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# Nickel phytoremediation potential of some plant species of the Lower Dir, Khyber Pakhtunkhwa, Pakistan

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**Abstract:** Nickel is a known hepatotoxic, haemotoxic, pulmonary toxic, nephrotoxic, reproductive toxic, carcinogenic, phytotoxic and neurotoxic agent. The adverse ecological impacts from unnecessary heavy metals include contamination of water and soil which pose serious threats to human health. This study was conducted to screen plants for the phytoremediation of nickel from sixty-one sites of the Lower Dir. Nickel-metal was analyzed in the soil, roots and shoots of plants. The total concentration of nickel in soil, roots and shoots was found to be in the range of 1.03-18.98, 12.63-540.73 and 12.00-295.86 mg kg–1 dry weight basis (DW) respectively. The highest nickel contents were present in the roots of Xanthium strumarium (540.73) and shoots of Bryophyllum daigremontianum (295.86). None of the plant species were identified as hyper accumulators for nickel but based on BCF, TF and BAC values most of the species showed feasibility for its phytoextraction and phytostabilization. Xanthium strumarium, Filago hurdwarica, Ranunculus arvensis, Medicago lupulina, Cannabis sativa, Geranium rotundifolium and Cerastium glomeratum are suggested for the phytostabilization of nickel whereas Bryophyllum daigremontianum, Rosularia adenotricha, Iris germanica, Asplenium dalhousiae and Isatis tinctoria for the phytoextraction of soil contaminated with nickel.

**Key words:** phytoremediation; phytoextraction, phytostabilization, nickel-metal

## Introduction

Heavy metals are currently of much environmental concern (Nazir et al. 2011). The adverse environmental effects of excessive heavy metals include contamination of water and soil, phytotoxicity and soil degradation, and pose serious risks to human health. Their destructive impacts on environments are causing increasing concern in scientists, politicians and the general public worldwide (Al Chami et al. 2015). Heavy metal concentrations beyond permissible limits have adverse health effects because they interfere with the usual functioning of living systems (Ali et al. 2013).

Nickel is a silvery-white, ductile, hard and transition metal. Usually, it occurs in combination with iron and sulphur in pentlandite, with arsenic and sulphur in nickel glance, with arsenic in the mineral nickeline and with sulphur in millerite. (Das et al. 2008). It is a nutritionally vital trace metal for numerous species of micro-organisms, plants as well as animals, and therefore either symptoms of toxicity or deficiency can occur when too much or too little nickel is taken up respectively. Nickel is

ubiquitous and is important for the function of numerous organisms; concentrations in some areas, from both naturally fluctuating levels and anthropogenic release, may be poisonous to living organisms (Cempel et al. 2006). The global input of nickel to the environment is almost 150,000-180,000 metric tons per year from various sources, including industrial production and emissions from fossil fuel consumption etc. (Kasprzak et al. 2003). Nickel remains associated with some metalloenzymes, but is poisonous at higher concentrations in plants. Its level in ambient air is small (approx. 6 to 20 ng $m^{-3}$) but it could exist at up to 150 ng $m^{-3}$ in contaminated air. Uncontaminated water contains almost 300 ng Ni $m^{-3}$, farm soils contain about 3-1,000 mg Ni $kg^{-1}$, but the concentration of Ni metal can reach up to 24,000-53,000 mg Ni $kg^{-1}$ in soil located near metal refineries and in dried sludge (Denkhaus et al. 2002).

In plants Nickel is responsible for yellowing and necrosis as well as chlorosis of leaves, stunted growth, deformation of plant parts, and generation of free radicals (Subhashini et al. 2013). It is carcinogenic to living organism (Smialowicz et al. 1984). Its carcinogenicity depends on its chemical form; living organisms usage, dose, route and period of exposure. Inhalation of nickel oxide and nickel subsulfide shows evidence of carcinogenicity in humans and other mammals (USEPA 1980). Its hazardous effects on the health of humans include, nickel itch; allergic dermatitis and cancer of the lungs, nose, sinuses, throat, and stomach due to its inhalation. It is hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic, pulmonary toxic, nephrotoxic, and hepatotoxic (Ali et al. 2013).

Hyperaccumulators are plants which can accumulate naturally higher quantities of heavy metals in their areal parts other than roots (Nazir et al. 2011). In the shoots of plants heavy metals can reach very high concentrations on a dry weight basis (1,000 µg $g^{-1}$ for Ni), while in their natural habitat (Baker et al. 2000). A suitable in situ technique, cost-effective and environmentally sustainable for removing metals like nickel from soils is represented by phytoremediation, the use of higher plants to clean up soils. One phytoremediation technique consists of phytoextraction, employing hyperaccumulator plants to concentrate metals at the shoot level (Lasat 2002; Ali et al. 2013). Care should be taken in choosing the right hyperaccumulator species for the application of phytoremediation techniques because the introduction of alien plants may alter and disrupt indigenous ecosystems (Angle et al. 2001), and because well-known hyperaccumulator species may be unsuitable for local climatic conditions (Vangronsveld et al. 2009).

