Phytoremediation Potential and Implication of Nickel of Plant Species of Mardan Industrial Estate

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Abstract- The present research study was carried out in Mardan Industrial Estate in Mardan to analyze the concentration of the heavy metals i.e Nickel (Ni) in the soil and plant parts (roots and shoots). Phytoremediation potential of the analyzed plants grown in their natural habitats were evaluated by the calculation of bioconcentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC). The concentration of the selected heavy metals was determined in the soil of different sites of the research area. The concentrations of Nickel in the soil of Twenty One sites were found in the range of 15.2 – 551 mg/kg. The maximum concentration of Nickel was found in the soil of Site 14 (551) mg/kg while its minimum concentration was present in the soil of Site 3 (15.1) mg/kg. Among all the twenty-one plant species, most of the plant species showed feasibility for the phytoremediation; phytostabilization and phytoextraction of the selected heavy metals. Based on the concentration of copper in shoots and BCFs, TFs and BACs values, *Mirabilis jalapa*, *Thymus vulgaris*, *Morus alba*, *Melia azedarach*, *Anagallis arvensis*, *Bombax ceiba*, *Verbena officinale*, *Datura metal*, *Convolvulus arvensis*, *Medicago polymorpha*, *Thlaspi arvense* and *Chrozophora tinctoria* were found most efficient plants for the phytoextraction of Nickel. Based on the concentration of the selected metals in roots and BCFs, TFs and BACs values, all the screened plants were found efficient for the phytostabilization of Nickel.

Index Terms- Heavy metals, Translocation factor, Phytoextraction, Industrial zone Mardan, Nickel

I. Introduction

Heavy metals toxicities are associated to its total deposition, route of exposure, specific chemical state, metal bonding condition and other chemical properties like pH, organic substance, soil texture and its quality (Muhammad et al., 2011). Toxic Heavy metals damaged vital biochemical and metabolic activities and displayed a risk to human health, plants development and growth as well as for animal life (Ikenaka et al., 2010). Heavy metals are considered as critical contaminants in the environment, due to their high potential to enter and accumulate in food chains (Erbilir and Erdoĝrul, 2005). These metal pollutants are very hazardous due to their level of toxicity, higher tenacity and persistence, non-biodegradable nature, capabilities to be absorbed and accumulate in the body (Dhaneesh et al., 2012), and severely effect food chain. Although, at lower concentration most of the metals (Cr, Cu, Ni, Co, Mn, Fe and Zn) are necessary for the metabolic activities of living organism, while at high concentration become toxic. However, Cd and Pb show toxicity at any concentration level (Yipel and Yarsan, 2014). Extensive use of fertilizers, insecticides, pesticides and herbicides for crop protection is another major cause of soil, air and food (vegetables and fruits) contamination and is directly affecting the human health. As a result, cultivated lands are rapidly contaminated by heavy metals (Hill, 2002). Heavy metal contaminations in the natural environment considered as serious threat to the human health and life due to their bio-magnifications, bioaccumulation and toxicity. The most common toxic heavy metals released from automobiles on roads were Cd, Cu, Pb, Ni and Zn that potentially caused risk to the natural environment (Kabir et al., 2022).

Heavy metal accumulation in soils is of major concern in agricultural production due to adverse effect in food quality, food safety and crop growth (Fergusson and Prucha, 1990). Plants are dependent on local soil and fertilized soil. Plant food is an important source of heavy metal intake into human body which cause harmful effects on health (Oliver, 1997). Being an important component of human diet, heavy metal contamination of vegetables cannot be underestimated. These foodstuffs have beneficial anti-oxidative effects, and they are also a rich source of vitamins, minerals and fibers (Sharma et al., 2008; Sharma et al., 2009). The concentrations of essential heavy metals beyond threshold limits have adverse health effects because they interfere with the normal functioning of living systems (Tchounwou et al., 2012). Heavy metal concentration in the soil solution plays a critical role in controlling metal availability to plants. Studies have proved that higher contents of heavy metals in soil increases the uptake by plants. Though, the solubility and availability of heavy metal ions are influenced by various factors such as pH, physical and chemical soil properties, clay content and Mn oxide concentration (Xian and In Shokohifard, 1989). Sequential extraction is widely used to obtain qualitative information on the form and association of metals and also indirectly it provides information on their availability for plant uptake and migration in the soil (Sabienë et al., 2004).

