33± 1.53
		Sisymbrium irio L.	21.	Thanga (Shah)	6.76 ±0.4	53 ±2	79.67 ±1.53
8.	Buxaceae	*Sarcococca saligna* (D. Don) Muell-Arg. in DC. Prodr.	22.	Rabat (Chena)	17 ±0.27	392 ±2	144.66± 2.516
9.	Cannabaceae	*Cannabis sativa* L.	23.	Shehzadi (Banr)	5.33 ±0.45	194 ±2	139 ±1
10.	Caryophyllaceae	*Cerastium glomeratum* Thuill.	24.	Khema (Shorgar)	16.6 ±0.36	44.67 ±1.15	218.33± 1.53
11.	Crassulaceae	*Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger	25.	Andhera (College)	7.97 ±0.5	220 ±2	162.66± 2.08
		Rosularia adenotricha (Wall. ex Edgew.) C.-A. Jansson	26.	Bar Darmal (Khwar)	5.7 ±0.27	246.66 ±1.53	194 ±2
12.	Euphorbiaceae	*Euphorbia helioscopia* L.	27.	Udigram (Kalle)	18.63 ±0.35	50.33 ±1.53	98.33 ±1.53
13.	Fabaceae	*Argyrolobium stenophyllum* Boiss.	28.	Asharigat (Pull)	14.7 ±0.36	32 ±2	32.67 ±1.53
		Medicago lupulina L.	29.	Kuz Darmal (Gharr)	19.9 ±0.2	42.67 ±1.15	61.67 ±2.12
		Medicago minima L.	30.	Tissu Neher (Ghar)	32.3 ±0.36	303.33 ±2.89	394 ±2
		Vicia sativa L.	31.	Kuz Darmal (Khwar)	11.17 ±0.25	48 ±2	80 ±2
14.	Geraniaceae	*Geranium rotundifolium* L.	32.	Mian Banda (Shorgar)	11.53 ±0.31	48 ±2	20.67 ±2.52
15.	Iridaceae	*Iris germanica* L.	33.	Tissue Neher (Kalle)	8.07 ±0.25	127.66 ±1.53	67.67 ±1.53
16.	Ixioliriaceae	*Ixiolirion tataricum* (Pall.) Schult. & Schult. F.	34.	Khall (Ghar)	2.33 ±0.38	76 ±1	179 ±2
17.	Lamiaceae	*Ajuga integrifolia* Buch.-Ham.	35.	Jabagai (Osai Ghar)	9.17 ±0.25	60.53 ±0.64	31 ±2
		Phlomoides superba (Royle ex Benth.) Kamelin & Makhm.	36.	Nara Thangai (Ghar)	1 ±0.17	88.33 ±1.53	219 ±2
		Micromeria biflora (Buch.-Ham. ex D.Don) Benth.	37.	Ranai	8.13 ±0.2	22 ±3	97.33 ±1.53
		Marrubium vulgare L.	38.	Khadang Ghar (Bar Darmal)	1.6 ±0.26	309.33 ±1.53	221.66± 3.51

		Rydingia limbata (Benth.) Scheen & V.A. Albert	39.	Behari (Ghar)	30.5 ±0.44	91.67 ±1.53	99 ±1
		Salvia moorcroftiana Wall. ex Benth.	40.	Majar Camp (Khwar)	1.53 ±0.25	112 ±2.52	239.66± 2.81
		Teucrium stocksianum Boiss.	41.	Sado	1.47 ±0.15	86.33 ±1.52	24.67 ±1.53
18.	Papilionaceae	*Astragalus pyrrhotrichus* Boiss.	42.	Beghamdara	2.57 ±0.31	60.67 ±1.53	138.33± 1.53
19.	Plantaginaceae	*Plantago lanceolata* L.	43.	Behari (Kalle)	25.6 ±0.1	116.33 ±1.53	70.67 ±1.53
20.	Plumbaginaceae	*Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen.	44.	Jabagai (Thor Baba)	12.73 ±0.32	167.66 ±1.53	160 ±2.65
21.	Polygalaceae	*Polygala abyssinica* R.Br. ex Fresen.	45.	Shehzadi (Kundao)	10.23 ±0.32	64.33 ±2.08	56.33 ±1.53
22.	Polygonaceae	*Emex spinosa* (L.) Campd.	46.	Haji Abad	1.17 ±0.15	112.33 ±1.53	88.33 ±1.53
		Persicaria glabra (Willd.) M. Gómez	47.	Udigram (Ghar)	1.4 ±0.2	79 ±1	54.33 ±1.53
23.	Pteridaceae	*Cheilanthes pteridoides* C. Chr.	48.	Haya Serai	3.27 ±0.25	28.67 ±1.53	28.67 ±1.53
		Pteris cretica L.	49.	Behari (Khwar)	2.27 ±0.23	31.67 ±1.527	98.67 ±1.527
24.	Ranunculaceae	*Delphinium uncinatum* Hook.f. & Thomson	50.	Bar Darmal (Shorgur)	28.8 ±0.2	116.33 ±1.527	251.66± 1.527
		Delphinium suave Huth	51.	Lajbok	4.9 ±0.2	177 ±2	219.33± 2.52
		Ranunculus arvensis L.	52.	Murnera	7.6 ±0.2	501.33 ±1.154	249 ±3.605
25.	Rosaceae	*Duchesnea indica* (Jacks.) Focke	53.	Bar Darmal (School)	5.83 ±0.21	221.66 ±3.06	108.66± 2.52
		Sanguisorba minor Scop.	54.	Rabat (Kalle)	21.93 ±0.31	96.33 ±1.53	149 ±2
		Rosa macrophylla Lindl.	55.	Shezadi (Konahi)	1.63 ±0.15	220 ±2	67.67 ±2.52
26.	Scrophulariaceae	*Verbascum thapsus* L.	56.	Khongai	1.8 ±0.2	101.66 ±2.52	69.67 ±2.08
		Wulfeniopsis amherstiana (Wall. Ex Benth.) D.Y. Hong	57.	Nara Thangai (Kalle)	1.87 ±0.12	232.33 ±2.08	240.33± 1.53
27.	Solanaceae	*Solanum nigrum* L., Sp. Pl.	58.	Nawe Kalle (Pori Ghar)	1.9 ±0.3	26 ±2	97.67 ±1.53
28.	Thymelaeaceae	*Daphne mucronata* Royle	59.	Balambat (Chaoni)	9.83 ±0.21	88 ±2	169.33± 1.53
29.	Urticaceae	*Urtica pilulifera* L.	60.	Timur	18.93 ±0.25	304.66 ±1.15	40 ±2
30.	Verbenaceae	*Verbena officinalis* L.	61.	Thraskun Hotel (Timergara)	6.8 ±0.2	65.67 ±1.53	269.33± 1.53