In the present research work sixty-one plant species belonging to thirty families were collected and analyzed for the concentration of nickel. Nickel was analyzed in the soil of the root zone and in the roots and shoots of each plant. The phytoremediation potential of the analyzed plants grown in their natural habitats was evaluated by the calculation of their Bioconcentration Factor (BCF), Translocation Factor (TF) and Biological Accumulation Coefficient (BAC).

## Materials and methods

### Study area

The Lower Dir is one of the 26 districts in 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's administrative centre 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 state capital during the Nawabs era, Dir (princely state). It borders the Swat District to the East, Afghanistan to the West, Upper Dir to the North-West and Malakand to the south. Pashto is the main spoken language of the population, followed by Kohistani and Gujri. Plants and soil for the analysis of nickel was collected from Timergara and its surrounding villages in the Lower Dir District (Fig. 1).

### Collection of plants and soil from the study area

Sixty-one plant species were collected from different locations in the Lower Dir District , Khyber Pakhtunkhwa, Pakistan. Soil was also collected from the root zone of each collected plant. The collected plants were pressed, dried and identified with the help of Flora of Pakistan or by matching them with the already preserved specimens at the Herbarium of Islamia College University Peshawar following the previously published protocol (Ashfaq et al. 2018;

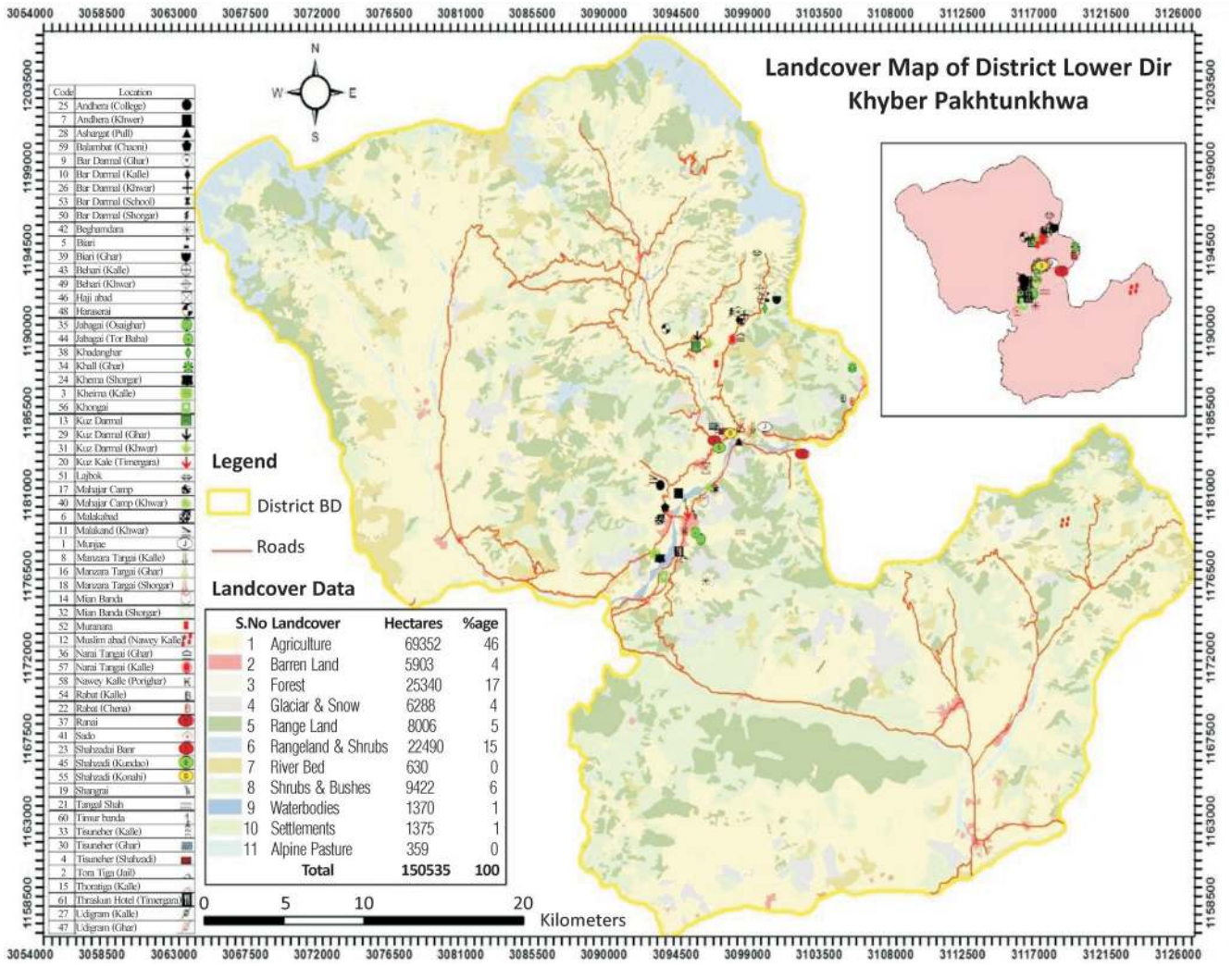


Fig. 1. Land cover map of Lower Dir District, Khyber Pakhtunkhwa, Pakistan

Bahadur et al. 2018). The correct scientific names of the collected plants were confirmed using The Plant List (TPL) and Tropicose Flora of Pakistan (Sufyan et al. 2018). After identification, each plant was separated into roots and shoots. These plant parts were dried in shade for a week and then fully dried in an oven at 75°C for 24 hours. Plant parts were ground with the help of a pestle and mortar. The powdered samples were digested using $HNO_3$ and $HClO_4$ and analyzed for the concentrations of nickel using Atomic Absorption Spectroscopy (AAS). The Bioconcentration Factor (BCF), Translocation Factor (TF) and Biological Accumulation Coefficient (BAC) of the collected plants were determined and their overall feasibility for the phytoremediation of nickel-metal was evaluated (Zhuang et al. 2007; Padmavathiamma and Li 2007; Adesodun et al. 2010; Malik et al. 2010; Nazir et al. 2011).

## Analysis of nickel in soil samples

The collected soil of the root zone of each plant was analyzed for background concentrations of nickel. Nickel-metal in the soil was determined according to Sharidah (1999): 5 g of the soil sample were put into a 100 mL beaker and 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 and it was heated on a hot plate for 2 hours. The digest was filtered through a Whatman filter paper. The filtrate was used for the determination of nickel-metal by atomic absorption spectrometry (AAS). The analysis

was conducted in triplicate. Results were shown as mean values ±SD (standard deviation).

Analysis of accumulated nickel in plant samples