Nickel is a metallic element that is naturally present in the earth's crust. Due to unique physical and chemical properties, metallic nickel and its compounds are widely used in modern industry. Human exposure to nickel occurs primarily via inhalation and ingestion. Significant amounts of nickel in different forms may be deposited in the human body through occupational exposure and diet over a lifetime. Since nickel has not been recognized as an essential element in humans it is not clear how nickel compounds are metabolized (Cancer, 1990). It was reported that nickel depletion in rats resulted in increased perinatal mortality as well as alterations of grooming behavior, liver development, and decreased growth. The growth dependence on nickel was more significant in the second depleted generation (Nielsen et al., 1975). The second depleted generation also showed anemia that manifested in decreased hemoglobin and hematocrit values (Schnegg and Kirchgessner, 1975). Additionally, nickel deficiency impairs the absorption of iron from the intestine. Nickel-induced alterations in serum and hepatic lipids are similar to those that develop after a moderate iron deficient diet. It was suggested that nickel is involved in CO2- fixation to propionyl-CoA to form D-methylmalonyl-CoA. The depletion of nickel in the diet also indicated that nickel may be involved in lipid metabolism, particularly in the synthesis of phospholipids (Gawkrodger et al., 2000).

Phytoremediation is a promising technology for cleaning the polluted sites by using plants to extract the heavy metals from the contaminated soil and accumulate them in roots, stems, and branches. Edible crops are not recommended for such a process for the fear of introducing these potentially toxic metal ions into the food chain; thus, fiber crop would be the best suited candidate for use in phytoremediation (Osmani et al., 2015). The efficiency of phytoremediation differs depending on plant morphological, physiological, and anatomical characteristics that affect the mechanisms of ion uptake. Logically, sequential cycles of planting and harvesting of the hyperccumulator plants will finally reduce the concentration of toxic metals in soils to an acceptable level for other uses (Osmani et al., 2015). Therefore the study is based on the following objectives: a) To determine the concentration of heavy metals (Nickel) and to find out ways and means for eradicating its environmental impacts. b) quantify the concentration levels of heavy metals (Nickel) in water, soil and their transfer and accumulation in plants. c) to investigate the uptake potential of heavy metals (Nickel) of the collected plants calculating bioconcentration factor (BCF). d) to calculate the translocation of the accumulated heavy metals (Nickel) from root to shoots by calculating translocation factor.

II. MATERIALS AND METHODS

Site Description

The study area presents in district Mardan within the geographic coordinate between 34°05′N–34°32′N and 71°48′E−72°25′E, with a total area of 1630 km^2 (Ibrahim et al., 2019). It is bounded in the North by Buner district and Malakand protected areas, in the Eastern side by district Swabi, South by district Nowshehra and on the West by district Charsadda (Fig 1). Mardan is one of the oldest cities in Asia and is the big city of Khyber Pakhtunkhwa and Mardan Industrial Zone is famous industrial zone of Mardan (Fig 2) which was established in late seventies (Ibrahim et al., 2019).

