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Phytoremediation potential of tree species in soil contaminated with lead and cadmium

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ABSTRACT

Phytoremediation is an economical and environmentally friendly technology in which the selection of species capable of adapting to contaminated environmental conditions is essential. This study aimed to investigate the rate of purification of lead (Pb)- and cadmium (Cd)- contaminated soil by Pine, *Pinus eldarica* Medw., Cypress, *Cupressus arizonica* Greene., Locust tree, *Robinia peseudoacacia* L., Elm tree, *Ulmus carpinifolia* var. *umbraculifera* Rehd. and Ash, *Fraxinus rotundifolia* Mill. in Tehran. For this purpose, in the summer 2022 to provide the control and contaminated sites, according to the dominant wind direction, for any tree species, a transect was chosen, each with 10 selected trees. The sampling of leaves and roots of trees was performed in a completely-randomized statistical design with three replications. Afterward, Pb and Cd concentrations in each were measured using Perkin Elmer 3030 Atomic Absorption Spectrophotometer. The results showed that the Pb and Cd concentrations in the tree leave and roots in the contaminated sites were higher than in the control site. Also, Pine, Cypress, and Locust exhibited the highest translocation factor (TF) of Pb (3.49 ppm, 2.99 ppm, and 2.82 ppm), and Cd (3.35 ppm, 2.83 ppm, and 1.92 ppm) from their roots to leaves. According to this issue and suitable adaptation conditions, these three species can be used to purify lead and cadmium contaminated soil in similar areas.

Keywords: Heavy metals, Hyperaccumulator, Soil pollution, Translocation factor, Tehran.
Article type: Research Article.

INTRODUCTION

According to the rapid population growth, the expansion of industry, as well as improper human intervention and planning, environmental pollution is constantly increasing. Among these pollutants, we can mention the pollution caused by heavy metals (Gosh & Singh 2005; Solhi *et al*. 2005; Sarwar *et al.* 2017). These metals enter the environment due to the natural erosion of some rocks and human activities such as incomplete combustion of fossil fuels, mining, refining of rocks containing metals, municipal wastewater, pesticides, dyes, and batteries (Memon & Schroder 2009; Abdu-Salam *et al.* 2016; Ullah Khan *et al*. 2023). Soil contamination with heavy elements is one of the most important environmental issues in the world (Soleimani *et al*. 2009). The amount of these metals in the soil is affected by various factors such as parent materials, industrial pollutants, chemical fertilizers used in agriculture, as well as industrial and urban wastes (Antonkiewicz & Jasiewicz 2002; Mohammadi-Roozbahani *et al.* 2015; Azizi *et al*. 2020). Due to the physical and chemical properties of soil and environmental conditions, the mentioned contamination's accumulation process in soil layers is different (Assareh *et al.* 2008; Hani *et al.* 2014). Lead has entered urban environments as a result of using leaded gasoline fuels. In recent years, the entry of lead in urban districts has decreased significantly because of removing lead from petrol, however, its accumulation still has remained in the environment (Ejidike & Onianwa 2015; Hosseini *et al.* 2015; Gholamipour-Fard *et al*. 2016). Cadmium is also present in car tires and enters the urban environment through vehicle depreciation and traffic distribution (Alexander, 2000; Sobhanardakani *et al.* 2017). Street conditions, traffic flow, and environmental parameters are factors affecting the distribution of these elements in the environment (Armstrong 1998; Coelho *et al*. 2005; Wang *et al.* 2010). Street conditions depend on the physical condition and architecture of the roads including length, slope, width, and lifespan of the street, average height, layout and life of surrounding buildings, sidewalk width, number of lanes, type of green space, and height of plants around each street (Johansson *et al.* 2009). Traffic flow is an important factor in the emission of vehicle pollutants including speed, traffic volume, and density of the traffic stream (Johnson & Ferreira 2001; Wang 2005). Environmental parameters also include temperature, amount of rainfall, wind direction and speed, and soil properties (McKenzie *et al.* 2009; Hosseinzadeh-Monfared *et al.* 2013). Although lead and cadmium do not play a significant role in the physiological reactions of plants, nevertheless, due to their chemical similarity to essential elements, they can be absorbed by plants (Pilon-Smits 2005). Nowadays, the use of biological methods as a new approach to the clean-up of contaminated soils is considered (Torresday *et al.* 2005; Doumett *et al.* 2008; Aziz *et al*. 2023). Some plant species can absorb and accumulate large amounts of heavy elements in the soil, albeit without causing obvious toxic effects for themselves. These species are called hyperaccumulators (Lasat, 2000; Chehregani *et al.* 2009; Rafati *et al.* 2011). For a plant species to be known as a hyperaccumulator of a heavy element, its concentration in the shoot should be reached to tolerance threshold, which for different elements depends on the type and amount of metals in the soil, bioavailability of elements, and type of plant species (Sebastini *et al.* 2004; Bonanno *et al.* 2010; Hu *et al.* 2014). One of the methods of bioremediation of contaminated soils in which resistant plants are used to refine organic and inorganic compounds is called phytoremediation (Liu *et al.* 2007; Burken *et al.* 2011; Ariyachandra *et al.* 2023). In this method, by harvesting plants from the soil and doing herbal extraction, contaminants are absorbed and collected from plant tissues (McGrath 2002; Pulford & Watson 2003). In the phytoremediation process, parameters such as tolerance, strong root system, translocation factor, and high growth rate are effective (Adriana 2001; Huang 2004; Ebrahimi 2015). This study aimed to investigate the accumulation of Pb and Cd in the soil in Pine, *Pinus eldarica* Medw., Cypress, *Cupressus arizonica* Greene., Locust tree, *Robinia peseudoacacia* L., Elm tree, *Ulmus carpinifolia* var *umbraculifera* Rehd. and Ash *Fraxinus rotundifolia* Mill. trees in Tehran. This study caused the species that are useful hyperaccumulators of these elements to be identified and in contaminated areas.

