Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd

ISSN: 1308-7576
e-ISSN: 1308-7584

Research Article

Investigation of Heavy Metal Concentrations and Accumulation Capacities of Naturally Growing Species in Old Garbage Area

Hava Şeyma İNCİ*[1], Mihriban AHISKALI[2], Merve MACİT[3], Erdal ÇAÇAN[4]

[1,2,3,4]Department of Crop and Animal Production, Food Agriculture and Livestock Vocational School, Bingol University, Bingol, Türkiye
[2]Department of Biology, Faculty of Science, Bursa Uludag University, Bursa, Türkiye
[3]Department of Botany, Faculty of Science, Istanbul University, Istanbul, Türkiye

[1]https://orcid.org/0000-0002-2670-401X, [2]https://orcid.org/0000-0003-0580-7594, [3]https://orcid.org/0000-0001-9648-4799
[4]https://orcid.org/0000-0002-9469-2495

*Corresponding author e-mail: hsyilmaz@bingol.edu.tr

Article Info

Received: 01.12.2023
Accepted: 03.02.2024
Online published: 15.03.2024
DOI: 10.29133/yyutbd.1399025

Keywords

Garbage leachate,
Heavy metal,
Hyperaccumulator plant,
Phytoremediation

Abstract: In underdeveloped and/or developing countries, garbage is often randomly piled up in open areas. This method has been used to dispose of garbage/solid waste in Turkey for many years. Although pollution is not at the forefront in Bingöl province, the area located in the city center of the city has been used as a wild garbage storage area for approximately 18 years. Since the garbage in the area poses a danger to people and the environment, this area has become inactive with the establishment of a new solid waste disposal facility in the city. There are plants that have adapted to this area, which has been empty for about ten years. In this study, it was tried to determine in what proportions and organs the plant species distributed in the area accumulate heavy metals that may have come from garbage leachate. Plants identified in the field; *Alyssum simplex*, *Cirsium libanoticum*, *Descurainia sophia*, *Fumaria asepala*, *Fumaria officinalis*, *Matricaria chamomilla*, *Papaver dubium*, *Scrophularia canina*, *Trifolium repens* and *Ziziphora capitata* species. Fe, Cr, As, Cd and Pb concentrations (mg kg^{-1}) of these species were measured in root, stem, leaf and flower organs and translocation factors (TF) were calculated for these species. In conclusion; *Alyssum simplex*, *Cirsium libanoticum* and *Fumaria asepala* for Fe, *Cirsium libanoticum*, *Fumaria asepala*, *Fumaria officinalis* and *Matricaria chamomilla* Cr and As, *Cirsium libanoticum*, *Papaver dubium* and *Scrophularia canina* for Cd and all other species except *Alyssum simplex* and *Scrophularia canina* for Pb translocation factors (TF) were found to be greater than 1 (TF>1). The accumulation potential of these species is thought to be promising so that they can be evaluated in phytoremediation.

To Cite: İnci, H Ş, Ahiskali, M, Macit, M, Çaçan, E, 2024. Investigation of Heavy Metal Concentrations and Accumulation Capacities of Naturally Growing Species in Old Garbage Area. *Yuzuncu Yil University Journal of Agricultural Sciences*, 34(1): 151-165.
DOI: https://doi.org/10.29133/yyutbd.1399025

1. Introduction

Today, one of the most important issues that the earth, nature, the world, and all humanity struggle with passively or actively is undoubtedly pollution. This is the main reason underlying environmental problems, health problems, and many other problems. Among the types of pollution, heavy metal pollution, which can enter the food chain and threaten humans, is at the forefront. The term "heavy metal" is generally used for metals with a specific gravity of more than 5 g cm^{-3} (Holleman and Wiberg, 1985; Sharma and Agrawal, 2005). The heavy metals of most concern are the metalloids cadmium (Cd), mercury (Hg), lead (Pb) and arsenic (As). The uptake and accumulation of health-threatening toxic metals by plants are potential entry routes into human and animal food. Emissions of toxic heavy metals have greatly increased over the last 200 years (Clemens, 2006).

Heavy metal pollution is mainly caused by burning fossil fuels, municipal waste, sewage, pesticides, and smelting (Naila et al., 2019). Their high presence in the environment is due to anthropogenic activities, including the application of paint, batteries, metal scraps, motor oil, pesticide-herbicides, and fertilizers (Awokunmi, 2010). The development in industry, agriculture, and mining and the increase in their activity has led to increased heavy metal pollution (Kalay and Yasam 2000; Kuzu et al., 2018).

