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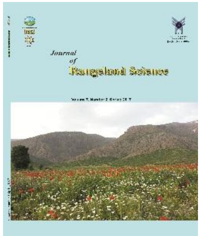

Research and Full Length Article:

Rangeland Plants Potential for Phytoremediation of Contaminated Soils with Lead, Zinc, Cadmium and Nickel (Case Study: Rangelands around National Lead & Zinc Factory, Zanjan, Iran)

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Abstract. There are many remediating methods for the polluted soils but only phytoremediation is a cost effective, environmental friendly, aesthetically pleasing approach that is most suitable for many countries. The purpose of this study was to investigate the potential of native plants for phytoremediation of contaminated soils with lead, zinc, cadmium and nickel in the rangelands around National Lead & Zinc Factory, Zanjan, Iran. Sampling was done at 11 sites on May, 2014 and plant samples were collected from 14 native plant species. Three soil samples were taken at each site. Soil samples were taken from the rooting zone. Extraction of Pb, Zn, Cd and Ni from plants was done by acid digestion. Plant samples were digested in the di-acid mixture (3:1) of nitric acid (HNO_3) and perchloric acid (HClO) and soil samples were digested with 4M HNO_3 acid. Metals of Pb, Zn, Cd and Ni were extracted from plant and soil samples were determined using Inductively Coupled plasma Optical Emission Spectroscopy “ICP-OES”. In general, the results showed that no hyperaccumulators of Pb and Zn were identified in the area. All plants were classified as low lead accumulators, excluder and moderate accumulators, low zinc accumulators or excluders; though Pb and Zn concentrations in the plants were higher than standard range. Standard range of lead and zinc in rangeland plants is 0.2-20 and 1-400 $mgkg^{-1}$, respectively whereas the species of *Brassica juncea* and *Scariola orientalis* were classified as Cd hyperaccumulators and *Scariola orientalis and Echium amoenum* were classified as Ni hyperaccumulators. The normal value of Cd and Ni in these plants were 0.1-2.4 and 0.02-5.0 $mgkg^{-1}$, respectively. Thus, these native plants had an implication of carrying out phytoremediation in the rangeland soils around National Iranian Lead & Zinc Factory, Zanjan.

Key words: Native plants, Contaminated soil, Heavy metal, Phytoremediation

Introduction

Industrial and municipal wastes generate a great deal of particulate emissions and waste slag enriched in heavy metals that contaminate the surrounding soil, water and air. Heavy metals contamination in soils is one of the world's major environmental problems, posing significant risks to human health as well as ecosystems. Such effects are particularly serious and pose a severe ecological and human health risk when smelting works are located in the vicinity of urban environments. Traditionally, techniques of soil remediation are costly and may cause the secondary pollution (Nazir *et al*., 2011). There are many methods used for remediating heavy metals pollution but only phytoremediation is a cost effective, environmental friendly, aesthetically pleasing approach which is most suitable for many countries (Ghosh and Sing, 2005). Among different areas embraced by the field of phytoremediation, special interest has been devoted to the phytoextraction of metals from the contaminated soils. In this case, metals are removed from soils by concentrating them in the aerial parts of the plant. Harvesting and disposal of shoot biomass allow the metal to be removed in significant quantities from the soil (Zayed and Terry, 1994). Another application of phytoremediation is phytostabilization where plants are used to minimize metal mobility in the contaminated soils (Rosselli *et al*., 2003).

Phytoremediation as an emerging solution which refers to the use of green plants for the removal of contaminants or rendering them harmless is cost-effective, and environmental-friendly and can be applied to large-scale soils (Wei *et al*., 2010). It is important to use the rangeland plants for phytoremediation because these plants are often better in terms of survival, growth and reproduction under environmental stress as compared to the plants introduced from the other environments. There has been a continuing interest in searching for rangeland plants that are tolerant to heavy metals; however, studies have evaluated the phytoremediation potential of native plants under field conditions (Mc Grath and Zhoa, 2003). Some phytoremediation projects have utilized native species. The explanations for doing so include avoiding the introduction of exotic species into sensitive ecosystems (Newman *et al*., 1998), statutory requirements for restoration, and the benefits from the adaptation of indigenous species to local growing conditions (Frick *et al*., 1999).

Heavy metals can cause severe phytotoxicity and may act as a powerful force for the evolution of tolerant plant community. So, it is possible to identify metal tolerant plant species from natural vegetation in the field sites that are contaminated with various heavy metals (Nazir *et al*., 2011). The plant species, which are often identified as accumulators, have the ability to take up soil contaminants and saved them in their roots, shoots and leaves.

