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RESEARCH ARTICLE

Phytoextraction and Phytostabilization of Copper, Zinc, and Iron by Growing Plants in Chahar Gonbad Copper Mining Area, Iran

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Abstract Phytoremediation is a promising cleanup technology for heavy-metal-polluted soil. This research examined the measure of metal accumulation and phytoremediation by plants of the Chahar Gonbad copper mining area 110 km southwest of Kerman. In this study, 38 plant species were collected with soil around their roots from near the mine, and after identifying plants, Cu, Zn, and Fe in roots and shoots of plants were measured. Then, low translocation factor (TFs) and high bioconcentration factor (BCFs) were calculated for trace elements (Cu, Fe, and Zn). Including species collected from the polluted site, *Euphorbia gedrosiaca* and *Eremurus persicus* were the most effective in the phytostabilization of Cu. In addition, *Scariola orientalis* is proposed as the most efficient species in the phytostabilization of soils polluted with zinc and iron. According to the research, *Scorzonera intricata*, *Onobrychis Mill*, and *Pteropyrum aucheri* are considered the most suitable species for phytoextraction of Cu and also *Nepeta glomerulosa* the most suitable in the phytoextraction of Fe. Also, species of *Scorzonera intricata* which concentrate > 1000 mg kg^{-1} copper can be observed to be hyperaccumulator species for copper. Our investigation displays that several endemic plant species growing on this polluted site may have the potential for phytoremediation.

Significance statement In the current manuscript, *Scorzonera intricata*, *Onobrychis Mill*, and *Pteropyrum aucheri* have shown their potential for phytoextraction of Cu and *Nepeta glomerulosa* for phytoextraction of Fe. Also, species of *Scorzonera intricata* can be observed to be hyperaccumulator species for Cu.

Keywords Accumulation · Heavy metals · Phytoremediation Cu mine

Introduction

Heavy metals are environmental hazards to humans, animals, and plants through mining activities, greenhouse gas emissions, toxins, and fertilizers [1]. High levels of heavy metals can be a danger to the environment and human health because of their toxic effects on living organisms. Several heavy metals such as Cu, Zn, Fe, Mo, Cr, and Mn are toxic to living organisms in high concentrations [1, 2]. Plants use two different strategies, exclusion and accumulation, to deal with high levels of metals [3, 4]. Reconstruction of soil contaminated with potentially dangerous elements by plants can be classified into three groups: (1) phytoextraction; (2) rhizofiltration; and (3) phytostabilization [4, 5].

More than 500 hyperaccumulator plants are able to accumulate large quantities of heavy metals in their shoots [6]. Hyperaccumulators are plants that accumulate more than 1000 µg g^{-1} of Cu, Ni, Pb, Cr, and Co or more than 10,000 µg g^{-1} Mn and Zn in their shoot dry matter [7], so that they are able to remove heavy metals from soils contaminated with heavy metals by phytoremediation. Other metal-excluding species have much potential for phytostabilization [8]. Both the translocation factor (TF) and bioconcentration factor (BCF) can be used to estimate a plant's potential for phytoremediation purposes. The ability

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of a plant to accumulate metals from soils can be estimated using the BCF, which is defined as the quotient of the metal concentration in the roots to that in soil. The ability to translocate metals from the roots to the shoots is measured using the TF, which is defined as the quotient of the metal concentration in the shoots to the roots.

Most of the hyperaccumulator plants have been identified from metalliferous soils of the Democratic Republic of Congo, for example, the "Zambian copper flower" (*Becium centraliafricanum*) [6].

Because there is no regular research on the type of vegetation, the amount of Cu, Zn, and Fe in plants surrounding the Chahar Gonbad mine is not available. Therefore, the aim of this study was to (1) identify the plant species growing on mineralized and contaminated soils in the Chahar Gonbad mining area; (2) determine the concentration of Cu, Zn, and Fe in plant biomass growing on a contaminated site; (3) compare metal concentrations in the shoot, roots, and soils; and (4) estimate the feasibility of using these plants for phytoremediation purposes. Results from this study provide insight into the possibilities for using native plants to remediate Iranian metal-contaminated sites.

Material and Methods

Site Characterization

The Chahar Gonbad copper mining area is located 110 km southwest of Kerman and 80 km northeast of Sirjan. The mine is 2300 m above sea level with an average annual rainfall of 296 mm and minimum temperatures of – 7 °C and a maximum of 37.5 °C in August. The relative humidity is 47% annually. Pyrite and chalcopyrite are the most important sulfide ores. Several exploration projects have been done in this area, resulting in open and underground Cu extraction. Surface soils contain high concentrations of Cu, Zn, and Fe. The soils around the mines are more contaminated with Zn, Cu, and Fe due to mining activities. In this research, sampling of soils and plants was done at five different sites near Chahar Gonbad mine: wastewater drainage (site 1; 0.5 km); the area around smelter plant (site 2; 0.1 km); the foot of the hill near the wastewater drainage (site 3; 0.3 km); one around a tailings dam (site 4; 0.2 km); and an area around Chahar Gonbad village (site 5; 2 km). Site 5, which is at a distance from the mining area of the study area, was examined as a control sample in this study.