Plants that can take up more metals than other species from the same soils and above the metal concentrations determined in the soil are called hyperaccumulator plants (Kabata-Pendias, 2011). Phytoremediation is an effective, inexpensive, and environmentally friendly technique in which living green plants are used to transfer or stabilize heavy metals and environmental pollutants in contaminated soil or groundwater (Saleem et al., 2020a). Hyperaccumulator plants have the potential to accumulate high concentrations of heavy metals in their above-ground parts without showing signs of stress. They have been used in phytoremediation of metal contaminated areas with promising results (Wan et al. 2023; Doku et al. 2024). It is reported that there are nearly 400 plant species that accumulate metals in their above-ground organs. Important families with this feature are Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Fabaceae, Lamiaceae, Poaceae, Violaceae and Euphorbiaceae. Brassicaceae family is the largest family with 11 genera and 87 species (Ozbek, 2015; Boysan Canal et al., 2022).

The increase in the world's population in parallel with increasing industrial activities has led to the generation of large volumes of household and industrial waste (Lagerkvist and Dahlén, 2019). In underdeveloped and/or developing countries, garbage/solid waste is often deposited randomly in open areas (away from residential areas). For many years in Turkey, this method has been used for the disposal of garbage/solid waste (Gokce and Hasanoglu, 2015).

Today, with wild landfilling still in place, of the 32.3 million tons of waste collected by municipalities (waste service providers), 69.4% was disposed of in sanitary landfills, 17% in municipal dumps, 13.2% in recycling facilities and 0.4% by open burning, burial, dumping in streams or land (TUIK, 2020).

Rainwater inflow to landfills causes biochemical and physical breakdown of garbage/waste, resulting in the formation of highly polluted leachate (Ebin, 2004). The content of leachate varies according to the type of waste stored, and landfill leachate can contain high levels of organic and inorganic substances, ammonia-nitrogen, heavy metals, and chlorinated organic compounds. Heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), and copper (Cu) are commonly found in landfill leachate (Oksuz, 2019).

These landfills, which are known to be responsible for toxic leachate from waste, have been reported to significantly affect all forms of life. Such leachate is often found in surface water, groundwater, soils, and other biophysical components of the environment, causing adverse impacts on humans, aquatic organisms, plants, and animals (Agbeshie et al., 2020). However, most people use such sites without knowing the risk of plants taking up heavy metals found in soils. Therefore, risk assessment of heavy metal pollution in landfills is an important issue (Agbeshie et al., 2020).

The area located in the city center of Bingöl province was used as a wild landfill for about 18 years where both domestic and medical wastes were dumped. Due to the constant spontaneous combustion of garbage in the area and the danger it posed to people and the environment (Anonymous, 2013a), this area became inactive with the establishment of a new solid waste disposal facility in the city (Anonymous, 2013b).

The region is a place where some animal husbandry (grazing, beekeeping) activities continue in spring. There are many plants adapted to this area. Today, it is still unknown whether these plants contain the pollution materials and heavy metals emitted by these landfill leachates. This study aimed to identify the plant species adapted to the area, investigate their hyperaccumulatory properties, determine their potential for use in phytoremediation, and make suggestions and predictions for similar areas.

2. Material and Methods

2.1. Study area

The area in the auto industry zone of Bingöl province was used as a wild garbage storage area for approximately 18 years, from 1996 to 2013, and became inactive with the establishment of a new solid waste disposal facility in the city (Anonymous, 2013b). The size of the study area is approximately 11 ha (Figure 1).

Figure 1. Location of the Old Landfill in Bingöl Province.

In April, May, and June 2022, the vegetation was monitored and the species adapted to the region were collected during the development of roots, stems, leaves, and flowers. Visuals of the region are presented in Figure 2.

Figure 2. Residue Images from Bingöl Province Old Landfill (May 2022).

Plant material was sampled and 10 species were identified. Soil samples were taken from 4 different points of the area.

2.2. Plant species

Ten (10) plant species were collected from the landfill area and identified according to the 11-volume Flora of Turkey (Davis, 1965-1985; Davis et al., 1988; Guner et al., 2000). The altitude of the area where the samples were collected was 1225 m and the coordinates were 38° 54' 13" N-40° 32' 47" E. After recording the location, the general view of the area was photographed together with the general view of the plant and the habitat area.

During the collection of samples, an attempt was made to collect as many parts as possible for species identification, such as fruits, seeds, flowers, and basal leaves. Information about the study area and the collected samples, which may be important in identification and may change when dried or pressed (color, odor, shape), was also recorded in the field notebook. Scientific names and authors of the taxa were checked from the current Turkey Plants List book (Guner et al., 2012). The plant species identified as a result of the study are given in Table 1.