For this purpose, each plant part was thoroughly washed with tape water and then with distilled water in order to remove dust and soil particles. The clean plant parts (roots and shoots) were dried in an oven at 105şC for 24 hours. Then the plant samples were grinded with the help of pistil and mortar. The powder was digested according to Awofolu (2005): 0.5 g of the plant part sample was taken into a 100 mL beaker and 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 nickel-metal by AAS. As mentioned previously, each experiment was run in triplicate, and the results were shown as mean values ±SD.

## Results

Concentration of nickel in the soil and various parts of the collected plants

The family, botanical name, number of site and name of the site of collection as well as the concentration of nickel in the soil and plant parts (root and shoot) are shown in (Table 1). The concentration of nickel in the soil of different sites and plant parts (roots and shoots) was found in the range of 1.03- 18.98, 12.63-540.73 and 12-295.86 mg $kg^{-1}$ respectively.

Evaluation of the analysed plants for the phytoremediation of nickel

Bioconcentration Factor (BCF), Translocation Factor (TF) and Bioaccumulation Coefficient (BAC) of all the analysed plants were calculated. The data in Table 2 represent the feasibility report of each plant species for the phytoremediation of nickel-metal. The BCF, TF and BACvalues of the plants for nickel-metal were found in the range of 1.42-162.31, 0.08-15.22 and 1.82-264.16 respectively. Most of the plant species showed feasibility for the phytoremediation of nickel but based on its concentration in shoots (Table 1) and BCF, TF and BAC values, *A. dalhousiae, I. tinctoria, B. daigremontianum, R. adenotricha* and *I. germanica* are the most efficient plants for the phytoextraction of nickel while based on its concentration in roots (Table 1) and BCF, TF and BAC values, *F. hurdwarica, X. strumarium, C. sativa, M. lupulina*, and *R. arvensis* are the most efficient plants for the phytostabilization of nickel-metal.

## Discussion

In the present study a total of sixty-one plant species belonging to thirty families were collected from the sixty-one sites of the research area. The soil of the root zone of each collected plant species as well as their roots and shoots were analyzed for the concentration of nickel-metal by atomic absorption spectroscopy. Phytoremediation potential of the collected plants was evaluated by calculating BCF (Zhuang et al. 2007), TF (Padmavathiamma and Li 2007; Adesodun et al. 2010) and BAC (Li et al. 2007; Cui et al. 2007; Malik et al. 2010) indicators.

Analysis of nickel in the soil of the research area

The concentration of nickel in the sixty-one sites (soil) varied in the range of 1.03-18.98 mg $kg^{-1}$. The results indicate that the lowest concentration of nickel was recorded in site 41 (1.03) and the highest in site 46 (18.98). Farm soils contained about 3-1000 mg Ni $kg^{-1}$ (Denkhaus et al. 2002; Cempel and Nikel 2005). The concentration of nickel in the soil of most of the analyzed sites was found within this range, while in the remaining twenty-three sites (5, 8, 9, 13, 14, 18, 19, 24, 25, 26, 28, 29, 32, 38, 41, 42, 45, 51, 52, 53, 54, 56, 59), its concentration was recorded as less than 3 mg Ni $kg^{-1}$.