Sampling and Analysis of Plants and Soils

Thirty-eight plant and soil samples were gathered in the surrounding areas of the Chahar Gonbad mine from April 2018 to October 2019. For the analysis of plant dry matter, plant material was washed with tap water and once more with distilled water and dried at 70 °C for 48 h. About 0.05 g of dry weight was digested in a mixture of HNO_3 (65%), HCl (37%), and H_2O_2 (30%) (6:3:1, v/v/v) and heated at 120 °C for 1 h. After cooling, digests were made up of 10 ml with deionized water. The solutions were analyzed for Cu, Zn, and Fe by atomic absorption spectrophotometry (PG Instruments, model PG990, England). The accuracy and precision for determination of micronutrients were between 95 and 99%.

Soil samples near the roots of plants (0–20 cm depth) were also collected. All soil samples were air-dried and sieved to < 2 mm. For the analysis of total elements, subsamples of 4–5 g were ground to pass through a sieve (< 190 μm) and then oven-dried at 70 °C. A further subsample of 0.5 g was transferred to a digestion tube for extraction with 10 ml of an HCl/HNO_3 mixture. Tubes were left at room temperature overnight and were then placed in a heating block. Each was covered with an air condenser and refluxed gently a sieve (< 190 μm) and then oven-dried at 70 °C. After cooling, the digests were filtered through a moistened filter paper into a 50-ml volumetric flask and made up to volume with distilled water. Ten milliliters of the digest was added to 15-ml tubes, and analysis for Cu, Zn, and Fe performed by AAS [9]. The pH and EC values of soil samples were measured electrometrically after 10 g of soil had been stirred well in 30 ml distilled water in a beaker and allowed to stand for about 30 min.

BCF can be used to estimate the plant's ability to accumulate metals from the soil. The value of BCF is equal to the quotient of the metal concentration in the roots of the soils. TF can be used to estimate the plant's ability to translocate metals from the roots to the shoots, which is defined as the quotient of the metal concentration in the shoots to the roots. Plants display a TF, and individually $BCF < 1$ is inappropriate for phytoextraction [10]. While plants with both BCF and $TF > 1$ are used in phytoextraction, those with $BCF > 1$ and $TF < 1$ are more appropriate for phytostabilization [11].

Statistical Analysis

Cu, Zn, and Fe concentrations in shoots and roots were shown by three separate replicates. Further evaluation was performed via Duncan's multiple range tests at 5% probability level. The statistical analysis was performed using SPSS 20 software.

Results

Concentrations of total Cu, Fe, and Zn in the soils, pH, and electrical conductivity (EC) at the five sampling sites are given in Table 1. Total Cu concentrations were variable, ranging from 32 to 1448 mg kg^{-1} (Table 1). These sites also show elevated levels of Fe and Zn, ranging from 118.94 to 1453.14 mg kg^{-1} for Fe and from 41.46 to 1224 mg kg^{-1} for Zn (Table 1).

During this research, 38 plants were gathered from five mineral areas of the Chahar Gonbad mining area (Table 1). Cu, Zn, and Fe concentrations in soil and plant samples are summarized in Table 2. Concentrations of Cu in the roots ranged from 8 to as high as 845 mg kg^{-1} and shoot from 5 to 2289 mg kg^{-1}, with maximum values in shoots and roots of *Scorzonera intricata*. Also, species of *Scorzonera intricata* which concentrate > 1000 mg kg^{-1} Cu can be reported to be hyperaccumulator species for Cu.

Iron concentrations in roots ranged from 12.87 to 2136.8 mg kg^{-1} and shoot from 40.8 to 3701.2 mg kg^{-1}, with the maximum concentrations in the roots of *Scorzonera laciniata* and shoot of *Eremurus persicus*. Concentrations of Zn in roots were ranging from 20 up to 501.4 mg kg^{-1} and shoots from 19.7 to 1100 mg kg^{-1}, with the highest values in the roots of *Scariola orientalis* and shoots of *Paracaryum persicum*

Discussion

In soils excessively polluted by heavy metals like Cu, Pb, Zn, and Ni, metal toxicity limits the growth of all but the most tolerant plants. Toxic metals can also be harmful and affect the number, diversity, and activity of soil organisms, restraining soil organic matter decomposition and N-mineralization processes [9, 12, 13].