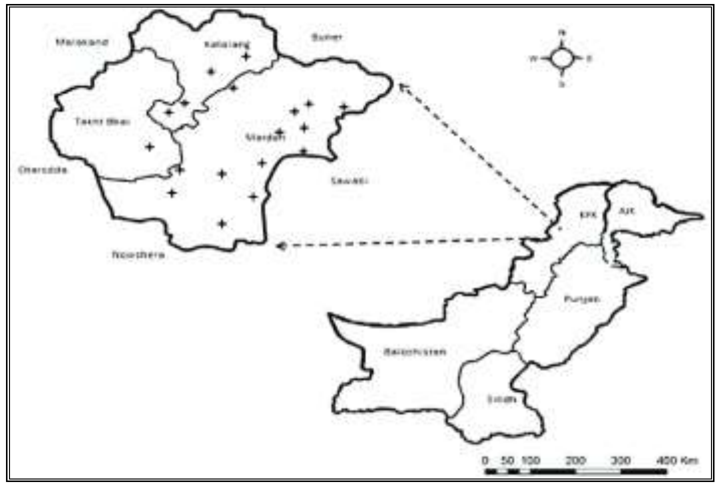

Figure 1: Map of the research area district Mardan, Pakistan

Figure 2: Location Map of Mardan Industrial Estate

Collection, identification and analysis of samples

Plants, soil and effluents were collected from different industries such as Steel, Marble, Match, Pipe, Aluminum, Beverages, Ghee and Pharmaceutical Industries from Mardan Industrial Estate, Khyber Pakhtunkhwa. Soil was also collected from the root zone of each plant and kept in polythene bags. Soil was analyzed for the background concentrations of the selected heavy metals. Collected plants were identified with the help of Flora of Pakistan (KHAN et al., 2022a; Nasir et al., 1972; Nasir, 1991; Stewart, 1967; Stewart, 1982; Stewart et al., 1972). The plants parts were kept in shade for a week and then were fully dried in an oven at 75 ^oC for 24 hours. Plant parts were grinded with pistil and mortar. The powdered samples were digested using HNO_3. The digested plants after dilution analyzed for the concentration of the selected heavy metals. The methodologies adopted to achieve the objectives of study are based on primary and secondary data collection. This study is based on both, primary data and secondary data. Primary data were collected in the field through collection of plants, collection of water samples and laboratory work. Secondary data were collected from the Govt offices associated with industrial estates.

Collection and Sampling of Effluents

Wastewater samples were collected at the discharge point of selected industrial units of Mardan Industrial Estate. The samples were collected in clean plastic containers of 0.5 L washed with metal free soap and was rinsed with 10% HNO_3 to avoid contamination and was washed finally with double deionized water (Chary et al., 2008) in such a way that no bubbles were formed in the containers. A total of 30 samples in the vicinity of the Estate were collected. Some important parameters like pH and EC (Electric Conductivity) were measured at the time of sample collection. Then collected samples was carried to laboratory and about 1 mL concentrated nitric acid was used for each sample to combat microbial growth. The samples were placed at room temperature for heavy metals detection. Heavy metals were measured with Atomic Absorption Spectrophotometer (AAS, Perkin- Elmer 700).

Soil analysis

Determination of pH and EC

Soil sampling tubes were utilized to collect soil samples from each site to a depth of 30 cm. The samples were air dried, grinded for composite sample, sieved through 2 mm to eliminate the stone fragments and large root particles. The soil analyses and physiochemical properties were evaluated at The University of Agriculture Peshawar's soil science laboratory, Department of soil and environmental science. A pH meter was used to determine the pH (Khan et al., 2017). Samples that had been saturated with water were filtered for the purpose of measuring the electrical conductivity (EC), and readings were taken using an electrical conductivity meter (Iqbal, 2018).

Determination of Nickel

The collected soil of the root zone of each plant was analyzed for the background concentration of the selected heavy metals. Heavy metals in the soil were determined according to the method of (Shriadah, 1999). 5g sample of the soil were taken in a 100 ml beaker; 3 ml of 30% H_2O_2 was added to it. This was left undisturbed for 1 hour until the vigorous reaction ceases. Then 75 ml of 0.5 M, HCl solution were added to it and were heated on hot plate for 2 hours. The digest was filtered through a Whatman filter paper. The filtrate was used for the determination of the selected heavy metals by atomic absorption spectrometry. The analysis was conducted in triplicate. Results were shown as mean and mg/Kg (milligram per kg).

Analysis of Accumulated Heavy Metals in Plant Samples

For this purpose, each plant part was thoroughly washed with tape water and then with distilled water in order to remove dust and soil particles. The clean plant part was dried in an oven at 105 ^oC for 24 hours. Then the samples were digested according to the standard procedure of (Awofolu, 2005). 0.5 g samples of the plant were taken into a 100 ml beaker, 5ml concentrated (65%) HNO_3 and 2ml $HClO_4$ was added to it and heated on hot plate until the digest become 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 marks with distilled water. The filtrate was used for the analysis of selected heavy metals. As mentioned previously, each experiment was in triplicate. Results was shown as mean.

Bioconcentration and Translocation Factor

Bioconcentration factor (BCF) indicates the efficiency of a plant in up taking heavy metals from soil and accumulating them into its tissues. "It is a ratio of the concentration of the heavy metal in shoots to that in its soil at steady state". It is calculated via given equation followed by (Ali et al., 2012).

$$\text{BCF} = \frac{C\ harvested\ tissue}{C\ soil}$$

Where $C_{\text{harvested tissue}}$ is the concentration of the metal in the plant harvested tissue (roots, stem or leaves) and C_{soil} is the concentration of the same metal in soil.