MATERIALS AND METHODS

Study area

Tehran City is geographically located at 51˚8´ to 51˚37´ east longitude and 35˚34´ to 35˚50´ north latitude. The altitude of this city fluctuates from 1100 m above sea level in the south to 1700 m in the north (Geological Survey and Mine Exploration of Iran, 2021). In this research, because the study areas were located within the meteorological stations of Mehrabad Airport and North Tehran, all meteorological statistics were extracted from these stations over 10 years (2012-2021). According to the statistics of these stations, the average annual precipitation and the average annual temperature are 245.5 mm, and 18.45 °C respectively. It has a cold semi-arid climate, and the number of dry months is seven. However, according to the meteorological station in North Tehran, the average annual precipitation and average annual temperature are 344 mm and 15.6 °C respectively. It has a cold semi-wet climate, and the number of dry months is six (Meteorological Organization of Iran 2021).

Sampling and analysis

Using the reports of the Department of Environment Islamic Republic of Iran, the Tehran Air Quality Control Company, the Tehran Municipality Transport and Traffic Organization, as well as conducting sampling from the air by air sampling pump, S_1, S_2, and S_3, were considered as contaminated sites, while S_4 as control (Fig. 1). Afterward, Pine, *Pinus eldarica* Medw., Cypress, *Cupressus arizonica* Greene., Locust tree, *Robinia peseudoacacia* L., Elm tree, *Ulmus carpinifolia* var. *umbraculifera* Rehd., and Ash, *Fraxinus rotundifolia* Mill. which existed as dominant and common species among the sites, was selected as the studied ones. In September 2022, in each site, according to the dominant wind direction, for any tree species, a transect was provided, each with 10 selected tree. Sampling from leaves and roots of trees was accomplished in a completely-randomized statistical design with three repetition. According to the studied treatments, 240 samples were prepared, which were transferred after coding to the laboratory. Afterward, samples were washed with distilled water and dried in a ventilated oven for 48 h at 75°C. The dried samples were powdered by an electric grinder and for extraction by digestion method. Nitric acid (HNO_3) was used at 95°C (Westerma, 1990). After purifying the extracts, the Pb and Cd concentrations in each sample were measured using the Perkin Elmer 3030 Atomic Absorption Spectrophotometer (James & Wells 1990). In each site, soil sampling was accomplished under tree coverage at two different depths of 0-10 and 10-20 cm, then in the laboratory, its physical and chemical characteristics were determined. In addition, the soil samples were dried at environmental temperature, then hammered with a plastic hammer, and passed through a 2-mL sieve. Afterward, Pb and Cd concentrations in each sample were measured according to standard methods (Table 2; Klute 1986). Statistical analyses were accomplished using SPSS software. The two-way analysis of variance (ANOVA) test was used to judge the significance of the effect of treatments on the components of the study, and Duncan's test to compare the average of the components at a 95% confidence level.