Industrial and mining activities in the Chahar Gonbad copper mining area have increased the levels of Cu, Zn, and Fe in surface soils. Analyses of soils at the five different sites showed that the Cu, Zn, and Fe concentrations increased at site 2 compared to site 5 (site control), up to 1448, 1224, and 1453 mg kg^{-1}, respectively. This process is due to weathering of rocks and pollution caused by mining activities. There are significant differences in the concentration of elements in locations, which points to the heterogeneous dispersion of individual minerals in mine waste [14–16].

According to this study, soils in all areas of the Chahar Gonbad mine showed high concentrations of Cu and Fe and relatively low concentrations of Zn. The amount of total Cu in unpolluted soils is about 20 mg kg^{-1}, and its average is 6 to 80 mg kg^{-1} [17]. The global baseline for Zn in unpolluted soils is 80–120 µg g^{-1} [18] and for Fe 14,000 µg g^{-1} [19]. Therefore, concentrations of Cu, Fe, and Zn in the Chahar Gonbad copper mining area soils were significantly higher than for unpolluted soils.

Concentrations of metals vary between plant species depending on the type of plant [20, 21]. Copper concentration in plant tissues is normally 5–25 mg kg^{-1}, and concentrations > 100 mg kg^{-1} are rare even in the presence of high soil Cu concentrations [6]. In this study of the 38 plants identified, 15 plant species accumulate amounts of more than 100 mg kg^{-1} of Cu in their leaves. Copper concentrations in plants in this study ranged from 8 to as high as 845 mg kg^{-1} in the roots and shoots from 5 to 2289 mg kg^{-1}, with maximum values in the roots and shoots of *Scorzonera intricata*. These high levels of Cu in the leaves of plants in the area can be due to the high amount of Cu in the mine soil, the solubility of the elements in the soil due to the high annual precipitation, and the low pH of the soil due to high amounts of sulfur in the soil. Also, large amounts of Zn and Fe in soil solution limit the uptake of Cu by the plant, possibly due to competition for transporters present in the root [22]. This is consistent with the present study. Plants can be defined as hyperaccumulators of Cu that accumulate > 1000 mg kg^{-1} of Cu in shoot dry weight [7]. In the present study, species of *Scorzonera intricata* were identified as the hyperaccumulator of Cu that is first reported from the Chahar Gonbad mineral zone.

Kabata and Pendias reported that the amount of Cu in most plants is in the range of 5–20 mg kg^{-1} in dry weight

Table 1 Selected properties of soil samples from the contaminated site in the Chahar Gonbad mining area

Site #	Soil pH	EC (ms cm^{-1})	Total Cu (mg kg^{-1})	Total Zn (mg kg^{-1})	Total Fe (mg kg^{-1})
1	7.5	5.3	280–364	512–950.3	214.2–1213.14
2	7.0	8.7	1251–1448	1010–1224	1434.72–1453.14
3	7.3	8.1	305–965	973–1060	1258.94–1439.36
4	7.1	8.4	421–966	1082.2–1114	1398.94–1419.46
5	7.9	2.1	32–161	41.46–702.5	118.94–561.06

Table 2 Cu, Zn, and Fe concentrations in soil and plant samples (mg kg^{-1})