Translocation factor (TF) shows the efficiency of the plant in translocating the accumulated heavy metals from roots to shoots. "It is a ratio of the concentration of the heavy metal in shoots to that in its roots". It is calculated via given equation followed by (Yang et al., 2011).

$$\text{TF} = \frac{C\ shoots}{C\ roots}$$

Where C shoots is the concentration of the metal in shoots and C roots is the concentration of the metal in roots.

Both bioconcentration factor and translocation factor of the collected plants for selected heavy metals were calculated according to the above formulas. From these calculations, the feasibility of the plants for the phytoextraction of the selected heavy metals were evaluated.

III. Results

Nickle (Ni) concentration in selected Plants and their standard

Information (Table 1) regarding heavy metal (nickel in mg/kg) accumulation of selected plants of Mardan industrial zone revealed that nickel concentration were observed in soil, root and shoot of *Chrysanthemum indicum* at site MIE-ST-1, hence the maximum concentration were observed only in shoot (552.1± 0.23) followed by *Amaranthus retroflexus* at MIE-ST-4. At site MIE-ST-7, the highest concentration were detected in shoot (294±0.75) of *Thlaspi arvense* followed by roots (263± 0.55) while less concentration were in soil (54.4± 0.61). *Stellaria media*, *Convolvulus arvensis*, and *Chrozophora tinctoria* at sites MIE-ST-9, MIE-ST-6, MIE-ST-14 also exhibited higher concentration of nickel in soil, shoot and root. Similarly *Medicago polymorpha*, *Melia azedarach*, *Morus alba*, *Mirabilis jalapa*, *Anagallis arvensis* and *Ranunculus muricatus* showed highest percentage of Ni in shoot followed by root and soil at sites MIE-ST-19, MIE-ST-9, MIE-ST-22, MIE-ST-13, MIE-ST-4, and MIE-ST-44 while *Thymus vulgaris*, *Bombax ceiba*, *Cynodon dactylon*, *Polygonum plebeium*, *Gallium aparine*, *Datura metal*, *Verbascum thapsus*, *Verbena officinale* and *Tribulus terrestris* at sites MIE-ST-25, MIE-ST-6, MIE-ST-3, MIE-ST-40, MIE-ST-21, MIE-ST-29, MIE-ST-37, MIE-ST-30 and MIE-ST-35 observed highest content of Ni in root followed by shoot and soil. The Ni concentration in the soil ranges from 57.7±0.58 to 15.2±0.37 mg/kg, in the roots ranges from 754±0.49 to 41.54± 0.23 mg/kg and in the shoot ranges from 728±0.10 to 45± 0.25 mg/kg as shown in Table 1.

Evaluation of the analyzed plants for the phytoremediation of Nickel (Ni)

Results in table 2 revealed information on 21 recorded plants species, which are feasible for phytoremediation of Ni. *Chrysanthemum indicum* showed highest BAC (18.330) followed by BCF (13.792) and TF (1.329), similarly *Amaranthus retroflexus* showed highest BAC value followed by BCF and TF (4.163, 3.992 and 1.043). *Thlaspi arvense* (5.404), *Stellaria media* (10.727) and *Convolvulus arvensis* (11.205) had highest BAC followed by BCF (4.835, 9.737 and 9.237) while TF is 1.118, 1.102 and 1.213. *Medicago polymorpha* had BAC (7.740), BCF (7.558), and TF (1.024), *Melia azedarach* showed 19.891 (BAC), 18.470 (BCF), and 1.077 (TF). *Morus alba* showed 20.653, 18.977 and 1.088 values of BAC, BCF and TF while the remaining plants also showed different BAC, BFC and TF with regards to phytoremediation of Ni. *Chrysanthemum indicum*, *Amaranthus retroflexus*, *Thlaspi arvense*, *Stellaria media*, *Convolvulus arvensis*, *Medicago polymorpha*, *Morus alba*, *Mirabilis jalapa*, *Anagallis arvensis*, and *Ranunculus muricatus* are metal indicators and feasible for the phytoremediation of Ni, similarly *Chrozophora tinctoria*, *Thymus vulgaris*, *Melia azedarach*, *Bombax ceiba*, *Cynodon dactylon*, *Polygonum plebeium*, *Gallium aparine*, *Datura metal*, *Verbascum thapsus*, *Verbena officinale* and *Tribulus terrestris* are metal excluders and have feasibility for Ni phytoremediation (Table 2).