Vaverkov and Adamcov (2014) grouped plant species by their capability of heavy metal uptake and sensitivity to high metal pollution: hyperaccumulator plants BAC[2]>1, moderate accumulator plants 0.1<BAC<1.0, low accumulator plants 0.01<BAC<0.1 and non-accumulator plants BAC< 0.01. Plants that accumulate very high concentrations of metals in any aboveground tissue in their natural habitat are called hyper-accumulators. About 400 plant species have been reported to accumulate toxic heavy metals (Al-Taisan, 2009). Metal accumulators (hyperaccumulators) are plant species that concentrate metals in their above-ground tissues to levels far exceeding those present in the soil or in the non-accumulating species growing nearby. These plants are capable of

٢. Biological accumulation coefficient

extracting heavy metals from soils and concentrate them in their shoots, and they are widely used in phytoremediation.

Mganga *et al*. (2011) reported that determination of hyperaccumulator and excluder plant species is based on strict criteria. A plant is classified as a hyperaccumulator for heavy metal (s) when it meets four criteria; a) shoot/root ratio (TF)>1. b) extraction coefficient (BAC) > 1; extraction coefficient gives the proportion of total heavy metals in the soil which is taken up by the plant shoot/aerial part of the plant (Rotkittikhun *et al*., 2006), c) higher values of heavy metals of 10-500 times the values in normal plants (uncontaminated plants) according to Allen (1989) and Fifield and Haines (2000), and d) more than 1000µg/g of copper, lead, nickel, chromium; or more than 100µg/g of cadmium or more than 10000µg/g of zinc (Boularbah *et al*., 2006; Rotkittikhun *et al*., 2006; Sun *et al*., 2008). Furthermore, a plant which has high values of heavy metals in the roots but with shoot/root ratio less than 1 is classified as a heavy metal excluder (Boularbah *et al*., 2006). Normal ranges of Lead, Zinc, Cadmium and Nickel in plants are 0.2-20, 1-400, 0.1-2.4 and 0.02-5 ($mgkg^{-1}$), respectively (Alloway, 1990).

Mok *et al.* (2013) investigated native Australian species which were effective in extracting multiple heavy metals from biosolids. Their results demonstrated that *Grevillea robusta*, *Acacia mearnsii*, *Eucalyptus polybractea*, and *E. cladocalyx* had the greatest potential as phytoextractor species in the remediation of heavy metal-contaminated biosolids. Species survival and growth were the main determinants of metal extraction efficiency and these traits will be important for future screening of native species. Norozi Fard *et al*. (2016) suggested *Phragmites australis* as a useful plant for the reduction of heavy metals in sediments and as a bio-monitor for biological monitoring plans in order to evaluate the environmental conditions quantitatively with respect to the sediments of studied region. Ebrahimi and Madrid Diaz (2014) reported that *Festuca ovina* can be adapted to a soil having relatively high values of available Cu but Cu caused serious growth suppression of *F. ovina*.

The rangelands were around National Iranian Lead & Zinc Factory in Zanjan province located in north-west of Iran. This factory is one of the largest of its kind in Middle East with a large market capitalization. Zinc Specialized Industrial Complex (ZSIC) covering fifty eight zinc production units is another important industrial complex developed in the studied area with a current annual consumption of about one million tons of raw ore and a production of 0.19 million tons of Zn (Saba *et al*., 2015). The heavy metal contaminations of soil around these industrial complexes encouraged the assessment of heavy metals remediation by the means of their extraction or stabilization by rangeland plants. So, the aims of this study were: i) to evaluate the potential of rangeland plants for phytoremediation of contaminated soils with lead, Zinc, cadmium and nickel in the rangelands around National Iranian Lead & Zinc Factory, Zanjan and
ii) to evaluate which metals can be potentially extracted by rangeland plants.

Materials and Methods

Site Description

Zanjan province is located in north-west of Iran. It has a large metalliferous site and has been considered as a traditional mining region since antiquity. There are still large reserves of lead and zinc in the area. Both mines and smelting units within the province present a risk of contamination of soils, plants, and surface/groundwater resources through the dissemination of particles carrying metals by wind and/or runoff from the tailings (Chehregani *et al*., 2009).

National Iranian Lead and Zinc Factory, Zanjan is located between 36° 36' 40" and 36° 38' 25" N and 48° 37' 33" and 48° 38' 54" E in Zanjan province, Iran.