Species	Cu Roots	Shoots	Soil	Zn Roots	Shoots	Soil	Fe Roots	Shoots	Soil
Asteraceae									
Echinops lalesavicus L.	68 ± 2.6	93 ± 3.2	169 ± 6.3	480 ± 7.1	211.8 ± 2.6	735.5 ± 8.7	339.4 ± 3.2	681.5 ± 4.1	1432.1 ± 21.1
Cirsium spectabile DC	62 ± 2.8	17 ± 1.1	118 ± 4.3	358.4 ± 4.1	324 ± 5.4	1224 ± 32.3	1315.7 ± 45.3	976.3 ± 7.6	1408.4 ± 64.3
Lactuca glauciifolius Boiss	32 ± 1.4	9 ± 1.3	143 ± 5.6	55.3 ± 5.4	39.5 ± 2.1	109.81 ± 9.5	684.2 ± 45.4	1305.2 ± 67.9	1429.4 ± 34.8
Artemisia aucheri Boiss	61 ± 4.7	88.5 ± 8.3	66 ± 3.4	134.2 ± 6.9	146.7 ± 5.8	565.7 ± 67.9	225 ± 4.2	565.4 ± 9.7	1426.3 ± 76.4
Taraxacum neolobulatum Soest	160 ± 2.9	159 ± 6.8	161 ± 5.5	82.9 ± 3.6	44.3 ± 2.7	129.64 ± 8.6	415.7 ± 4.9	165.7 ± 5.6	1446.3 ± 56.9
Scariola orientalis Boiss	149 ± 4.8	167 ± 5.2	463.6 ± 54.3	501.4 ± 9.8	256.9 ± 4.6	500.5 ± 3.8	1459.7 ± 67.9	970.6 ± 7.7	939.4 ± 6.3
Scorzonera laciniata L.	63 ± 2.7	117 ± 6.7	323 ± 8.7	63.2 ± 5.5	59.5 ± 4.5	186 ± 3.5	2136.8 ± 98.8	278.9 ± 5.9	1420.8 ± 89.7
Hertia intermedia Kuntze	50.7 ± 4.6	38.5 ± 5.5	243.7 ± 8.9	92.3 ± 5.3	62.4 ± 6.6	178 ± 5.9	276.9 ± 8.8	585.5 ± 9.0	1418.1 ± 65.9
Scorzonera intricata Boiss	845 ± 7.8	2289 ± 89.8	364 ± 7.9	74.9 ± 4.6	58.2 ± 7.6	924.3 ± 11.1	1297.3 ± 32.7	709.2 ± 21.3	1430.5 ± 98.5
Tragopogon caricifolius Boiss	225 ± 12.1	605 ± 9.8	379 ± 3.8	228 ± 3.9	117 ± 11.1	290 ± 24.2	12.87 ± 1.1	107.8 ± 9.4	1417.3 ± 34.9
Asphodelaceae									
Eremurus persicus Boiss	164 ± 1.7	149.8 ± 6.9	82.7 ± 6.8	137 ± 2.8	130.2 ± 3.7	448 ± 7.4	895.8 ± 9.9	3701.2 ± 95.3	1378.9 ± 68.8
Apiaceae									
Eryngium billardieri F. Delaroche	21 ± 1.3	8 ± 1.1	198 ± 8.9	34 ± 3.4	21 ± 1.2	89 ± 4.3	544.7 ± 21.1	207.9 ± 8.9	1431.0 ± 45.8
Boraginaceae									
Paracaryum persicum Boiss	10 ± 1.5	15 ± 2.1	89 ± 4.3	82 ± 3.7	1100 ± 32.7	845 ± 9.9	852.6 ± 10.2	205.2 ± 5.8	1414.7 ± 68.4
Heliotropium ramosissimum Sieber ex DC	150 ± 2.6	126 ± 4.3	170 ± 5.2	160 ± 2.6	72 ± 6.9	396 ± 7.2	615.7 ± 6.9	581.6 ± 5.9	1453.1 ± 45.9
Cardaria draba (L.) Desv	61 ± 2.4	42 ± 5.2	280 ± 1.9	36 ± 1.1	31.5 ± 2.1	177.96 ± 98.4	224.95 ± 7.5	302.6 ± 4.9	1413.1 ± 78.1
Trichodesma aucheri DC	196 ± 3.6	428 ± 8.5	286.5 ± 4.3	21.6 ± 1.5	24.1 ± 3.2	63.1 ± 5.9	372.3 ± 7.9	391.5 ± 4.7	1442.3 ± 46.2
Chenopodiaceae									
Bassia eriantha (Fisch. & C.A. Mey.) Kuntze	94 ± 5.3	25 ± 3.2	104 ± 8.9	34 ± 4.2	42 ± 4.6	96 ± 7.9	750 ± 11.6	265 ± 5.9	1444.2 ± 45.1
Salsola kali L.	40.3 ± 3.2	37.3 ± 2.5	127 ± 8.7	156.9 ± 6.9	115.4 ± 4.8	479.5 ± 9.9	106 ± 9.2	302 ± 10.7	1425.4 ± 89.9
kochia roth	117 ± 9.4	102 ± 4.7	120 ± 5.4	39.9 ± 7.9	46.5 ± 9.4	89.3 ± 5.5	513.1 ± 21.4	344.7 ± 9.5	1213.1 ± 67.9
Seidlitzia florida (M. Bieb.) Boiss	5.9 ± 2.3	7 ± 5.2	32 ± 3.4	286 ± 56.3	56.3 ± 9.7	98.5 ± 8.5	328.2 ± 21.2	81.5 ± 8.9	1431.0 ± 89.4
Caryophyllaceae									
Acanthophyllum sordidum Bunge ex Boiss	32 ± 3.2	79 ± 5.7	116 ± 9.9	117.6 ± 5.7	85 ± 3.2	218.5 ± 6.9	1292.1 ± 23.8	794.7 ± 11.7	1441.5 ± 56.8
Convolvulaceae									
Convolvulus schirazianus Boiss	621 ± 21.7	958 ± 65.3	1448 ± 56.9	132.5 ± 3.9	204.3 ± 8.4	482.8 ± 11.8	892.1 ± 12.9	721.2 ± 13.3	1425.78 ± 98.6