Water effluents characteristics of mardan industrial estate

Effluents samples were collected at the discharge point of selected industrial units of Mardan Industrial Estate, in 2021. During the same period ground water samples were also collected from different tube and dug wells of the surrounding area to see if any contamination has occurred. The main drain where effluents of all industries are fallen was also sampled. A total of 25 samples including 18 from industrial effluents 2 from the main drain and 5 from tube wells in the vicinity of the Estate were collected. Results shows that most of the parameters are within permissible limits, however, the values rise up in sample taken 7th Street near (Rehman Cotton Mills). Water samples were tested for the determination of pH and E.C from upstream to downstream of Mardan Industrial Estate. Water samples collected from the area shows that pH and E.C (Electric Conductivity) of most samples analyzed exceed safe limits according to (Organization, 2010) USEPA (1999) and PSQCA.

Physicochemical characteristics of water

pH and EC

pH ranges from 8.74 to 9.58 and its mean value is 9. According to (Organization, 2010) the maximum permissible limit for pH in fresh water is 6.5-8.5. No samples remain in the range of 6.5 to 8.5. There is no guide line value (NGV) set by (Organization, 2010) for E.C in fresh water, but the water having E.C above than 0.007 S/m is not considered as quality water. E.C varies between 6.36 S/m to 38.9 S/m and its mean value is 12.8 S/cm.

Concentration of "Ni" in Water

Heavy metals (Nickel) were analyzed in water samples collected from the study area. The detail of heavy metal concentrations i.e. Range, Mean and Standard Deviation are summarized in Table 3. Figure 4 shows that the Nickle concentration ranges from 1.75 to 6.33 mg/l; the concentration of Nickle, has got a higher value at dumping point near Sher Match Industries and lower at collection point near "Olympia Foam Industries". The samples collected from the main drain have higher values due to the minimum dilution/flow of water. In contrast, downward stream samples have a lower concentration because of the maximum dilution/flow of Industrial Water. The samples collected near "Maso Print Packages" and intermingling point of "Arco Industries and Hamdard Laboratories" have higher values of 5.04, 5.11 and 6.12 mg/l respectively". Onward to that, a random sequence has been adopted by the samples.

IV. Discussion

In the current study a total of twenty one plant species were collected from twenty 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, TF and BAC (Sajad et al., 2020). The Ni concentration in the soil ranges from 57.7±0.58 to 15.2±0.37 mg/kg, in the roots ranges from 754±0.49 to 41.54± 0.23 mg/kg and in the shoot ranges from 728±0.10 to 45± 0.25 mg/kg. The permissible limit of nickel in plants recommended by the WHO is 10 mg kg^{-1} (Sajad et al., 2020). The results showed that the concentration of nickel in the roots of all the plants was higher than the permissible limit. 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 (Liu et al., 2011). The Biological Concentration Factor (BCF) was calculated as the metal concentration ratio of plant roots to soil (Malik et al., 2010). Similarly Sukumaran (2013) stated that the plants are not feasible for the phytoextraction of metal if bioconcentration factor is less than 0.2 mg/kg. Muhammad et al. (2011) demonstrated that plants exhibiting BCF value less than 0.2 mg/l are unsuitable the phytoextraction of metals. Results showed that the calculated bioconcentration factor of all the plants were greater than 0.2 mg/kg. On the same way Translocation factor value > than 0.2 mg/kg indicates translocation of metal from root to above ground part (Maiti and Jaiswal, 2008). Results showed that the TF value is greater than one while none is lesser than 0.2 mg/kg, it is pertinent to mention here that only plant species with BCF, BAC and TF > than 01 mg/kg have the potential for the remediation process (Qureshi et al., 2020). Results showed that the BAC value of all the plants is greater than 01 mg/kg. The heavy metals persist in the soils of industrial areas or other parts with mining facilities and that is why, biological and natural reclamation of such polluted sites are challenging (Ikram et al., 2018). Unplanned industrial and urban development in the last few decades have massively increased the heavy metals' level in the environment, which raised noteworthy apprehensions across the globe. Different plant species have been reported as hyperaccumulator but most of them are edible plants which increase the risk of food chain contamination (Ahmad et al., 2022). TF factor or mobility index (MI) is considered one of the important factors in assessing hyperaccumulator plants (TF > 1) reveals phytoremediation potential, particularly for heavy metals. Mobilization inside plants increases the level of metals in aboveground parts which may be attributed to aerial deposition and absorption of metals through surfaces of the leaves (Ullah et al., 2021). Therefore some worker also reported the phytoremediation potential of heavy metals; Ahmed et al. (2015) studied the evaluations of some trace metal from the leaves of *Salix nigra* in Hayatabad industrial estate Peshawar. Naz et al. (2022) analyzed the phytoremediation potential of native plant species naturally growing in a heavy metal-polluted industrial soils from Peshawar, Pakistan and phytoremediation of heavy metals from irrigation water by (Khan et al., 2022b).