S*No = Site number, Concentration of lead in soil and plant parts is shown as mean (n=3) ± SD

Table 2. Name of the plant Species and their Bioconcentration Factor, Translocation Factor and Bioaccumulation Coefficient for Lead

S. No	Plant Species	Bioconcentration Factor, Translocation Factor and Bioaccumulation Coefficient			Feasibility of the plant for the phytoremediation of Lead
		BCF	TF	BAC	
1.	*Allium griffithianum* Boiss.	3.45	5.39	18.58	++**
2.	*Torilis leptophylla* (L.) Rchb.f.	51.52	0.47	23.94	+*
3.	*Catharanthus roseus* (L.) G. Don	6.18	1.96	12.1	++**
4.	*Asplenium dalhousiae* Hook.	2.04	2.05	4.17	++**
5.	*Artemisia japonica* Thunb.	70.54	0.37	25.97	+*
6.	*Artemisia vulgaris* L.	15.91	1.13	18.03	++**
7.	*Calendula arvensis* Boiss.	189.97	0.05	8.94	+*
8.	*Cirsium vulgare* (Savi) Ten.	7.63	5.01	38.25	++**
9.	*Cousinia buphthalmoides* Regel	5.06	0.56	2.81	+*
10.	*Erigeron canadensis* L.	1.86	8.3	15.41	++**
11.	*Filago hurdwarica* (Wall. ex DC.) Wagenitz	7.53	1	7.46	++**
12.	*Lactuca dissecta* D. Don	6.11	1.46	8.94	++**
13.	*Himalaiella heteromalla* (D. Don) Raab-Straube	3.21	3.6	11.56	++**
14.	*Silybum marianum* (L.) Gaertn.	37.24	0.46	17.01	+*
15.	*Xanthium strumarium* L.	101.73	0.29	29.67	+*
16.	*Nonea edgeworthii* A. DC.	100.68	0.21	21.11	+*
17.	*Onosma hispida* Wall. ex G. Don	15.5	1.91	29.65	++**
18.	*Arabidopsis thaliana* (L.) Heynh.	111.11	0.81	90	+*
19.	*Isatis tinctoria* L.	10.73	3.23	34.67	++**
20.	*Stellaria media* (L.) Vill.	15.92	1.15	18.27	++**
21.	*Sisymbrium irio* L.	7.84	1.5	11.79	++**
22.	*Sarcococca saligna* (D. Don) Muell.-Arg. in DC., Prodr.	23.06	0.37	8.51	+*
23.	*Cannabis sativa* L.	36.4	0.72	26.08	+*
24.	*Cerastium glomeratum* Thuill.	2.69	4.89	13.15	++**
25.	*Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger	27.6	0.74	20.41	+*
26.	*Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson	43.27	0.79	34.04	+*
27.	*Euphorbia helioscopia* L.	2.7	1.95	5.28	++**
28.	*Argyrolobium stenophyllum* Boiss.	2.18	1.02	2.22	++**
29.	*Medicago lupulina* L.	2.14	1.45	3.1	++**
30.	*Medicago minima* (L.) L.	9.39	1.3	12.2	++**
31.	*Vicia sativa* L.	4.3	1.67	7.16	++**
32.	*Geranium rotundifolium* L.	4.16	0.43	1.79	+*
33.	*Iris germanica* L.	15.82	0.53	8.39	+*
34.	*Ixiolirion tataricum* (Pall.) Schult. & Schult. f.	32.62	2.36	76.82	++**
35.	*Ajuga integrifolia* Buch.-Ham.	6.6	0.51	3.38	+*
36.	*Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm.	88.33	2.48	219	++**
37.	*Micromeria biflora* (Buch.-Ham. ex D.Don) Benth.	2.71	4.42	11.97	++**