Plants and soil sampling and analysis

Plant samples were collected from 14 native plant species including *Stipa hohenackeriana*, *Hulthemia persica*, *Gundelia tournefortii*, *Brassica juncea*, *Astragalus* effusus, *Taeniatherum crinitum*, *Scariola orientalis*, *Brassica juncea*, *Tragopogon collinus*, *Descurainia sophia*, *Achillea millefolium*, *Centaurea virgata*, *Stachys lavandulifolia* and *Echium amoenum* in the rangelands around National Iranian Lead & Zinc Factory. These plants are distributed in the study area and can survive under a wide range of temperature and grow in almost any types of soil in the studied area. Totally, 14 plant species belonging to 7 families were collected including 1 perennial grass, 1 annual grass, 8 annual herbs, 2 perennial herbs and 2 shrubs. Plant descriptions are provided in Table 1. During field survey, it was noticed that *S. hohenackeriana* was frequently represented on different sites.

Table 1. Plant species identified and studied in the research

Name of species	Family	Habit
Stipa hohenackeriana	Poaceae	Perennial grass
Hulthemia persica	Rosaceae	Shrub
Gundelia tournefortii	Asteraceae	Annual herb
Brassica juncea	Brassicaceae	Annual herb
Astragalus effusus	Fabaceae	Annual herb
Taeniatherum crinitum	Poaceae	Annual grass
Scariola orientalis	Asteraceae	Shrub
Brassica juncea	Asteraceae	Annual herb
Tragopogon collinus	Brassicaceae	Annual herb
Descurainia sophia	Asteraceae	Annual herb
Achillea millefolium	Asteraceae	Annual herb
Centaurea virgata	Asteraceae	Perennial herb
Stachys lavandulifolia	Lamiaceae	Annual herb
Echium amoenum	Boraginaceae	Perennial herb

Sampling was conducted on 11 sites. The area of sites was 10 ×10 m^2. The first site was selected randomly at the sidewalls of factory. Root and shoot samples of study plants from an area of 1 m^2 along the one of the diagonals were collected by cutting all of the plants in all sampling points. Therefore, at each site, 3 plant samples were taken.

The samples were collected in brown paper bags and transferred to laboratory for sample preparation and analysis. In the laboratory, samples were dried in an oven for 48 hours at 60°C.

Extraction of Pb, Zn, Cd and Ni from plant samples was done by the acid digestion. Plant samples were digested in di-acid mixture (3:1) of nitric acid (HNO_3) and perchloric acid (HClO) at 150°C for 2h and 210°C for 1h (Miller, 1998; Ebrahimi *et al*., 2014).

After digestion, the samples were left to cool and then transferred to 100-ml volumetric flasks. Then, they were filtered (with cellulose acetate filter paper, 0.23 mm Thickness) and diluted with the deionized water to 100 mL (Brainina *et al*., 2004). Then, total concentrations of Zn, Pb, Ni and Cd were determined using “ICP-OES” (Inductively Coupled Plasma Emission Spectroscopy, GBC, Australia).

Three soil samples were taken at each site within plots. Soil samples were taken from the rooting zone. Soil was sampled at 33 profiles (11 sites) on May 2014. At each profile, 1 kg of soil was collected. Soil samples were air-dried at room temperature for two weeks and passed through 2 mm sieve to remove the gravels and debris.

Soil texture and particle size distribution (Bouycous hydrometer method) (Day, 1982), EC (solid: the deionized water=1:2 w/v, Model DDS-307) (Rhoades, 1996), pH (1:1 soil/water ratio, Model 691) (Thomas, 1996), organic carbon (Walkley-Black method) (Nelson and Sommers, 1996), Calcium carbonate equivalent percent (CCE) (Calcimetric method), CEC (Cation Exchange Capacity) (Bower and Hatcher, 1966), Total N (Kjeldahl method) (Bremner, 1996), available phosphorus (Olsen Method) (Kuo, 1996), available Potassium (acetate ammonium method), and total K (Flame photometry method) (Hemke and Sparks, 1996) were determined as the basic soil properties (Table 2).

Soil samples were then analyzed for total metals (Pb, Zn, Cd and Ni). The total concentration of Pb, Zn, Cd and Ni in soil samples was determined after digesting soil with 4M HNO3 acid (1:10 ratio) at 60 °C water bath for 14 hours (Amacher and Selim, 1994). Metals of Pb, Zn, Cd and Ni extracted from soil samples were determined using Inductively Coupled plasma Optical Emission Spectroscopy "ICP-OES" (GBC Avanta, Australia).