Analysis of nickel in the roots of the collected plants

The collected plant species at these sites were the most dominant and common species. The nickel concentration in the roots of the analyzed plants was found in the range of 12.63-540.73 mg $kg^{-1}$ as shown in (Table1). The permissible limit of nickel in plants recommended by the WHO is 10 mg $kg^{-1}$ (Nazir et al. 2015). The results showed that the concentration of nickel in the roots of all the plants was higher than the permissible limit.

Table 1. Concentration (mean value and standard deviation) of nickel (mg $kg^{-1}$ d.w.) in the collected soil and plant parts (root and shoot) from Lower Dir District. Number of samples n = 3

| Family | Species | Site | Nickel concentration | | |
|---|---|---|---|---|---|
| | | | Soil | Root | Shoot |
| Amaryllidaceae | *Allium griffithianum* Boiss. | 1 | 4.24 ±0.05 | 60.07 ±0.03 | 61.87 ±0.32 |
| Apiaceae | *Torilis leptophylla* (L.) Rchb.f. | 2 | 9.74 ±0.02 | 59.47 ±0.50 | 130.13 ±0.49 |
| Apocynaceae | *Catharanthus roseus* (L.) G. Don | 3 | 3.81 ±0.03 | 12.63 ±0.15 | 29.87 ±0.15 |
| Aspleniaceae | *Asplenium dalhousiae* Hook. | 4 | 13.55 ±0.04 | 59.63 ±0.42 | 239.73±0.25 |
| Asteraceae | *Artemisia japonica Thunb.* | 5 | 1.7 ±0.01 | 38.33 ±0.31 | 35.2 ±0.30 |
| | *Artemisia vulgaris* L. | 6 | 6.65 ±0.04 | 28.33 ±0.35 | 36.5 ±0.20 |
| | *Calendula arvensis* Boiss. | 7 | 5.88 ±0.02 | 73 ±0.20 | 111.1 ±0.40 |
| | *Cirsium vulgare* (Savi) Ten. | 8 | 2.49 ±0.03 | 29.57 ±0.31 | 61.3 ±0.46 |
| | *Cousinia buphthalmoides* Regel | 9 | 1.44 ±0.04 | 27.07 ±0.15 | 20.43 ±0.45 |
| | *Erigeron canadensis* L | 10 | 5.26 ±0.05 | 93.07 ±0.21 | 17.17 ±0.31 |
| | *Filago hurdwarica* (Wall. ex DC.) Wagenitz | 11 | 4.28 ±0.03 | 317.06 ±0.95 | 23.87 ±0.25 |
| | *Lacuta dissecta* (D. Don) | 12 | 5.03 ±0.04 | 45.97 ±0.25 | 23.17 ±0.35 |
| | *Himalaiella heteromalla* (D. Don) Raab-Straube | 13 | 2.29±0.03 | 51.77 ±0.31 | 39.67 ±0.31 |
| | *Silybum marianum* (L.) Gaertn. | 14 | 1.21 ±0.03 | 196.4 ±0.60 | 90.03 ±0.35 |
| | *Xanthium strumarium* L. | 15 | 6.01 ±0.03 | 540.73 ±1.10 | 67.4 ±0.56 |
| Boraginaceae | *Nonea edgeworthii* A. DC. | 16 | 14.84 ±0.04 | 24.53 ±0.61 | 35.13 ±0.06 |
| | *Onosma hispida* Wall. ex G. Don | 17 | 4.46 ±0.05 | 97.93 ±0.25 | 27.17 ±0.40 |
| Brassicaceae | *Arabidopsis thaliana* (L.) Heynh. | 18 | 1.78 ±0.03 | 129.93±0.50 | 39.4 ±0.40 |
| | *Isatis tinctoria* L. | 19 | 1.97 ±0.03 | 14.83 ±0.25 | 225.66 ±0.31 |
| | *Stellaria media* (L.) Vill. | 20 | 3.4 ±0.02 | 82.8 ±0.92 | 44.13 ±0.35 |
| | *Sisymbrium irio* L. | 21 | 8.0 ±0.04 | 110.0 3±0.35 | 26.07 ±0.25 |
| Buxaceae | *Sarcococca saligna* (D. Don) Muell.-Arg. in DC., Prodr. | 22 | 6.89 ±0.02 | 21.53 ±0.50 | 79.90 ±0.20 |
| Cannabaceae | *Cannabis sativa* L. | 23 | 5.78 ±0.03 | 216.86 ±0.80 | 119.73 ±0.25 |
| Caryophyllaceae | *Cerastium glomeratum* Thuill. | 24 | 2.1 ±0.03 | 196.86 ±0.81 | 31.77 ±0.31 |
| Crassulaceae | *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A. Berger | 25 | 1.12 ±0.03 | 127.66 ±0.50 | 295.86 ±0.40 |
| | *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson | 26 | 1.31 ±0.03 | 109.66±0.35 | 259.53±0.64 |
| Euphorbiaceae | *Euphorbia helioscopia* L. | 27 | 4.78 ±0.02 | 64.07 ±0.31 | 118.50 ±0.50 |
| Fabaceae | *Argyrolobium stenophyllum* Boiss. | 28 | 2.52 ±0.04 | 144.26±0.81 | 12.00 ±0.20 |
| | *Medicago lupulina* L. | 29 | 2.89 ±0.04 | 274.8 ±0.80 | 65.00 ±0.30 |
| | *Medicago minima* (L.) L. | 30 | 5.73 ±0.04 | 79.5 ±1.32 | 68.47 ±0.99 |
| | *Vicia sativa* L. | 31 | 4.37 ±0.04 | 188.13±0.42 | 20.03 ±0.45 |
| Geraniaceae | *Geranium rotundifolium* L. | 32 | 2.99 ±0.03 | 197.06 ±0.50 | 17.40 ±0.37 |
| Iridaceae | *Iris germanica* L. | 33 | 8.51 ±0.03 | 84.00 ±0.20 | 249.63 ±0.35 |
| Ixioliriaceae | *Ixiolirion tataricum* (Pall.) Schult. & Schult f. | 34 | 8.88 ±0.03 | 161.56 ±0.42 | 16.20 ±0.36 |