Table 2 continued

Species	Cu Roots	Shoots	Soil	Zn Roots	Shoots	Soil	Fe Roots	Shoots	Soil
Euphorbiaceae									
Euphorbia gedrosiaca Rech.f., Aellen & Esfand	825.6 ± 21.5	267.2 ± 3.8	792 ± 15.7	16.3 ± 3.9	13.8 ± 5.9	61.3 ± 2.8	252.6 ± 9.3	40.8 ± 3.7	1448.9 ± 67.3
Euphorbia hebecarpa Boiss	72.5 ± 2.2	96 ± 4.2	325.5 ± 8.4	134.7 ± 3.9	123.9 ± 5.3	849.3 ± 16.3	482.8 ± 12.3	211.9 ± 2.9	1431.5 ± 34.4
Fabaceae									
Astragalus sect. Hymenostegis Fisch	69 ± 4.8	91 ± 5.4	280 ± 3.8	52.1 ± 5.2	69.3 ± 7.9	702.5 ± 13.4	155.2 ± 9.5	97.3 ± 6.9	1373.6 ± 94.6
Astragalus myriacantha Boiss	8 ± 1.1	5 ± 1.4	41 ± 3.3	40.46 ± 2.2	19.7 ± 3.1	72.46 ± 4.4	336.8 ± 6.9	584.2 ± 12.8	561.06 ± 13.6
Onobrychis Mill	218 ± 8.3	662 ± 5.8	72 ± 8.8	29 ± 2.2	31.4 ± 3.2	69.8 ± 5.9	473.6 ± 12.8	457.9 ± 15.5	1425.2 ± 89.4
Lamiaceae									
Marrubium vulgare L.	16 ± 3.5	112 ± 7.7	84 ± 6.4	19.2 ± 1.4	38.9 ± 3.2	41.46 ± 3.4	244.7 ± 8.8	1278.9 ± 98.6	1376.3 ± 54.4
Nepeta meyeri Benth.	179.1 ± 7.7	690.9 ± 21.6	186 ± 3.7	78 ± 4.4	105 ± 8.8	907 ± 23.2	202.62 ± 12.1	872.3 ± 67.3	1952.6 ± 68.7
Nepeta glomerulosa Boiss	138 ± 8.6	72 ± 4.6	965 ± 32.1	79.5 ± 4.9	80.5 ± 4.6	973 ± 12.5	134.2 ± 4.9	265.7 ± 7.7	118.9 ± 3.7
Ajuga chamaecistus Ging. ex Benth	39.5 ± 6.6	48.5 ± 4.8	58 ± 7.6	95 ± 4.4	66 ± 3.7	48 ± 3.4	427.1 ± 9.9	1010.5 ± 21.7	1438.9 ± 45.6
Malvaceae									
Malva neglecta Wallr.	97 ± 5.8	85.7 ± 6.6	112.3 ± 4.4	52.5 ± 4.8	68.2 ± 8.8	59.7 ± 5.7	421 ± 23.1	965.3 ± 34.4	1402.62 ± 76.4
Nitrariaceae									
Peganum harmala L	35.2 ± 3.4	82.6 ± 7.6	262.7 ± 8.9	119.6 ± 3.7	253.5 ± 6.5	731.1 ± 12.6	743.4 ± 14.4	682.7 ± 21.4	1469.2 ± 78.6
Poaceae									
Boissiera squarrosa (Sol.) Nevski	14 ± 1.3	25 ± 2.3	65 ± 5.9	39.5 ± 5.3	48 ± 5.7	86.8 ± 9.3	673.6 ± 21.6	2305.3 ± 99.4	1258.94 ± 38.6
Polygonaceae									
Pteropyrum aucheri Jaub. & Spach	86.8 ± 6.8	221.5 ± 3.9	47.8 ± 1.3	43.2 ± 2.2	32.4 ± 3.5	84.4 ± 6.2	890.7 ± 16.9	1000 ± 32.7	1416.3 ± 56.9
Thymelaeaceae									
Daphne mucronata Royle	17.5 ± 2.6	23.5 ± 5.5	97 ± 8.5	41.5 ± 3.8	25.5 ± 8.4	92 ± 4.6	614.4 ± 8.8	373.6 ± 6.4	1390.1 ± 89.5
Tamaricaceae									
Tamarix gallica L.	19 ± 1.1	27 ± 2.3	81 ± 3.6	20 ± 3.4	32 ± 3.3	190 ± 7.9	39.4 ± 5.5	181.6 ± 9.8	1418.4 ± 77.9
Reaumuria vermiculata L.	115 ± 2.8	87 ± 8.6	305 ± 9.9	42 ± 1.3	35 ± 4.3	107 ± 7.5	16.7 ± 3.4	236.8 ± 9.8	214.2 ± 3.8