Table 2. The mean physico-chemical properties of the soil samples in the study area

Clay (%)	Silt (%)	Sand (%)	Soil texture	pH	EC (dsm^{-1})	Organic matter %)	CCE (%)	CEC (meqg/100g)	N (%)	Exchangeable P (ppm)	Exchangeable K (ppm)
13.4	14.81	71.6	Silty Sand	7.76	0.2	0.85	3.35	16.53	0.063	87.51	200

Accumulation and translocation potential of native plants

The mobility of heavy metals from the contaminated soil into the roots of plants and the ability to translocate the metals from roots to the harvestable aerial part were evaluated respectively by the means of the Bio-Concentration Factor (BCF), the Biological Absorption Coefficient (BAC) and the Translocation Factor (TF) (Behrouz *et al*., 2008; Lorestani *et al*., 2011; Zu *et al.,* 2005; Cheraghi *et al.,* 2011). In this study, the BAC, TF and BCF values for heavy metals are given by:

Bio-Concentration Factor (BCF) = [Metal] root / [Metal] soil

Biological Absorption Coefficient (BAC) = [Metal] shoot / [Metal] soil

Translocation Factor (TF) = [Metal] shoot / [Metal] root

Data analysis and statistical analysis

Data were controlled for their normality with the Kolmogorov–Smirnov test and for homogeneity of variance with the Levene test ($p<0.05$). The mean difference test (t-test) was performed to assess the differences between the heavy metals concentration in soil with maximum allowable concentrations. One-way analysis of variance (ANOVA) was used to identify significant differences in concentrations of heavy metals in soil, plant shoots and roots.

Results and Discussion

Maximum allowable concentrations (MAC) of Lead, Zind, Cadmium and Nickel of rangeland soil of Iran are 290, 500, 8.0 and 530 ($mgkg^{-1}$), respectively (Iranian Environmental Protection Agency, 2014). The statistical analysis reveals that the mean concentrations of Pb, Zn and Cd in the soil of all sites were significantly higher than the MAC in rangelands soil of Iran (Iranian Environmental Protection Agency, 2014) meaning that the soils are not safe for rangeland and nature ecosystems. But Ni content was significantly lower than that for MAC. This indicates that Pb, Zn and Cd had accumulated in soils in this area and the soil was evidently polluted by these metals (Table 3). This is the reason for the accumulation of heavy metals of processing lead and zinc in the National Iranian Lead & Zinc Factory. Saba *et al*. (2015) and Moameri *et al*. (2015) reported that very high concentrations of heavy metals in the stations of National Iranian Lead & Zinc Factory, Zanjan are certainly anthropogenic and the industrial activity is the main cause of soil/plant pollution.

Table 3. Comparison of heavy metals concentration in soil with Maximum allowable concentrations (MAC)

Heavy metals	MAC values* ($mgkg^{-1}$)	Mean ± S.E ($mgkg^{-1}$)	t-Test
Pb	290	4515.90 ± 959.5	35.77**
Zn	500	988.36 ± 153.27	25.88**
Cd	8	32.76 ± 10.83	13.29**
Ni	530	21.05 ± 6.40	-4556 **

**: Represent significant at probability level of 1%. *: Iranian Environmental Protection Agency Iran, 2014

Pb, Zn, Cd and Ni accumulation in soil and plants

The highest concentration of Pb (5725.9 $mgkg^{-1}$) in soil was occurred at the habitats of *Scariola orientalis* and *Tragopogon collinus*. Table 4 shows a comparative analysis of the average concentrations of Pb plants from the field survey. The results showed that the mean concentrations of Pb in the plant tissues differed among species at the polluted sites indicating their different capacities for metal uptake (Ebrahimi *et al*., 2014). The species with the highest Pb concentration for shoots and roots were *S. orientalis* (213.9 ± 37.3 $mgkg^{-1}$) and *T. collinus* (210.2 ± 5.2 $mgkg^{-1}$), respectively. In general, a large number of plants could extract considerable Pb in their roots or shoots.

The results also showed that *Stipa hohenackeriana*, *Hulthemia persica*, *Scariola orientalis, Descurainia sophia*, *Stachys lavandulifolia* and *Echium amoenum* had the translocation factor (TF) > 1 for lead. High root to shoot translocation of Pb indicated that these plant species had vital characteristics to be used in the phytoremediation of metal (Ghosh and Sing, 2005). The bioconcentration factor (BCF) and the Biological Absorption Coefficient (BAC) of all species were <1 for Pb. This indicates that the concentration of lead in soil was more than the plant organs.