Table 1. Continuation

| | | | | | |
|---|---|---|---|---|---|
| Lamiaceae | *Ajuga integrifolia* Buch.-Ham. | 35 | 12.23 ±0.04 | 115.76 ±0.31 | 140.03 ±0.42 |
| | *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. | 36 | 11.48 ±0.03 | 16.27 ±0.35 | 133.5 ±0.30 |
| | *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. | 37 | 13.64 ±0.05 | 88.63 ±0.31 | 56.47 ±0.31 |
| | *Marrubium vulgare* L. | 38 | 1.17 ±0.04 | 60 ±0.53 | 65.07 ±0.15 |
| | *Rydingia limbata* (Benth.) Scheen & V.A. Albert | 39 | 5.4 ±0.03 | 116.4 ±0.26 | 50 ±0.26 |
| | *Salvia moorcroftiana* Wall. ex Benth. | 40 | 4.29 ±0.03 | 13.27 ±0.32 | 69.8 ±0.30 |
| | *Teucrium stocksianum* Boiss. | 41 | 1.03 ±0.03 | 78.97 ±0.15 | 67.1 ±0.36 |
| Papilionaceae | *Astragalus pyrrhotrichus* Boiss. | 42 | 1.86 ±0.03 | 63.13 ±0.31 | 44.83 ±0.21 |
| Plantaginaceae | *Plantago lanceolata* L. | 43 | 9.22 ±0.04 | 25.1 ±0.20 | 77.9 ±0.10 |
| Plumbaginaceae | *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. | 44 | 6.57 ±0.04 | 21.63 ±0.42 | 26.13 ±0.15 |
| Polygalaceae | *Polygala abyssinica* R.Br. ex Fresen. | 45 | 2.34 ±0.04 | 94.43 ±0.40 | 18.27 ±0.21 |
| Polygonaceae | *Emex spinosa* (L.) Campd. | 46 | 18.98 ±0.04 | 115.66 ±0.25 | 189.7 ±0.44 |
| | *Persicaria glabra* (Willd.) M. Gómez | 47 | 8.92 ±0.05 | 85.1 ±0.20 | 53.17 ±0.40 |
| Pteridaceae | *Cheilanthes pteridoides* C. Chr. | 48 | 6.73 ±0.03 | 21.93 ±0.42 | 14.83 ±0.06 |
| | *Pteris cretica* L. | 49 | 11.84 ±0.05 | 70.37 ±0.51 | 32.00 ±0.20 |
| Ranunculaceae | *Delphinium uncinatum* Hook.f. & Thomson | 50 | 3.98 ±0.02 | 27.63 ±0.31 | 68.27 ±0.4 |
| | *Delphinium suave* Huth | 51 | 2.62 ±0.03 | 21.7 ±0.20 | 15.77 ±0.25 |
| | *Ranunculus arvensis* L. | 52 | 2.24 ±0.04 | 299.73 ±0.31 | 51.13 ±0.42 |
| Rosaceae | *Duchesnea indica* (Jacks.) Focke | 53 | 1.68 ±0.03 | 82.23 ±0.31 | 52.73 ±0.15 |
| | *Sanguisorba minor* Scop. | 54 | 2.78 ±0.02 | 109.86 ±0.32 | 150.03 ±0.25 |
| | *Rosa macrophylla* Lindl. | 55 | 6.39 ±0.02 | 162.46 ±0.83 | 140.13 ±0.31 |
| Scrophulariaceae | *Verbascum Thapsus* L. | 56 | 1.49 ±0.02 | 135.9 ±0.26 | 143.63 ±0.47 |
| | *Wulfeniopsis amherstiana* (Wall. Ex Benth.) D.Y. Hong | 57 | 5.86 ±0.03 | 43.33 ±0.31 | 17.27 ±0.42 |
| Solanaceae | *Solanum nigrum* L., Sp. Pl. | 58 | 4.4 ±0.02 | 15.63 ±0.31 | 19.27 ±0.31 |
| Thymelaeaceae | *Daphne mucronata* Royle | 59 | 1.25 ±0.03 | 59.83 ±0.25 | 56.1 ±0.26 |
| Urticaceae | *Urtica pilulifera* L. | 60 | 3.8 ±0.02 | 119.06 ±0.61 | 36.17 ±0.21 |
| Verbenaceae | *Verbena officinalis* L. | 61 | 7.5 ±0.04 | 39.83 ±0.21 | 109.73 ±0.31 |