Table 3 Accumulation and translocation of Cu, Zn, and Fe in the selected plants

Species	Bioconcentration factor (BCF)			Translocation factor (TF)		
	Zn	Fe	Cu	Zn	Fe	Cu
Asteraceae						
Echinops lalesavicus L.	0.65 ± 0.2	0.23 ± 0.1	0.40 ± 0.1	0.44 ± 0.2	2.00 ± 0.3	1.36 ± 0.2
Cirsium spectabile DC	0.29 ± 0.1	0.93 ± 0.2	0.52 ± 0.1	0.90 ± 0.3	0.74 ± 0.2	0.27 ± 0.1
Lactuca glauciifolius Boiss	0.50 ± 0.2	0.47 ± 0.1	0.22 ± 0.1	0.71 ± 0.2	1.90 ± 0.4	0.28 ± 0.1
Artemisia aucheri Boiss	0.47 ± 0.1	0.15 ± 0.1	0.87 ± 0.2	0.79 ± 0.2	2.63 ± 0.3	1.12 ± 0.4
Taraxacum neolobulatum Soest	0.63 ± 0.2	0.28 ± 0.1	0.99 ± 0.3	0.53 ± 0.1	0.39 ± 0.1	0.99 ± 0.3
Scariola orientalis Boiss	1.0 ± 0.2	1.05 ± 0.1	0.34 ± 0.1	0.56 ± 0.1	0.66 ± 0.2	0.95 ± 0.2
Scarzonerala laciniata L.	0.33 ± 0.1	1.50 ± 0.3	0.19 ± 0.1	0.94 ± 0.2	0.13 ± 0.1	1.85 ± 0.4
Hertia intermedia Kuntze	0.51 ± 0.2	0.19 ± 0.1	0.41 ± 0.1	0.75 ± 0.2	2.58 ± 0.1	0.84 ± 0.1
Scorzonera intricata Boiss	0.08 ± 0.1	0.90 ± 0.2	2.32 ± 0.3	0.77 ± 0.2	0.54 ± 0.1	2.70 ± 0.2
Tragopogon caricifolius Boiss	0.10 ± 0.1	0.009 ± 0.1	0.59 ± 0.1	1.6 ± 0.3	8.376 ± 0.5	2.68 ± 0.3
Asphodelaceae						
Eremurus persicus Boiss	0.49 ± 0.1	0.65 ± 0.2	1.98 ± 0.2	0.94 ± 0.1	3.59 ± 0.5	0.91 ± 0.2
Apiaceae						
Eryngium billardieri F. Delaroche	0.38 ± 0.1	0.38 ± 0.1	0.1 ± 0.1	0.61 ± 0.2	0.381 ± 0.1	0.38 ± 0.1
Boraginaceae						
Paracaryum persicum Boiss	0.09 ± 0.1	0.60 ± 0.1	0.11 ± 0.1	13.41 ± 0.6	0.24 ± 0.1	1.5 ± 0.4
Heliotropium ramosissimum Sieber ex DC	0.2 ± 0.1	0.15 ± 0.1	0.21 ± 0.1	0.85 ± 0.2	1.34 ± 0.6	0.68 ± 0.2
Cardaria draba (L.) Desv	0.45 ± 0.1	0.09 ± 0.1	0.65 ± 0.2	0.75 ± 0.2	1.563 ± 0.4	2.4 ± 0.2
Trichodesma aucheri DC	0.24 ± 0.1	0.42 ± 0.2	0.91 ± 0.3	0.73 ± 0.2	0.94 ± 0.2	0.73 ± 0.1
Chenopodiaceae						
Bassia eriantha (Fisch. & C.A.Mey.) Kuntze	0.2 ± 0.1	0.51 ± 0.1	0.6 ± 0.2	2.01 ± 0.3	0.35 ± 0.1	0.26 ± 0.1
Salsola kali L.	0.45 ± 0.1	0.07 ± 0.1	0.38 ± 0.1	1.05 ± 0.2	2.92 ± 0.4	1.20 ± 0.3
Kochia roth	0.28 ± 0.1	0.422 ± 0.2	0.97 ± 0.1	0.82 ± 0.2	0.67 ± 0.2	0.87 ± 0.2
Seidlitzia florida (M. Bieb.) Boiss	0.27 ± 0.1	0.22 ± 0.1	0.18 ± 0.1	1.54 ± 0.4	0.24 ± 0.1	1.18 ± 0.3
Caryophyllaceae						
Acanthophyllum sordidum Bunge ex Boiss	0.29 ± 0.1	0.89 ± 0.2	0.27 ± 0.1	0.09 ± 0.1	0.61 ± 0.2	2.46 ± 0.4
Convolvulaceae						
Convolvulus schirazianus Boiss	0.53 ± 0.1	0.62 ± 0.1	0.42 ± 0.1	0.72 ± 0.2	0.80 ± 0.2	1.54 ± 0.6
Euphorbiaceae						
Euphorbia gedrosiaca Rech.f., Aellen & Esfand	1.48 ± 0.3	0.17 ± 0.1	3.08 ± 0.5	0.39 ± 0.1	1.08 ± 0.3	0.33 ± 0.1
Euphorbia hebecarpa Boiss	0.18 ± 0.1	0.33 ± 0.1	0.22 ± 0.1	0.98 ± 0.2	0.41 ± 0.1	1.69 ± 0.5
Fabaceae						
Astragalus sect. Hymenostegis Fisch	0.81 ± 0.2	0.11 ± 0.1	0.6 ± 0.1	0.63 ± 0.1	0.62 ± 0.1	1.53 ± 0.3
Astragalus myriacantha Boiss	0.07 ± 0.1	0.6 ± 0.1	0.19 ± 0.1	1.33 ± 0.2	1.734 ± 0.4	0.62 ± 0.2
Onobrychis Mill	0.55 ± 0.1	0.33 ± 0.1	3.03 ± 0.6	0.48 ± 0.1	0.96 ± 0.2	3.03 ± 0.5
Lamiaceae						
Marrubium vulgare L	0.41 ± 0.1	0.17 ± 0.1	0.19 ± 0.1	1.08 ± 0.3	5.22 ± 0.2	7.0 ± 0.3
Nepeta meyeri Benth	0.46 ± 0.1	0.10 ± 0.1	0.96 ± 0.1	2.02 ± 0.3	4.30 ± 0.5	3.85 ± 0.3
Nepeta glomerulosa Boiss	0.08 ± 0.1	1.12 ± 0.4	0.14 ± 0.1	1.34 ± 0.2	1.97 ± 0.4	0.52 ± 0.1
Ajuga chamaecistus Ging. ex Benth	0.69 ± 0.1	0.29 ± 0.1	0.68 ± 0.1	1.97 ± 0.3	2.36 ± 0.5	1.22 ± 0.4
Malvaceae						
Malva neglecta Wallr	0.78 ± 0.2	0.3 ± 0.1	0.86 ± 0.2	0.51 ± 0.1	2.29 ± 0.5	0.88 ± 0.2