Table 4. Total means Pb concentrations in soil, shoots, and roots, Bio-Concentration Factor (BCF), Biological Absorption Coefficient (BAC) and Translocation Factor (TF) for the different plant species

Name of species	Soil	Shoots	Roots	TF	BAC	BCF
Stipa hohenackeriana	5317.3±880.3b	210.9±56.6 a	198.38±32.2ab	1.06	0.039	0.037
Hulthemia persica	5244.2±213.1b	132.7±45.2b	97.89±17.5 d	1.35	0.025	0.018
Gundelia tournefortii	4384.3±123.7e	9.46±4.08 g	58.11±4.98 e	0.16	0.002	0.013
Brassica juncea	4985.6±93.4 c	24.15±4.64e	44.36±13.86f	0.54	0.004	0.088
Astragalus effusus	4808.5±20.3 d	127.59±6.4b	127.74±2.5 c	0.99	0.026	0.002
Taeniatherum crinitum	4016.0±114.7f	32.44±3.72e	54.81±6.12 e	0.59	0.008	0.013
Scariola orientalis	5725.9±380.0 a	213.9±37.3a	188.5±30.5 b	1.13	0.037	0.032
Tragopogon collinus	5725.2±120.0 a	19.20±4.10 f	210.2±5.20 a	0.09	0.003	0.036
Descurainia sophia	4241.4±880.0 e	67.30±3.30 d	7.20±1.130 i	9.34	0.015	0.001
Achillea millefolium	3767.5±342.0 g	16.20±4.20 f	33.53±5.60 g	0.04	0.004	0.008
Centaurea virgata	4018.1±183.0 f	17.60±2.90 f	42.90±5.68 f	0.41	0.004	0.010
Stachys lavandulifolia	3817.6±530.0 g	30.70±4.20 e	20.40±4.20 h	1.50	0.008	0.005
Echium amoenum	3517.1±8.00 h	83.50±3.10 c	54.81±6.12 e	1.52	0.023	0.015

Mean values are reported with S.E (Standard Errors). Values within a column followed by the same letter do not differ significantly (p<0.05, post hoc Duncan test)

The highest concentration of Zn (1213.2 $mgkg^{-1}$) in soil was occurred at the habitats of *Scariola orientalis*, *Tragopogon collinus* and *Gundelia tournefortii*. The results showed that the mean contents of Zn in the plant tissues differed among species (Table 5). The highest value of zinc as 439.3 $mgkg^{-1}$ was found in the shoots of *Scariola orientalis* whereas the lowest value of zinc as 52.25

mgkg^{-1} was found in the shoot of *Centaurea virgata*. In addition, the highest value of zinc of roots (381.4 mgkg^{-1}) was found in *Tragopogon collinus* and the lowest value of zinc of roots (28.8 mgkg^{-1}) was found in *Descurainia sophia*. Furthermore, *Stipa hohenackeriana*, *Hulthemia persica*, *Scariola orientalis*, *Astragalus effusus*, *Descurainia sophia*, *Stachys lavandulifolia* and *Echium amoenum* had the translocation factor (TF)> 1 for zinc. Plant species with high TF values were considered suitable for phytoremediation that generally requires translocation of heavy metals in easily harvestable plant parts i.e., shoots (Yoon *et al*., 2006). The same results also show that the BCF and the BAC of all species were <1 for Zn and the concentration of lead in soil was more than the plant tissues. Ebrahimi *et al*. (2014) reported that the plants, which had low metal bioaccumulation in their roots and high TF, could play important roles in the removal of heavy metals through phytoextraction.

Table 5. Total means Zn concentrations in soil, shoots, and roots, Bio-Concentration Factor (BCF), Biological Absorption Coefficient (BAC) and Translocation Factor (TF) for the different plant species

Name of species	Soil	Shoots	Roots	TF	BAC	BCF
Stipa hohenackeriana	1081.5±123c	235.8±75.0b	202.01±64 b	1.16	0.210	0.180
Hulthemia persica	1054.5±23 c	165.6±49.0c	123.9±17.7d	1.33	0.150	0.110
Gundelia tournefortii	1213.3±123a	116.0±4.15de	132.05±8.3d	0.09	0.095	0.108
Brassica juncea	1051.6±93 c	91.4±21.60 f	109.5±23.9e	0.83	0.830	0.104
Astragalus effusus	1134.5±290b	157.5±2.20c	108.10±3.5e	1.45	0.130	0.095
Taeniatherum crinitum	1013.0±214c	64.5±0.60 c	150.08±4.9c	0.43	0.060	0.140
Scariola orientalis	1213.2±180a	439.3±87.6a	197.6±46.8b	2.22	0.360	0.160
Tragopogon collinus	1213.2±10 a	88.4±4.10 f	381.4±5.6 a	0.23	0.070	0.310
Descurainia sophia	939.6±70 d	78.96±2.80g	28.8±4.90 i	2.74	0.080	0.030
Achillea millefolium	963.7±32 d	65.5±1.20 g	68.8±0.80 h	0.95	0.060	0.070
Centaurea virgata	861.3±83 e	52.25±2.5 h	81.9±11.6 g	0.63	0.060	0.090
Stachys lavandulifolia	860.6±30 e	132.1±5.14d	73.8±2.20 h	1.79	0.150	0.080
10 Echium amoenum	810.8±68 e	112.5±1.5 e	95.16±0.16f	1.18	0.130	0.110