Table 2. Bioconcentration Factor (BCF), Translocation Factor (TF), Bioaccumulation Coefficient (BAC) for nickel and feasibility of the plants for the phytoremediation of nickel

| Site | Species | BCF | TF | BAC | Feasibility |
|---|---|---|---|---|---|
| 1 | *Allium griffithianum* Boiss. | 14.17 | 1.03 | 14.59 | ++ |
| 2 | *Torilis leptophylla* (L.) Rchb.f. | 6.11 | 2.19 | 13.36 | ++ |
| 3 | Catharanthus roseus (L.) G. Don | 3.31 | 2.37 | 7.84 | ++ |

Table 2. Continuation

| | | | | | |
|---|---|---|---|---|---|
| 4 | *Asplenium dalhousiae* Hook. | 4.40 | 4.02 | 17.69 | ++ |
| 5 | *Artemisia japonica* Thunb. | 22.55 | 0.92 | 20.71 | + |
| 6 | *Artemisia vulgaris* L. | 4.26 | 1.29 | 5.49 | ++ |
| 7 | *Calendula arvensis* Boiss. | 12.41 | 1.52 | 18.89 | ++ |
| 8 | *Cirsium vulgare* (Savi) Ten. | 11.88 | 2.07 | 24.62 | ++ |
| 9 | *Cousinia buphthalmoides* Regel | 18.80 | 0.75 | 14.19 | + |
| 10 | *Erigeron canadensis* L. | 17.70 | 0.18 | 3.26 | + |
| 11 | *Filago hurdwarica* (Wall. ex DC.) Wagenitz | 74.08 | 0.08 | 5.58 | + |
| 12 | *Lactuca dissecta* D. Don | 9.14 | 0.50 | 4.61 | + |
| 13 | *Himalaiella heteromalla* (D. Don) Raab-Straube | 22.61 | 0.77 | 17.32 | + |
| 14 | *Silybum marianum* (L.) Gaertn. | 162.31 | 0.46 | 74.4 | + |
| 15 | *Xanthium strumarium* L. | 89.97 | 0.12 | 11.21 | + |
| 16 | *Nonea edgeworthii* A. DC. | 1.65 | 1.43 | 2.37 | ++ |
| 17 | *Onosma hispida* Wall. ex G. Don | 21.96 | 0.28 | 6.09 | + |
| 18 | *Arabidopsis thaliana* (L.) Heynh. | 72.99 | 0.30 | 22.13 | + |
| 19 | *Isatis tinctoria* L. | 7.53 | 15.22 | 114.55 | ++ |
| 20 | *Stellaria media* (L.) Vill. | 24.35 | 0.53 | 12.98 | + |
| 21 | *Sisymbrium irio* L. | 13.75 | 0.24 | 3.26 | + |
| 22 | *Sarcococca saligna* (D. Don) Muell.-Arg. in DC., Prodr. | 3.12 | 3.71 | 11.6 | ++ |
| 23 | *Cannabis sativa* L. | 37.52 | 0.55 | 20.71 | + |
| 24 | *Cerastium glomeratum* Thuill. | 93.74 | 0.16 | 15.13 | + |
| 25 | *Bryophyllum daigremontianum* (Raym.-Hamet & Perrier) A.Berger | 113.98 | 2.32 | 264.16 | ++ |
| 26 | *Rosularia adenotricha* (Wall. ex Edgew.) C.-A. Jansson | 83.71 | 2.37 | 198.11 | ++ |
| 27 | *Euphorbia helioscopia* L. | 13.4 | 1.85 | 24.79 | ++ |
| 28 | *Argyrolobium stenophyllum* Boiss. | 57.25 | 0.08 | 4.76 | + |
| 29 | *Medicago lupulina* L. | 95.09 | 0.24 | 22.49 | + |
| 30 | *Medicago minima* (L.) L. | 13.87 | 0.86 | 11.95 | + |
| 31 | *Vicia sativa* L. | 43.05 | 0.11 | 4.58 | + |
| 32 | *Geranium rotundifolium* L. | 65.91 | 0.09 | 5.82 | + |
| 33 | *Iris germanica* L. | 9.87 | 2.97 | 29.33 | ++ |
| 34 | *Ixiolirion tataricum* (Pall.) Schult. & Schult. f. | 18.19 | 0.1 | 1.82 | + |
| 35 | *Ajuga integrifolia* Buch.-Ham. | 9.47 | 1.21 | 11.45 | ++ |
| 36 | *Phlomoides superba* (Royle ex Benth.) Kamelin & Makhm. | 1.42 | 8.21 | 11.63 | ++ |
| 37 | *Micromeria biflora* (Buch.-Ham. ex D.Don) Benth. | 6.50 | 0.64 | 4.14 | + |
| 38 | *Marrubium vulgare* L. | 51.28 | 1.08 | 55.62 | ++ |
| 39 | *Rydingia limbata* (Benth.) Scheen & V.A. Albert | 21.56 | 0.43 | 9.26 | + |
| 40 | *Salvia moorcroftiana* Wall. ex Benth. | 3.09 | 5.26 | 16.27 | ++ |
| 41 | *Teucrium stocksianum* Boiss. | 76.67 | 0.85 | 65.15 | + |
| 42 | *Astragalus pyrrhotrichus* Boiss. | 33.94 | 0.71 | 24.1 | + |
| 43 | *Plantago lanceolata* L. | 2.72 | 3.10 | 8.45 | ++ |
| 44 | *Limonium macrorhabdon* (Boiss.) O. Kuntze, Rev. Gen. | 3.29 | 1.21 | 3.98 | ++ |
| 45 | *Polygala abyssinica* R.Br. ex Fresen. | 40.35 | 0.19 | 7.81 | + |
| 46 | *Emex spinosa* (L.) Campd. | 6.09 | 1.64 | 9.99 | ++ |
| 47 | *Persicaria glabra* (Willd.) M. Gómez | 9.54 | 0.62 | 5.96 | + |
| 48 | *Cheilanthes pteridoides* C. Chr. | 3.26 | 0.68 | 2.20 | + |