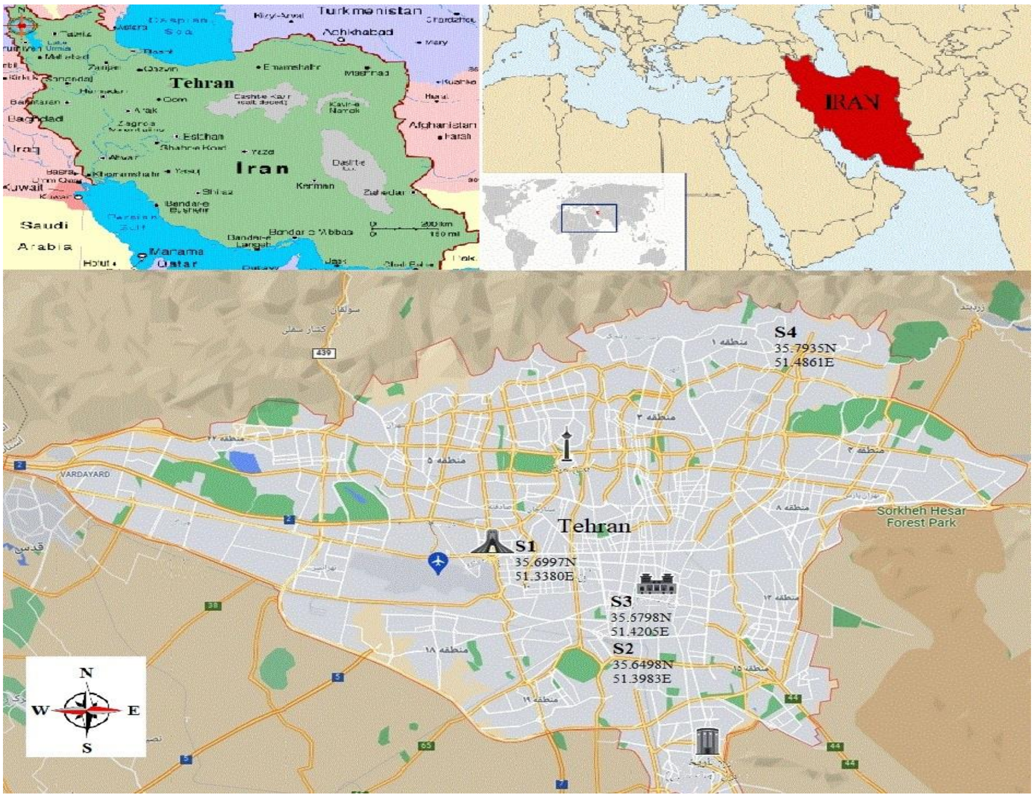

Fig. 1. Location map showing the Tree Species in control site (S_4) and contaminated sites (S_1, S_2 and S_3).

RESULTS AND DISCUSSION

Pb and Cd Content in the Atmosphere

According to the results of air sampling, the Pb and Cd concentrations in the atmosphere of S_1 site exhibited the highest values (19.63 ppb and 7.27 ppb respectively) during September, while the lowest (1.28 ppb and 0.47 ppb respectively) in S_4 during July (Table 1).

Table 1. The concentration of Pb and Cd in the atmosphere.