Table 3 continued

Species	Bioconcentration factor (BCF)			Translocation factor (TF)		
	Zn	Fe	Cu	Zn	Fe	Cu
Nitrariaceae						
Peganum harmala L.	0.41 ± 0.1	0.50 ± 0.1	0.16 ± 0.1	0.47 ± 0.1	0.56 ± 0.1	2.65 ± 0.2
Poaceae						
Boissiera squarrosa (Sol.) Nevski	0.45 ± 0.1	0.53 ± 0.1	0.13 ± 0.1	1.21 ± 0.6	3.422 ± 0.3	1.0 ± 0.2
Polygonaceae						
Pteropyrum aucheri Jaub. & Spach	0.18 ± 0.1	0.62 ± 0.1	2.48 ± 0.4	2.07 ± 0.3	1.09 ± 0.3	2.15 ± 0.2
Thymelaeaceae						
Daphne mucronata Royle	0.53 ± 0.1	0.44 ± 0.1	0.18 ± 0.1	1.05 ± 0.5	0.92 ± 0.2	1.33 ± 0.2
Tamaricaceae						
Tamarix gallica L.	0.55 ± 0.1	0.027 ± 0.1	0.23 ± 0.1	1.09 ± 0.3	4.609 ± 0.6	1.42 ± 0.2
Reaumuria vermiculata L.	0.87 ± 0.1	0.078 ± 0.1	0.37 ± 0.1	1.29 ± 0.2	14.13 ± 0.6	0.75 ± 0.2

of the plant and that sensitive plants exhibit toxicity in excess [23]. Fifteen families have been identified as hyperaccumulators of Cu, majority of them being from the Democratic Republic of Congo [6]. Stoltz and Greger [24] showed Cu concentrations of 6.4–160 mg kg^{-1} in plant biomass, while those by Shu et al. [25] showed 7–198 mg kg^{-1} in plant biomass for sites in Florida. However, Cu concentrations of 6–352 mg kg^{-1} were reported by Yoon et al. in shoots dry matter [11].

Zn levels in plants were also measured between 6 and 126 mg kg^{-1}. Higher than 300 mg kg^{-1} may cause poison in the plant. Also, the usual concentration of Fe in plant tissues has been reported up to 350 mg kg^{-1} and concentrations greater than 350 mg kg^{-1} cause toxicity in the plant. Identification of heavy metal-resistant plants has become more important over the past two decades as soil contamination with these elements has increased in recent years due to increased industrial activity [18, 23]

Zn is necessary for plants and is usually available at concentrations of 10–200 mg kg^{-1} [26]. Hyperaccumulation of Zn by plants is extremely rare, owing to the preparation with which it can be precipitated as the insoluble sulfate in the rhizosphere, therefore minimizing potential transport and uptake to the shoot parts of the plants [7, 16]. In this study, Zn content in shoots of plants ranged from 19.7 to 1100 mg kg^{-1}; the maximum value was found in *Paracaryum persicum*. However, none of the plant species collected in this study accumulated Zn > 3000 mg kg^{-1} in their shoots, the notional criterion for Zn hyperaccumulation [27]. As for Cu, Zn concentrations were higher in the roots than in the shoots. There are numerous reports of the contents of Zn in plants grown in the mineral area. For instance, research done by Stoltz and Greger [24] showed Zn concentrations of 68–1630 mg kg^{-1} in plant biomass, while those by Mahdavian et al. [28] reported 124–4503 mg kg^{-1} in plant biomass for metalliferous mine sites in Iran. However, Zn concentrations of 17–453 mg kg^{-1} were reported by Yoon et al., a lower range than observed in plants in this research [11].