38.	*Marrubium vulgare* L.	193.33	0.72	138.54	+*
39.	*Rydingia limbata* (Benth.) Scheen & V.A. Albert	3.01	1.08	3.25	++**
40.	*Salvia moorcroftiana* Wall. ex Benth.	73.2	2.14	156.64	++**
41.	*Teucrium stocksianum* Boiss.	58.73	0.29	16.78	+*
42.	*Astragalus pyrrhotrichus* Boiss.	23.61	2.28	53.83	++**
43.	*Plantago lanceolata* L.	4.54	0.61	2.76	+*
44.	*Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen.	13.17	0.95	12.57	+*
45.	*Polygala abyssinica* R.Br. ex Fresen.	6.29	0.88	5.51	+*
46.	*Emex spinosa* (L.) Campd.	96.01	0.79	75.5	+*
47.	*Persicaria glabra* (Willd.) M. Gómez	56.43	0.69	38.81	+*
48.	*Cheilanthes pteridoides* C. Chr.	8.77	1	8.77	++**
49.	*Pteris cretica* L.	13.95	3.16	43.47	++**
50.	*Delphinium uncinatum* Hook.f. & Thomson	4.04	2.16	8.74	++**
51.	*Delphinium suave* Huth	36.12	1.24	44.76	++**
52.	*Ranunculus arvensis* L.	65.97	0.5	32.76	+*
53.	*Duchesnea indica* (Jacks.) Focke	38.02	0.49	18.64	+*
54.	*Sanguisorba minor* Scop.	4.39	1.55	6.79	++**
55.	*Rosa macrophylla* Lindl.	134.97	0.31	41.52	+*
56.	*Verbascum thapsus* L.	56.48	0.69	38.71	+*
57.	*Wulfeniopsis amherstiana* (Wall. Ex Benth.) D.Y. Hong	124.91	1.03	129.21	++**
58.	*Solanum nigrum* L., Sp. Pl.	13.68	3.76	51.41	++**
59.	*Daphne mucronata* Royle	8.95	1.92	17.22	++**
60.	*Urtica pilulifera* L.	16.09	0.13	2.11	+*
61.	*Verbena officinalis* L.	9.66	4.1	39.61	++**

Bioconcentration Factor (BCF) = Conc. of lead in root ÷ Conc. of lead in Soil, Translocation Factor (TF) = Conc. of lead in Shoot ÷ Conc. of lead in root, Bioaccumulation Coefficient (BAC) = Conc. of lead in Shoot ÷ Conc. of lead in soil, +* = Metal excluders; may be used for the phytostabilization of metal, ++** = Metal indicators; May be used for the phytoextraction of metal, +++*** = Metal hyper accumulator; may be used for the Phytoextraction and recovery of metal., -; cannot be used for the metal remediation processes

Conclusions

Among the studied sites the concentration of lead in the soil of site 30 was found higher (32.3 mg/kg) than the allowable limit while in the rest of the sites it is less than the allowable limit. The concentration of lead was found more than the permissible limits in the roots and shoots of all the analyzed plants. The BCFs, TFs and BACs values of the plants for lead metal was found in the range of 1.86-193.33, 0.05-8.3 and 1.79-219 respectively. Among the analysed plants, based on the concentration of lead in shoots and BCFs, TFs and BACs values, *Erigeron canadensis* L., *Stellaria media* (L.) Vill. *Medicago minima* (L.) L., *Delphinium uncinatum* Hook. f. & Thomson and *Verbena officinalis* L. were found the most efficient plants for the phytoextraction of lead. Based on lead concentration in roots and BCFs, TFs and BACs values, Nonea edgeworthii A. DC., *Arabidopsis thaliana* (L.) Heynh. *Sarcococca saligna* (D. Don) Muell.-Arg. in DC., Prodr., *Marrubium vulgare* L. and *Ranunculus arvensis* L. were found best for the phytostabilization of lead metal. Based on the findings of this research work it is recommended that the plants which were found efficient for the phytoremediation; phytoextraction and phytostabilization may be used for the lead remediation purposes from the lead contaminated sites. Further research work on the mentioned efficient plants is required to determine the tolerance capacity of these plants to lead contamination in their habitats.

Authors' contributions

Conceived and designed the experiments: MS Khan & H Ali, Performed the experiments: MS Khan, Analyzed the data: MS Khan, Contributed materials/ analysis/ tools: MS Khan, Wrote the paper: MS Khan & ZU Nisa.

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