Time	Concentration (ppb)	Site			
		S_1	S_2	S_3	S_4
July	Pb	16.45	11.06	9.15	1.28
	Cd	5.1	4.09	3.38	0.47
August	Pb	17.34	13.21	8.26	2.84
	Cd	6.42	4.89	3.05	1.01
September	Pb	19.63	14.29	11.17	3.09
	Cd	7.27	5.29	4.13	1.14

Physical and chemical Properties and elements concentration in the Soil

Some soil physical and chemical properties and also the Pb and Cd concentrations in the soil of studied sites are presented in Table 2. The soil of these regions is calcareous with a mainly loamy-clay texture. According to the results, the Pb and Cd concentrations in different soil depths of the studied site exhibited a significant difference in such a way that at a depth of 0-10 cm in S_1 had the highest values, while in S_4 at 10-20 cm the lowest. In the contaminated site, the Pb and Cd concentrations in the trees shoots and roots was higher than in the control, so that elevated in S_4 (control), S_3, S_2, and S_1, respectively. These significant differences can be related to the soil physical and chemical properties, including the presence of clay particles, pH, total concentration, and capability of absorbing elements in the soil. Previous studies have referred to the proportionality of the concentration of elements in the environment (atmosphere and soil) with their absorbing capability by plants (Marry *et al.* 1996; Al-Shayeb & Seaward 2001; Hani *et al.* 2014). There was a significant relationship between clay particle rates (%) in the soil and the amount of lead and cadmium absorption in the investigated trees. In accordance with these results, Chehregani *et al.* (2009) and Abdu Salam *et al.* (2016) stated that clay colloids present on the soil surface, by absorbing heavy elements, prevent leaching and transferring them to the lower layers of the soil, therefore the amount of element absorption by plants will be upraised. The accessibility of plants to heavy metals has an inverse relation to soil pH, in a way that by drop in pH, the deposition of metal elements in the form of hydroxides, as well as insoluble carbonates and organic complexes decreases, and the capability of plants to absorb metals in the soil will be elevated (Johnson & Ferreira 2001; Hosseinzadeh-Monfared *et al.* 2013).

Table 2. Physical and chemical characteristics and concentration of Pb and Cd in the soil samples.

Site	Sample	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Salinity (ds/m)	Acidity	Calcareous (%)	Organic carbon (%)	Organic matter (%)	Potassium (ppm)	Total nitrogen (%)	Phosphorus (ppm)	Pb (ppm)	Cd (ppm)
S1	1	0-10	47	32.4	20.6	0.43	7.26	15.83	0.43	0.9	260	0.32	5.4	19.01	8.69
		10-20	44.2	31.54	24.26	0.38	7.12	17.26	0.37	0.81	270	0.29	5.7	5.1	2.56
	2	0-10	42.1	46.8	11.1	0.39	7.35	14.1	0.29	0.59	255	0.26	6.0	17.24	7.06
		10-20	39.5	45.2	15.3	0.48	7.19	12.2	0.25	0.46	250	0.23	6.2	4.8	2.26
S2	1	0-10	48.1	18.3	33.6	0.34	7.31	18.6	0.35	0.63	285	0.3	7.1	14.21	5.55
		10-20	37.3	20	42.7	0.40	7.22	16.3	0.31	0.54	245	0.27	7	4.02	1.9
	2	0-10	33.0	34.2	32.8	0.51	7.51	16.5	0.4	0.6	290	0.25	8.0	12.08	5.15
		10-20	29.2	31.9	38.9	0.48	7.45	18.6	0.32	0.43	265	0.19	8.5	3.27	1.37
S3	1	0-10	40	24.8	35.2	0.41	7.48	19.13	0.51	0.87	280	0.26	8.8	9.36	4.06
		10-20	33.8	27.2	39	0.39	7.36	17.06	0.44	0.60	240	0.28	9.5	2.47	1.07
	2	0-10	29.06	37.03	33.91	0.29	7.73	20.50	0.47	0.95	200	0.31	6.8	8.85	3.13
		10-20	26.80	31.65	41.55	0.32	7.56	22.16	0.38	0.48	185	0.23	6.9	1.94	0.95
S4	1	0-10	28.2	38.6	33.2	0.50	7.87	19.05	0.63	1.08	270	0.37	11.1	2.16	0.93
		10-20	24.64	44.2	31.16	0.52	7.79	20.21	0.52	0.86	240	0.46	11.4	0.54	0.23
	2	0-10	25.2	47.6	27.2	0.46	8.02	18.10	0.56	0.73	265	0.39	10.02	2.01	0.87
		10-20	24.3	52.3	23.4	0.49	7.86	20.06	0.44	0.61	220	0.34	9.3	0.46	0.28