Table 1. List of identified plant species

	Species	Family
1	*Alyssum simplex* Rudolph	Brassicaceae
2	*Cirsium libanoticum* DC.	Asteraceae
3	*Descurainia sophia* (L.) Webb ex Prantl	Brassicaceae
4	*Fumaria asepala* Boiss	Papaveraceae
5	*Fumaria officinalis* L.	Papaveraceae
6	*Matricaria chamomilla* L.	Asteraceae
7	*Papaver dubium* L.	Papaveraceae
8	*Scrophularia canina* L.	Scrophulariaceae
9	*Trifolium repens* L.	Fabaceae
10	*Ziziphora capitata* L.	Lamiaceae

Two species of Brassicaceae family (*Alyssum simplex, Descurainia sophia*), 2 species from Asteraceae family (*Cirsium libanoticum, Matricaria chamomilla*), Papavereraceae family 3 species (*Fumaria asepala, Fumaria officinalis, Papaver dubium*) and Scrophulariaceae (*Scrophularia canina*) and 1 species of Lamiaceae family (*Ziziphora capitata*) was determined. Images of the species are presented in Figure 3.

Figure 3. a:*Cirsium libanoticum*, b:*Ziziphora capitata*, c: *Descurainia sophia*, d: *Scrophularia canina*, e:*Alyssum simplex*, f:*Fumaria asepala*, g:*Matricaria chamomilla*, h:*Fumaria officinalis*, ı:*Trifolium repens*, j:*Papaver dubium.*

Heavy metal (Fe, Cr, As, Cd and Pb) contents and pH levels of soil samples taken from the area are given in Table 2. The concentrations of Fe, Pb and Cr, except Cd and As, are similar to the results of Tas and Demir (2022) on heavy metals in the agricultural soils of Bingol plain.

Table 2. Fe, Cr, As, Cd and Pb contents and pH levels of soils

pH	Fe (mg kg^{-1})	Cr (mg kg^{-1})	As (mg kg^{-1})	Cd (mg kg^{-1})	Pb (mg kg^{-1})
6.58	3037.44	7.13	2.00	0.50	7.50

Permissible limit values for toxic heavy metal concentrations in soil and plants (WHO/FAO, 2007) are presented in Table 3.

Table 3. Permissible limit values for toxic heavy metal concentrations in soil and plants (WHO/FAO, 2007; Sonmez and Kılıc, 2021)

Metal	Soil (mg kg^{-1})	Plant (mg kg^{-1})
Fe	50.000	450
Cr	150	5.00
As	20	0.10
Cd	3	0.20
Pb	300	0.30

2.3. Heavy metal (Fe, Cr, As, Cd and Pb) analysis in plants and soil

Plants were collected from the field with all their organs present and separated into their organs as roots, stems, leaves, and flowers in the laboratory, then washed with water and dried in a drying oven at 70 °C. Dried plant parts were ground in a hand mill and made ready for analysis. The total combustion process in the microwave was applied according to the method described in the literatüre (Campbell and Plank, 1998; Kacar and Inan, 2008: Gurbuz et al., 2016). Then, filtration was done with filter paper and the volume of the tubes was completed to 50 mL with ultrapure water. Elemental readings were made in diluted samples with the ICP-MS device. Soil samples were sieved and wet digestion was performed. Then, filtration and dilution were performed in the same way and heavy metal concentrations were read on the ICP-MS device.

2.3.1. Translocation factor (TF)

It is the ratio of the heavy metal concentration in the shoot of the plant to the heavy metal concentration in the root and indicates the ability of heavy metals to be transported from the root to other organs of the plant. If the TF values of plants are greater than 1, they can be used as bioaccumulators in phytoremediation (Surmen et al., 2019).

$$\mathrm{TF} = \frac{\text{Heavy metal concentration in the aerial parts (mg kg}^{-1}\text{)}}{\text{Heavy metal concentration in the roots (mg kg}^{-1}\text{)}} \quad (1)$$

2.4. Statistical analysis

Analysis of variance was applied to the obtained data in the JMP program and the differences were compared with the Tukey test (JMP, 2018).

3. Results

3.1. Distribution of Fe, Cr, As, Cd and Pb concentrations in plant organs and translocation factor (TF) values of species

Concentrations of Fe, Cr, As, Cd, and Pb metals in organs (root, stem, leaf, and flower) and Translocation Factor values of plant species are shown in Table 4.