Table 1: Concentration of Nickel in mg/kg in different plants of Mardan Industrial zone

S. No.	Family	Species	*C.P	Name of Site	Concentration of Nickel (mg/kg)		
					Soil	Root	Shoot
1	Asteraceae	*Chrysanthemum indicum* L.	1	MIE-ST-1	30.12±0.85	41.54± 0.23	552.1± 0.23
2	Amaranthaceae	*Amaranthus retroflexus* L.	2	MIE-ST-4.	52.6± 0.40	210± 0.45	219± 0.10
3	Brassicaceae	*Thlaspi arvense* L.	3	MIE-ST-7	54.4± 0.61	263± 0.55	294±0.75
4	Caryophyllaceae	*Stellaria media* (L.) Vill.	4	MIE-ST-9	49.5±7.18	482± 0.73	531± 1.30
5	Convulvulaceae	*Convolvulus arvensis* L.	5	MIE-ST-6	52.54±0.31	485.3± 0.46	588.7± 0.11
6	Euphorbiaceae	*Chrozophora tinctoria* (L.)	6	MIE-ST-14	55.1± 0.49	78± 0.60	74± 0.39
7	Fabaceae	*Medicago polymorpha* (L.)	7	MIE-ST-19	38.5± 0.19	291±0.22	298± 0.86
8	Lamiaceae	*Thymus vulgaris* L.	8	MIE-ST-25	26.2± 0.61	535±0.36	534±0.55
9	Meliaceae	*Melia azedarach* L.	9	MIE-ST-9	36.6± 0.88	676± 0.50	728±0.10
10	Malvaceae	*Bombax ceiba* L.	10	MIE-ST-6	49.84±0.50	754±0.49	635.4±0.27
11	Moraceaee	*Morus alba* L.	11	MIE-ST-22	35.2± 0.43	668±0.51	727±0.71
12	Nyctaginaceae	*Mirabilis jalapa* L.	12	MIE-ST-13	27±0.87	573±0.13	575±0.36
13	Poaceae	*Cynodon dactylon* (L.) Pers	13	MIE-ST-3	15.2±0.37	734± 0.71	702± 0.13
14	Polygonaceae	*Polygonum plebeium* R.Br.	14	MIE-ST-40	42.5±0.10	478± 0.50	449± 0.19
15	Primulaceae	*Anagallis arvensis* L.	15	MIE-ST-4	17.5±0.27	321± 0.59	340± 0.41
16	Rananculaceae	*Ranunculus muricatus* L.	16	MIE-ST-44	38.6±2.07	345±0.42	403± 0.29
17	Rubiaceae	*Gallium aparine* L.	17	MIE-ST-21	63.3±0.34	463± 0.24	449± 0.19
18	Solanaceae	*Datura metal* L.	18	MIE-ST-29	42.4±0.41	448±0.21	428± 0.33
19	Scrophulariaceae	*Verbascum thapsus* L.	19	MIE-ST-37	57.7±0.58	725± 0.31	645± 0.60
20	Verbenaceae	*Verbena officinale* L.	20	MIE-ST-30	27.4±0.20	328± 0.34	293± 0.37
21	Zygophyllaceae	*Tribulus terrestris* L.	21	MIE-ST-35	47±0.90	190± 0.07	45± 0.25

*C.P = Collection Point, HIE: Mardan Industrial Estate, St: Street, Concentration of Nickel (Ni) in soil and plant parts is shown as mean (n=3) ±SD.