Mean values are reported with S.E (Standard Errors). Values within a column followed by the same letter do not differ significantly (p<0.05, post hoc Duncan test)

The highest concentration of Cd (51.4 mg kg^{-1}) in soil was occurred at the habitats of *Gundelia tournefortii*. The results in Table 6 showed that the shoots of *Scariola orientalis* had the highest value of cadmium given as 68.47 mg kg^{-1} whereas the lowest value of cadmium was found in the shoots (0.71 mg kg^{-1}) of *Stachys lavandulifolia*. The highest accumulation of Cd in the roots of plants was occurred in the *Tragopogon collinus* and the lowest value of Cd was observed in the roots of *Centaurea virgata.* The results showed that the TF for *Brassica juncea, Scariola orientalis, Descurainia* sophia, *Achillea millefolium, Centaurea virgata* and *Stachys lavandulifolia* was > 1 for Cd. Furthermore, these plants had the Cd concentrations in the shoots larger than the roots. In addition, these plants were accumulators for Cd.

In the case of cadmium, the species which had BAC>1 were *Stipa hohenackeriana, Brassica juncea* and *Scariola orientalis.* Moreover, the BCF for *Stipa hohenackeriana, Brassica juncea* and *Tragopogon collinus* was > 1 for Cd. This indicates that the concentration of Cd in the plant organs was more than soil. These plants had capability of Cd uptake and were resistant to high Cd. Therefore, they can be classified as Cd hyperaccumulators.

Table 6. Total means Cd concentrations in soil, shoot and roots, Bio-Concentration Factor (BCF), Biological Absorption Coefficient (BAC) and Translocation Factor (TF) for the different plant species

Name of species	Soil	Shoots	Roots	TF	BAC	BCF
Stipa hohenackeriana	38.30±6.0 b	54.2±7.20 c	59.9±7.20 b	0.90	1.410	1.560
Hulthemia persica	39.23±11.0 b	9.20±0.70 f	10.07±0.5 e	0.85	0.230	0.250
Gundelia tournefortii	51.40±9.0 a	0.48±0.19 de	1.47±0.22 f	0.32	0.009	0.028
Brassica juncea	25.52±3.0 d	62.4±0.17 b	31.1±0.13 d	2.07	2.440	1.120
Astragalus effusus	37.17±7.0 b	1.93±0.20 g	2.53±0.23 f	0.76	0.05	0.060
Taeniatherum crinitum	28.38±4.7c	0.73±0.09 c	1.18±0.09 f	0.61	0.025	0.040
Scariola orientalis	49.50±10 a	68.47±4.02a	46.65±1.09c	1.46	1.380	0.940
Tragopogon collinus	49.30±6.0 a	21.17±0.0 d	68.1±1.60 a	0.31	0.420	1.380
Descurainia sophia	31.30±6.0 c	18.23±0.23de	12.8±0.10 e	1.42	0.580	0.400
Achillea millefolium	27.30±3.0 d	0.77±0.00 h	0.76±0.76 g	1.01	0.020	0.027
Centaurea virgata	23.66±3.0 e	2.10±0.50 g	0.41±0.01 g	5.12	0.088	0.010
Stachys lavandulifolia	21.10±6.0 e	0.71±0.00 h	0.68±0.00 g	1.04	0.033	0.032
Echium amoenum	22.80±5.0 e	1.40±0.00 g	1.67±0.20 f	0.83	0.060	0.070

Mean values are reported with S.E (Standard Errors). Values within a column followed by the same letter do not differ significantly ($p<0.05$, post hoc Duncan test)

The highest concentration of the soil nickel (27.5 mg kg^{-1}) was occurred at the habitats of *Scariola orientalis, Tragopogon collinus* and *Gundelia tournefortii*. The highest value of nickel of 119.95 mg kg^{-1} was found in the shoots of *Stipa hohenackeriana* whereas the lowest value of nickel of 6.5 mg kg^{-1} was found in the shoots of *Centaurea virgata*. In addition, the highest value of Ni in the roots (195.9 mg kg^{-1}) was found in *Stipa hohenackeriana* whereas the lowest value of Ni in the roots (28.8 mg kg^{-1}) was found in *Astragalus effusus*. Furthermore, *Stipa hohenackeriana*, *Taeniatherum crinitum*, *Scariola orientalis*, *Achillea millefolium* and *Echium amoenum* had the BAC> 1 for Ni. Moreover, the BCF for *Stipa hohenackeriana*, *Hulthemia persica*, *Brassica juncea*, *Taeniatherum crinitum*, *Scariola orientalis*, *Descurainia sophia*, *Achillea millefolium*, *Centaurea virgata*, *Stachys lavandulifolia* and *Echium amoenum* was > 1 (Table 7).