Pb and Cd content in the leaves

According to the obtained results, the highest concentrations of Pb and Cd (18.57 and 14.28 ppm respectively) were found in Pine trees of S_1, while the lowest levels in Ash trees of S_4 (1.21 ppm and0.93 ppm, respectively; Tables 3-4). According to the analysis of variance test, the site of sampling exhibited a significant difference on the Pb and Cd accumulations in the leaves of trees at a 95% confidence level (Tables 5-6), so that these elements concentrations in the leaves in S_1displayed the highest, while in S_4 (control) the lowest.

Table 3. The Pb concentration (ppm) in leaves of different tree species.

		Pine	Cypress	Locust	Elm	Ash
	S_1	18.57 ^{C}	15.01 ^{C}	13.09 ^{C}	10.42 ^{D}	7.18 ^{D}
Contaminated	S_2	16.61 ^{B}	13.40 ^{B}	11.58 ^{B}	9.94 ^{C}	5.64 ^{C}
	S_3	14.95 ^{B}	12.44 ^{B}	10.12 ^{B}	8.14 $_{B}$	3.89 ^{B}
Control	S_4	7.46 ^{A}	6.81 ^{A}	4.10 ^{A}	2.94 ^{A}	1.21 ^{A}

Note: Different letters indicate significant differences between treatments at *p*-value < 0.05.

Table 4. The Cd concentrations (ppm) in leaves of different tree species.

		Pine	Cypress	Locust	Elm	Ash
	S_1	14.28 ^{C}	11.64 ^{C}	10.06 ^{C}	8.01 ^{D}	5.52 ^{D}
Contaminated	S_2	12.77 ^{B}	10.1 ^{B}	8.9 ^{B}	7.64 ^{C}	4.33 ^{C}
	S_3	11.5 ^{B}	9.56 ^{B}	7.78 ^{B}	6.21 ^{B}	2.99 ^{B}
Control	S_4	5.73 ^{A}	5.23 ^{A}	3.15 ^{A}	2.26 ^{A}	0.93 ^{A}

Note: Different letters indicate significant differences between treatments at *p*-value < 0.05.

Table 5. Analysis of variance (ANOVA) test of Pb concentrations in the tree leaves.

variation	Df	Sum of squares	Mean squares	*F*	*P*
Site	3	752.362	250.787	83595.78	0.000*
Species	4	116.704	29.176	9725.33	0.002*
Site × Species	12	13.298	1.108	369.39	0.014*
Error	101	0.364	0.003		
Total	120	882.728			

*Significant difference between the samples (*p*-value < 0.05).

Table 6. Analysis of variance (ANOVA) test of Cd concentrations in the tree leaves.

variation	Df	Sum of squares	Mean squares	*F*	*P*
Site	3	278.652	92.884	92884	0.004*
Species	4	43.22	10.805	10805	0.000*
Site × Species	12	4.92	0.41	410	0.000*
Error	101	0.134	0.001		
Total	120	326.926			

*Significant difference between the samples (*p*-value < 0.05).

Pb and Cd contents in the root

According to the results of the present study, the highest Pb and Cd concentrations (10.51 and 8.08 ppm respectively) were found in the Elm trees of S_1, while the lowest in Pine trees of S_4 (1.91 and 1.46 ppm respectively; Tables 7-8). According to the analysis of variance test the site of sampling exhibited a significant difference on the Pb and Cd accumulations in the roots of trees at a 95% confidence level (Tables 9-10), so that these elements concentrations in the roots in S_1 displayed the highest, while in S_4 (control) the lowest.

Table 7. Concentrations of Pb (ppm) in the roots of different tree species.

		Pine	Cypress	Locust	Elm	Ash
	S_1	6.10 ^{C}	5.47 ^{C}	4.63 ^{C}	10.51 ^{D}	8.84 ^{D}
Contaminated	S_2	5.29 ^{B}	4.86 ^{B}	3.65 ^{B}	8.97 ^{C}	8.16 ^{C}
	S_3	3.17 ^{B}	3.61 ^{B}	2.98 ^{B}	7.19 ^{B}	6.73 ^{B}
Control	S^4	1.91 ^{A}	2.01 ^{A}	2.27^{A}	4.41 ^{A}	4.03 ^{A}

Note: Different letters indicate significant differences between treatments at *p*-value < 0.