Table 2: Name of the plant species and their bio-concentration factor, translocation factor and bioaccumulation coefficient for nickel.

S. No.	Family	Species	BCF	TF	BAC	Feasibility for the phytoremediation of Ni
1	Asteraceae	*Chrysanthemum indicum* L.	13.792	1.329	18.330	$M.I^{++}$
2	Amaranthaceae	*Amaranthus retroflexus* L.	3.992	1.043	4.163	$M.I^{++}$
3	Brassicaceae	*Thlaspi arvense* L.	4.835	1.118	5.404	$M.I^{++}$

4	Caryophyllaceae	*Stellaria media* (L.) Vill.	9.737	1.102	10.727	M.I++
5	Convulvulaceae	*Convolvulus arvensis* L.	9.237	1.213	11.205	M.I++
6	Euphorbiaceae	*Chrozophora tinctoria*	1.416	0.949	1.343	Ƹ+
	Fabaceae	*Medicago polymorpha* (L.)	7.558	1.024	7.740	M.I++
8	Lamiaceae	*Thymus vulgaris* L.	20.420	0.998	20.382	Ƹ+
9	Meliaceae	*Melia azedarach* L.	18.470	1.077	19.891	Ƹ+
10	Malvaceae	*Bombax ceiba* L.	15.128	0.843	12.749	Ƹ+
11	Moraceae	*Morus alba* L.	18.977	1.088	20.653	M.I++
12	Nyctaginaceae	*Mirabilis jalapa* L.	21.222	1.003	21.296	M.I++
13	Poaceae	*Cynodon dactylon* (L.) Pers	48.289	0.956	46.184	Ƹ+
14	Polygonaceae	*Polygonum plebeium* R.Br.	11.247	0.939	10.565	Ƹ+
15	Primulaceae	*Anagallis arvensis* L.	18.343	1.059	19.429	M.I++
16	Rananculaceae	*Ranunculus muricatus* L.	8.938	1.168	10.440	M.I++
17	Rubiaceae	*Gallium aparine* L.	7.314	0.970	7.093	Ƹ+
18	Solanaceae	*Datura metal* L.	10.566	0.955	10.094	Ƹ+
19	Scrophulariaceae	*Verbascum thapsus* L.	12.565	0.890	11.966	Ƹ+
20	Verbenaceae	*Verbena officinale* L.	11.971	0.893	10.693	Ƹ+
21	Zygophyllaceae	*Tribulus terrestris* L.	4.043	0.763	1.343	Ƹ+