Table 2. Continuation

| | | | | | |
|---|---|---|---|---|---|
| 49 | *Pteris cretica* L. | 5.94 | 0.45 | 2.70 | + |
| 50 | *Delphinium uncinatum* Hook.f. & Thomson | 6.94 | 2.47 | 17.15 | ++ |
| 51 | *Delphinium suave* Huth | 8.28 | 0.73 | 6.02 | + |
| 52 | *Ranunculus arvensis* L. | 133.81 | 0.17 | 22.83 | + |
| 53 | *Duchesnea indica* (Jacks.) Focke | 48.95 | 0.62 | 31.39 | + |
| 54 | *Sanguisorba minor* Scop. | 39.52 | 1.37 | 53.97 | ++ |
| 55 | *Rosa macrophylla* Lindl. | 25.42 | 0.86 | 21.93 | + |
| 56 | *Verbascum thapsus* L. | 91.21 | 1.06 | 96.4 | ++ |
| 57 | *Wulfeniopsis amherstiana* (Wall. Ex Benth.) D.Y. Hong | 7.39 | 0.40 | 2.95 | + |
| 58 | *Solanum nigrum* L., Sp. Pl. | 3.55 | 1.23 | 4.38 | ++ |
| 59 | *Daphne mucronata* Royle | 47.86 | 0.94 | 44.88 | + |
| 60 | *Urtica pilulifera* L. | 31.33 | 0.30 | 9.52 | + |
| 61 | *Verbena officinalis* L. | 5.31 | 2.75 | 14.63 | ++ |

Bioconcentration Factor (BCF) = concentration of nickel in roots to concentration of nickel in soil ratio; Translocation Factor (TF) = concentration of nickel in shoots to concentration of nickel in root ratio; Bioaccumulation Coefficient (BAC) = concentration of nickel in shoots to concentration of nickel in soil ratio. Feasibility: + = metal excluders, may be used for the phytostabilization of metal; ++ = metal indicators, may be used for the phytoextraction of metal

## Analysis of nickel in the shoots of the collected plants

The concentration of nickel in the shoots of the analyzed plant is shown in (Table 1). The concentration of nickel in plant leaves ranged from 0.05 to 5 mg $kg^{-1}$; its concentrations > 10 ppm are generally considered to be toxic to sensitive species or cultivars (Brown 2006). The results indicated that the concentration of nickel was higher in the shoots of all the analyzed plants. It indicates that the shoots of the analyzed plants were not sensitive to nickel-metal.