Table 8. Concentrations of Cd (ppm) in the roots of different tree species

		Pine	Cypress	Locust	Elm	Ash
	S_1	4.69 ^{C}	4.2 ^{C}	5.56 ^{C}	8.08 ^{D}	6.8 ^{D}
Contaminated	S_2	4.06 ^{B}	3.73 ^{B}	4.80 ^{B}	6.9 ^{C}	6.47 ^{C}
	S_3	2.53 ^{B}	2.77 ^{B}	4.29 ^{B}	5.89 ^{B}	5.07 ^{B}
Control	S_4	1.46 ^{A}	1.54 ^{A}	3.74 ^{A}	3.39 ^{A}	3.1 ^{A}

Note: Different letters indicate significant differences between treatments at *p*-value < 0.

Table 9. Analysis of variance (ANOVA) test of Pb concentration in the tree roots.

variation	Df	Sum of squares	Mean squares	*F*	*P*
Site	3	518.115	172.705	86352.5	0.001*
Species	4	82.367	20.841	10420.87	0.066
Species × Site	12	10.229	0.854	426.21	0.010*
Error	101	0.261	0.002		
Total	120	611.972			

* Significant difference between the samples (*p*-value < 0.05).

Table 10. Analysis of variance (ANOVA) test of Cd concentrations in the tree roots.

variation	Df	Sum of squares	Mean squares	*F*	*P*
Site	3	207.246	69.082	69082	0.000*
Species	4	33.346	8.336	8336	0.053
Species × Site	12	4.916	0.409	409000	0.012*
Error	101	0.104	0.001		
Total	120	245.612			

* Significant difference between the samples (*p*-value < 0.05).

Factor of translocation

According to the equation translocation factor (TF = HMS / HMR), where HMS = concentration of heavy metals in the shoot, and HMR = concentration of heavy metals in the root, the results showed that Pine, Cypress, and Locust have the highest transfer coefficient of Pb (3.49, 2.99 and 2.82 ppm) and Cd (3.35, 2.83 and 1.92 ppm) from root to shoot and could somehow transfer these elements to their shoot, hence exhibit the least accumulation in their root (Table 11). In the phytoremediation of heavy metals, the translocation factor of elements from root to leaves is very important and necessary.

Lasat (2000) and Mattina *et al.* (2003) stated that the element transfer factor from the root to the shoot is useful to identify hyperaccumulator species. Brooks (1998) and Adriana (2001) pointed out that based on the kind of plants which could transfer heavy metals to their leaves, some of them had the lowest accumulation of these elements in their root. Some authors also have used the ratio of metal concentration in the leaves to the root system in order to describe the tolerance and reaction of plants to the existence of a high amounts of metals in soil, so that, this ratio is greater than 1 in the accumulators–plants, while lower than 1 in the excluders–plants (Cooper *et al.* 1999; Pulford & Watson 2003; Hosseini *et al.* 2015).

Table 11. Translocation Factor (TF) of Pb and Cd in tree species.

Tree species	TF	
	ppm (Pb	Ppm(Cd)
Pine	3.49	3.35
Cypress	2.99	2.83
Elm tree	0.98	0.99
Locust tree	2.82	1.92
Ash	0.64	0.61

CONCLUSION

Heavy metal contamination is a serious issue for plants, animals, aquatic life, and human health. Phytoremediation of heavy metals is a stable and natural technique, easy, low cost, adaptive to the indigenous areas, environment-friendly, and applicable on a large scale, which we should consider some factors such as tolerance of plant against metals, root system, and capability of transferring from underground organs to the leaves and the rate of growth in this issue (Liu *et al.* 2007; Burken *et al.* 2011). The results of this research exhibited that Pine, Cypress, and Locust are suitable species for refining Pb and Cd contaminated soils that could be advised in similar regions. According to the aforementioned points, bioremediation technology using appropriate tree species is an effective method for contamination elimination due to the heavy metals in the contaminated soils in urban environments.

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