Table 7. Total means Ni concentrations in soil, shoot and roots, Bio-Concentration Factor (BCF), Biological Absorption Coefficient (BAC) and Translocation Factor (TF) for the different plant species

Name of species	Soil	Shoots	Roots	TF	BAC	BCF
Stipa hohenackeriana	21.82±3.30c	119.9±26.1a	195.9±16.4 a	0.61	4.49	8.97
Hulthemia persica	25.36±3.06ab	15.96±4.2 b	26.73±1.5 d	0.59	0.62	1.05
Gundelia tournefortii	27.5±2.50 a	20.93±4.1g	23.33±3.8 e	0.89	0.76	0.84
Brassica juncea	22.39±1.40c	21.21±3.6de	25.38±4.6cde	0.83	0.94	1.13
Astragalus effusus	20.96±2.33c	15.3±2.4 e	18.8±2.5 de	0.81	0.72	0.89
Taeniatherum crinitum	19.28±2.30c	34.5±7.7 c	40.66±7.2 b	0.84	1.78	2.10
Scariola orientalis	27.0±4.36 a	36.07±8.1c	32.19±2.5 bc	1.12	1.33	1.19
Tragopogon collinus	27.0±4.36 a	22.9±4.1 d	22.08±4.2 de	1.04	0.84	0.81
Descurainia sophia	25.7±1.21ab	21.06±2.3de	37.7±7.80 c	0.55	0.82	1.46
Achillea millefolium	15.6±2.36 d	21.5±6.2 de	30.94±5.6bcd	0.69	1.37	1.98
Centaurea virgata	15.1±0.70 d	6.5±0.90 f	22.05±6.8de	0.29	0.43	1.46
Stachys lavandulifolia	13.97±2.61e	7.0±0.20 f	20.4±4.20 h	0.34	0.50	1.46
Echium amoenum	15.28±0.76e	57.5±9.10b	21.14±3.1 de	2.71	3.76	1.38

Mean values are reported with S.E (Standard Errors). Values within a column followed by the same letter do not differ significantly ($p<0.05$, post hoc Duncan test)

Plants react differently when exposed to the elevated levels of heavy metals. Some plant species accumulate heavy metals; others exclude them whereas other plant species are sensitive (Magana *et al.,* 2011). In this study, we evaluated fourteen plants against lead, zinc, cadmium and nickel based on different criteria (Vaverkov and Adamcov, 2014; Mganga *et al*., 2011; Rotkittikhun *et al*., 2006; Fifield and Haines, 2000 and Sun *et al*., 2008). Table 8 summarizes the plant species in their respective classes. Some of these plant species were considered suitable for growing in the contaminated soils in the rangelands around National Iranian Lead & Zinc Factory as they accumulate considerable quantities of heavy metals from the soil with their root system and can be used as a potential plant species for cleaning heavy metals.

Table 8. Classes of 14 Plant Species based on Pb, Zn, Cd and Ni accumulation

Name of species	Hyperaccumulator	Moderate accumulator	Low accumulator	Non-accumulator (Excluder)
Stipa hohenackeriana	-	Cd, Ni, Zn	Pb	-
Hulthemia persica	-	Zn, Cd, Ni	Pb	-
Gundelia tournefortii	-	Ni	Zn	Pb, Cd
Brassica juncea	Cd	Zn, Ni	-	Pb
Astragalus effusus	-	Zn, Ni	Pb	Cd
Taeniatherum crinitum	-	Ni	Zn	Pb, Cd
Scariola orientalis	Cd, Ni	Zn	Pb	-
Tragopogon collinus	-	Cd, Ni	Zn	Pb
Descurainia sophia	-	Cd, Ni	Pb, Zn	-
Achillea millefolium	-	Ni	Zn, Cd	Pb
Centaurea virgata	-	Ni	Zn, Cd	Pb
Stachys lavandulifolia	-	Zn, Ni	Cd	Pb
Echium amoenum	Ni	Zn	Pb, Cd	-