## Bioconcentration Factor of the analyzed plants for nickel

The Biological Concentration Factor (BCF) was calculated as the metal concentration ratio of plant roots to soil (Yoon et al. 2006; Malik et al. 2010; Nazir et al. 2011) as shown in Table 2. According to Sheoran et al. (2001) plants are not feasible for the phytoextraction of metal if their bioconcentration factor is less than one. Fitz and Wenzel (2002) demonstrated that plants exhibiting a BCF value less than one are unsuitable the phytoextraction of metals. The results showed that the calculated bioconcentration factor of all the plants was greater than one.

## Translocation Factor of the analyzed plants for nickel

The Translocation Factor (TF) is defined as the ratio of heavy metals in plant shoots to that in plant roots (Cui et al. 2007; Li et al. 2007; Malik et al. 2010; Nazir et al. 2011). The calculated translocation factors of all the analyzed plants are shown in (Table 2). A Translocation factor value greater than one indicates translocation of metal from the roots to the above ground parts (Jamil et al. 2009). It is clear from Table 2 that thirty five plant species had a translocation factor value of less than one while that of twenty six plant species – *I. tinctoria* (15.22), *P. superba* (8.21), *S. moorcroftiana* (5.26), *A. dalhousiae* (4.02), *S. saligna* (3.71), *P. lanceolata* (3.10), *I. germanica* (2.97), *V. officinalis* (2.70), *D. uncinatum* (2.47), *R. adenotricha* (2.37), *C. roseus* (2.37), *B. daigremontianum* (2.32), *T. leptophylla* (2.19), *C. vulgare* (2.07), *E. helioscopia* (1.85), *E. spinosa* (1.64), *C. arvensis* (1.52), *N. edgeworthii* (1.43), *S. minor* (1.37), *A. vulgaris* (1.29), *S. nigrum* (1.23), *A. integrifolia* (1.21), *L. macrorhabdon* (1.21), *M. vulgare* (1.08), *V. Thapsus* (1.06), *A. griffithianum* (1.03) – was greater than one.

## Biological Accumulation Coefficient of the analyzed plants for nickel

The Biological Accumulation Coefficient (BAC) was calculated as the ratio of heavy metals in

shoots to that in soil (Li et al. 2007; Cui et al. 2007; Malik et al. 2010; Nazir et al. 2011). The calculated coefficient of each plant species can be seen clearly in Table 2. Only plant species with a BCF, BAC and TF greater than one have the potential for the remediation process (Nazir et al. 2011).

## Conclusions

In general, no one plant species was identified as a hyperaccumulator for nickel-metal because in the above ground parts of all the plant species nickel-metal content was found at less than 1,000 mg $kg^{-1}$ dry weight basis but the Bioconcentration factor (BCF), Translocation factor (TF) and Biological Accumulation Coefficient value of twenty-six plant species (*A. griffithianum*, *T. leptophylla, C. roseus*, *A. dalhousiae*, *A. vulgaris*, *C. arvensis*, *C. vulgare*, *N. edgeworthii*, *I. tinctoria*, *S. saligna*, *B. daigremontianum*, *R. adenotricha, E. helioscopia*, *I. germanica*, *A. integrifolia*, *P. superba*, *M. vulgare*, *S. moorcroftiana*, *P. lanceolata*, *L. macrorhabdon*, *E. spinosa*, *D. uncinatum, S. minor*, *V. Thapsus*, *S. nigrum*, *V. officinalis*) was found to be greater than one. Metal indicators accumulate heavy metals in their aerial parts. A Translocation factor value greater than one indicates the translocation of the metal from the roots to the above ground parts and only plant species with both BCF and TF values greater than one have the potential to be used for phytoextraction. These plant species may be used for the phytoextraction of nickel-metal. Thirty-five plant species (*A. japonica*, *C. buphthalmoides*, *E. canadensis*, *F. hurdwarica, H. heteromalla*, *S. marianum*, *X. strumarium*, *O. hispida*, *A. thaliana*, *S. media*, *S. irio*, *C. sativa*, *C. glomeratum*, *A. stenophyllum*, *M. lupulina*, *M. minima*, *V. sativa*, *G. rotundifolium*, *I. tataricum*, *M. biflora*, *R. limbata*, *T. stocksianum*, *A. pyrrhotrichus*, *P. abyssinica*, *P. glabra*, *C. pteridoides*, *P. cretica*, *R. arvensis*, *D. indica*, *R. macrophylla*, *W. amherstiana*, *D. mucronata*) were found to have a bioconcentration factor value greater than one but a Translocation factor of less than one. Metal excluders accumulate heavy metals from the substrate into their roots but restrict their transport and entryto their aerial parts. Such plants have a low potential for metal extraction but may be efficient for phytostabilization purposes. These plant species may be used for the phytostabilization of nickel-metal.

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