Given that the number of heavy metals in many plants grown in mineral areas is highly correlated with their amount in soil [28, 29], the amount of Zn in the soil of the Chahar Gonbad area is lower than the other elements, and consequently, its absorption rate in plants is lower. In other words, high value of Zn in soil solution limits the uptake of Cu by the plant, which may be due to competition for transporters in the root [22]. Therefore, according to the data in Table 2, the higher value of Cu metal in the soil and its uptake by plants is due to the low concentration of Zn in the soil of the Chahar Gonbad area.

Concentration of Fe in plant tissues is less than 350 µg g^{-1} (Suresh 2005). As shown in Table 2, among the sampled plants, *Boissiera squarrosa*, *Scariola orientalis*, *Pteropyrum aucheri*, *Lactuca glauciifolius*, *Marrubium vulgare*, *Ajuga chamaecistus*, *Cirsium spectabile*, *Malva neglecta*, and *Eremurus persicus* accumulated Fe in higher concentrations. The highest amount of Fe was observed in aerial parts of *Eremurus persicus* at 3701.2 mg kg^{-1}. Therefore, high amounts of Fe are due to the high amount of Fe in the soil of the mineral zone. High zinc concentrations inhibit Fe uptake and transfer to the plant, thus causing toxicity to zinc-like symptoms in the plant [30].

Plants with TF and BCF values > 1 are proper for phytoextraction and may be used for phytoextraction, while plants with BCF > 1 and TF < 1 may be used in phytostabilization [2, 11, 28]. Hence, according to Table 3, several of the sampled plant species could be appropriate for phytostabilization or phytoextraction of Cu, Zn, and Fe.

According to the research, *Scorzonera intricata*, *Onobrychis Mill*, and *Pteropyrum aucheri* are considered the most suitable plants for phytoextraction of Cu-enriched sites and also *Euphorbia gedrosiaca* and *Eremurus persicum* the most efficient in the phytostabilization of Cu. Whereas *Nepeta glomerulosa* is the most efficient in the phytoextraction of Fe and *Scariola orientalis* and *Scorzonera laciniata* are the most suitable for phytostabilization of Fe, *Scariola orientalis* and *Euphorbia gedrosiaca* are also suitable for the phytostabilization of Zn. Some of the plants gathered in this study display metal concentrations higher than normal. These results showed that the species grown in this area polluted with Cu, Zn, and Fe are tolerant of these metals. The limitation of upward movement of metals from roots to shoots may be proposed as a mechanism of plant tolerance [31]. Therefore, according to the present study, the above-mentioned plant species were suitable for phytostabilization and phytoextraction. The phytoremediation of Cu, Zn, and Fe mines is important because they can absorb high amounts of Cu, Zn, and Fe in their roots or shoots. Therefore, in this method, plants absorb large amounts of heavy metals and reduce the metal concentration in the soil. Several plants also displayed different accumulation patterns for different concentrations of metals in the soil. This difference between the different parts of the same plant due to the interaction of the plant and the soil should be taken into account when using plant species for phytoremediation.

Conclusions

This study of screening plants growing in a polluted place was conducted to distinguish the potential of metal accumulation. Plant species like *Scorzonera intricata* with concentration up to 2289 Cu kg^{-1} were identified. This plant species can be considered as hyperaccumulators of Cu that would be the first reported for Fe. Alone species with both BCFs and TFs > 1 showed potential for phytoextraction. Some plants had BCFs or TFs > 1. Including in plant species collected from the polluted site, *Euphorbia gedrosiaca* and *Eremurus persicum* were the most effective in the phytostabilization of Cu. In addition, *Scariola orientalis* is proposed as the most efficient species in the phytostabilization of soils polluted with Zn and Fe. According to the research, *Scorzonera intricata*, *Onobrychis Mill*, and *Pteropyrum aucheri* are known as the most suitable species for phytoextraction of Cu and also *Nepeta glomerulosa* the most effective in the phytoextraction of Fe. The phytoremediation potential of all these plant species needs to be further investigated.

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Data Availability All data generated or analyzed during this study are included in this article.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval This article is original and not published elsewhere. All authors discussed the results and read and approved the final manuscript. The authors confirm that there are no ethical issues in the publication of the manuscript.

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