Conclusion

Phytoremediation may be used as a short-term treatment option to rehabilitate land for heavy metals contamination. It is also possible to imagine it as the first step in the creation of wildlife habitat. This is only possible, however, if the used species are natives, well adapted to the local climate and soils. Only a small number of plant species were established as being effective in phytoremediation. This does not mean that many plants had been shown ineffective and relatively few had been carefully evaluated. Thus, it is valuable to determine whether native species are also effective. This study was investigated to be an initial effort to determine whether rangeland plants can be used in lead, zinc, cadmium and nickel contaminated soils for phytoremediation. In accordance with previous reports, the uptake and accumulation of heavy metals vary greatly with plant species (Lei *et al*., 2011). In general, the results showed that no hyperaccumulators of Pb and Zn were identified in the area. All plants were classified as low lead accumulator or excluder and moderate accumulator, and low zinc accumulator or excluder. Although Pb and Zn concentrations in the plants were higher than standard range, standard range of lead and zinc in plants was 0.2-20 and 1-400 mg kg^{-1}, respectively (Alloway, 1990). In this study, *Brassica juncea* and S*cariola orientalis* were classified as Cd hyperaccumulators. These plant species met only three criteria (TF>1, BAC>1 and higher value of Cd of 10 – 500 times the values in normal plants) for Cd hyperaccumulation. The normal value of Cd in plants was 0.10-2.4 mg kg^{-1} (Alloway, 1990). In addition, *Scariola orientalis and Echium amoenum* were classified as Ni hyperaccumulators. These plants met only three criteria (TF>1, BAC>1 and higher value of Ni of 10 – 500 times the values in normal plants) for Ni hyperaccumulation. The normal value of Ni in plants is 0.02-5 mg kg^{-1} (Alloway, 1990). Thus, they have an implication of carrying out phytoremediation in the rangelands around National Iranian Lead & Zinc Factory, Zanjan.

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پتانسیل گیاهان مرتعی برای گیاه پالایی خاک‌های آلوده به سرب، روی، کادمیم و نیکل (مطالعه موردی: مراتع اطراف شرکت ملی سرب و روی زنجان)

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چکیده. از روش‌های مختلفی برای پاکسازی خاک‌های آلوده استفاده می‌شود، اما تنها گیاه‌پالایی، روشی ارزان، دوستدار محیط زیست و دارای رویکرد زیبایی‌شناسی است که کاربرد آن در بسیاری از کشورهای دنیا نیز مناسب است. هدف از انجام این مطالعه بررسی پتانسیل گیاهان بومی برای گیاه‌پالایی خاک‌های آلوده به سرب، روی، کادمیم و نیکل در مراتع اطراف شرکت ملی سرب و روی ایران- زنجان بود. برای انجام این مطالعه، نمونه‌برداری از ۱۱ محل و در سال ۱۳۹۴ انجام شد. نمونه‌های گیاهان از ۱۴ گونه بومی در این ۱۱ محل جمع‌آوری شد. همچنین در هر محل سه نمونه خاک از عمق ریشه‌دوانی گیاهان برداشت شدند. استخراج سرب، روی، کادمیم و نیکل از نمونه‌های گیاهان و خاک به‌وسیله هضم توسط اسید انجام شد. نمونه‌های گیاهی در ترکیب ۳:۱ اسید نیتریک و اسید هیپوکلریک و نمونه‌های خاک در اسید نیتریک ۴ مولار هضم شدند. مقادیر فلزات سرب، روی، کادمیم و نیکل در عصاره حاصل توسط دستگاه ICP-OES تعیین شد. به‌طور کلی نتایج نشان داد که هیچ کدام از گیاهان مورد مطالعه در این تحقیق بیش‌اندوزگر یا دارای توانایی متوسط بیش‌اندوزی برای سرب و روی نبودند. همه گیاهان مورد مطالعه برای سرب کم بیش‌اندوز (دافع) بوده و برای روی دارای توانایی متوسط بیش‌اندوزی (کم‌بیش-اندوز) بودند. با این وجود، غلظت سرب و روی در گیاهان بیشتر از محدوده استاندارد بود. محدوده استاندارد سرب و روی در گیاهان به‌ترتیب ۲۰-۰/۲۰ و ۴۰۰-۱ میلی‌گرم در کیلوگرم بود. گونه‌های *Brassica juncea* و *Scariola orientalis* به‌عنوان بیش‌اندوزگر کادمیم و *Scariola orientalis* و *Echium amoenum* به‌عنوان بیش‌اندوزگر نیکل شناسایی شدند. سطح نرمال کادمیم و نیکل در گیاهان مرتعی به‌ترتیب ۲/۴-۰/۱۰ و ۵-۰/۰۲ میلی‌گرم در کیلوگرم بود. بنابراین این گیاهان برای گیاه‌پالایی در خاک مراتع اطراف شرکت ملی سرب و روی ایران- زنجان قابل استفاده هستند.

کلمات کلیدی: گیاهان بومی، خاک آلوده، فلزات سنگین، گیاه‌پالایی