Keys:
Ƹ+= Metal excluders, M.I++ =Metal indicators

Table 3: Heavy Metal Concentration in water

S. No	Value	Ni
1	Range	1.75-6.33
2	Mean	4.04
3	St. Dev.	0.84

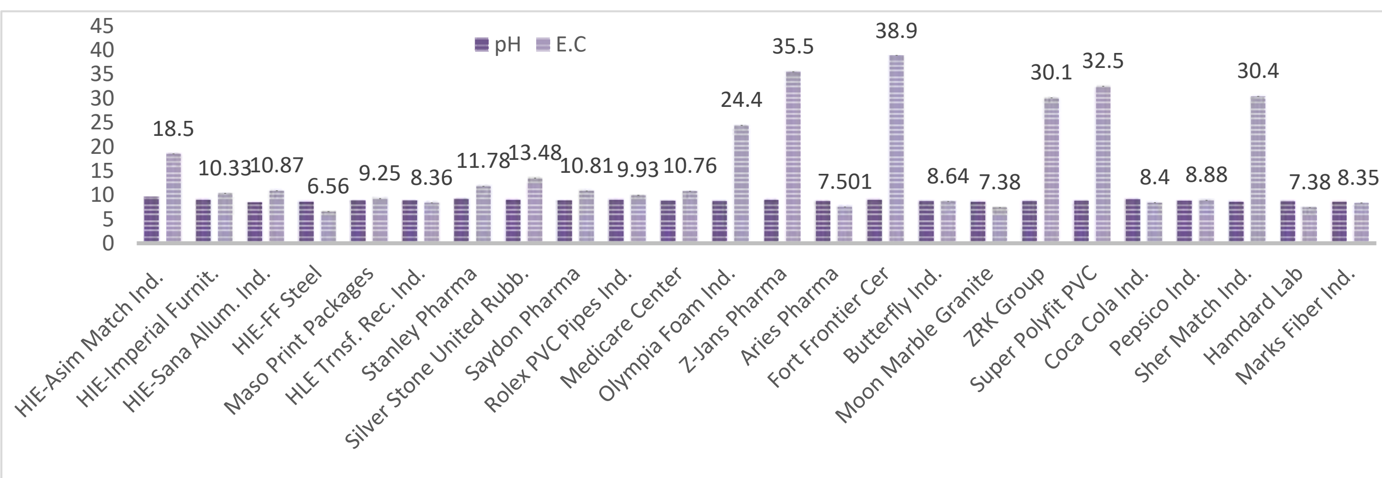

Figure 3: pH and Electric conductivity of different water samples from Mardan Industrial Estate.

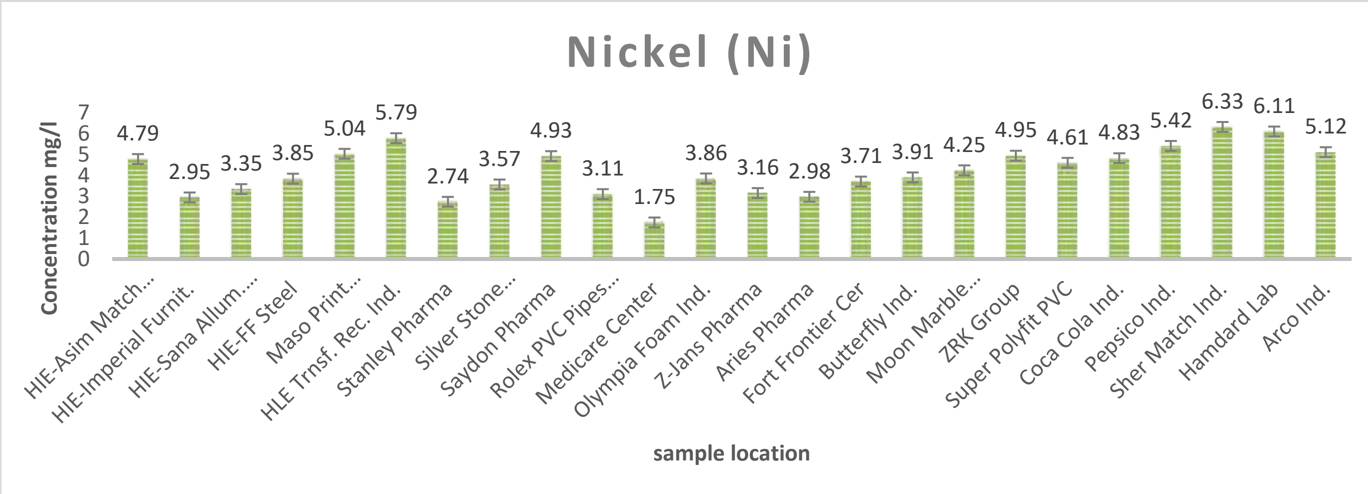

Figure 4: Concentration of Nickle (Ni) in the sample of water collected from a different location in the study area.

V. CONCLUSION

In conclusion, this research study provides valuable information on the concentration of nickel in soil and plant parts in Mardan Industrial Estate, as well as the potential of selected plant species for heavy metal phytoremediation. The findings suggest that the identified plants may be useful for heavy metal remediation in polluted sites, particularly for nickel phytoextraction and phytostabilization. Furthermore, the selection and testing of additional plant species for heavy metal phytoremediation in the Mardan Industrial Estate and other polluted sites. Furthermore, the findings of this study can be used to develop effective phytoremediation strategies on a larger scale, and the integration of phytoremediation with other remediation techniques can be investigated for improved outcomes. Overall, this research can contribute to the development of sustainable and environmentally friendly solutions for heavy metal pollution management. This provides promising direction for the development of low-cost, sustainable, and environmentally friendly phytoremediation techniques to tackle heavy metal pollution.

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