Alyssum simplex species accumulated chromium most in its roots (1.56 mg kg^{-1}) and stem (1.44 mg kg^{-1}), and arsenic and cadmium accumulated most in its roots, stems and leaves. Similar amounts of iron and lead accumulated in all organs of *Alyssum simplex*. Accumulation of Fe, Cr, As, Cd and Pb metals in the organs of *Cirsium libanoticum* species was not found to be statistically significant. *Descurainia sophia* accumulated chromium (1.78 mg kg^{-1}) and arsenic (0.21 mg kg^{-1}) mostly in its roots, and lead in its leaves (0.18 mg kg^{-1}) and flowers (0.16 mg kg^{-1}). *Fumaria asepala* accumulated iron (366.78 mg kg^{-1}) and arsenic (0.17 mg kg^{-1}) mostly in its leaves, while chromium (1.92 mg kg^{-1}) and cadmium (0.11 mg kg^{-1}) accumulated mostly in its stem. *Fumaria officinalis* accumulated iron (335.03 mg kg^{-1}) and arsenic (0.22 mg kg^{-1}) mostly in its leaves, chromium (1.53 mg kg^{-1}) mostly in its flower and cadmium (0.08 mg kg^{-1}) mostly in its root. The analysis results showed that the heavy metal concentrations in the soil did not exceed the allowed limit values for toxic heavy metal concentrations in soil and plants (Table 2).

Matricaria chamomilla accumulated iron (327.29 mg kg^{-1}) and arsenic (0.20 mg kg^{-1}) mostly in its leaves, chromium mostly in its above-ground organs, cadmium (0.18 mg kg^{-1}) mostly in its roots and lead mostly in its flowers (0.12 mg kg^{-1}). *Papaver dubium* accumulated iron (222.46 mg kg^{-1}) and chromium mostly in its root (2.91 mg kg^{-1}). *Scrophularia canina* accumulated iron (302.79 mg kg^{-1}), chromium (0.88 mg kg^{-1}) and lead mostly in its roots (0.53 mg kg^{-1}), arsenic (0.09 mg kg^{-1}) mostly in its leaves and cadmium (0.25 mg kg^{-1}) mostly in its stems. *Trifolium repens* accumulated iron (331.65 mg kg^{-1}), chromium (0.68 mg kg^{-1}), arsenic (0.06 mg kg^{-1}) and lead (0.19 mg kg^{-1}) mostly in leaves and cadmium (0.02 mg kg^{-1}) mostly in roots. *Ziziphora capitata* accumulated iron, chromium and arsenic mostly in roots and leaves, cadmium mostly in roots and lead mostly in roots, leaves and flowers (Table 4).

3.2. Translocation factor (TF) values of species

Translocation factor (TF) is the ratio of heavy metal concentration in the shoot of the plant to the heavy metal concentration in the root and indicates the ability of heavy metals to be transported from the root to other organs of the plant. If the TF values of plants are greater than 1, they have the possibility of being used as bioaccumulators in phytoremediation (Surmen et al., 2019).

The translocation factor measures plant defense mechanisms that tend to limit inorganic pollutants to the roots to prevent the translocation of trace elements to the above-ground organs of the plant, especially seeds. Normally, plants exhibit TF<1 when under heavy metal stress. TF>1 indicates that plants not only tolerate but also utilize the contaminant, which is often seen as a general characteristic of hyperaccumulators. Thus, TF>1 is a determining factor in the classification of plant species for phytoremediation (Chanu and Gupta, 2016).

As seen in Table 4, TF>1 for Fe in *Alyssum simplex*, *Cirsium libanoticum*, *Fumaria asepala* species, TF>1 for Cr in *Cirsium libanoticum*, *Fumaria asepala*, *Fumaria officinalis* and *Matricaria chamomilla* species, TF>1 for As in *Cirsium libanoticum*, *Fumaria asepala*, *Fumaria officinalis*, *Matricaria chamomilla* and *Papaver dubium* species, TF>1 for Cd in *Cirsium libanoticum*, *Papaver dubium* and *Scrophularia canina* species, TF>1 for Pb in all species except *Alyssum simplex* and *Scrophularia canina* (Table 4).

Table 4. Distribution of Fe, Cr, As, Cd and Pb concentrations (mg kg^{-1}) in organs and TF values

	Fe	Cr	As	Cd	Pb
***Alyssum simplex* Rudolph.**					
Root	79.88^{ns}	1.56a**	0.16ab*	0.40a**	0.27^{ns}
Stem	92.50	1.44a	0.14ab	0.34a	0.11
Leaf	52.65	1.27b	0.22a	0.36a	0.14
Flower	100.62	1.09c	0.10b	0.22b	0.07
TF	1.03	0.81	0.93	0.76	0.41
***Cirsium libanoticum* DC.**					
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	132.13^{ns}	1.84^{ns}	0.14^{ns}	0.19^{ns}	0.18^{ns}
Stem	146.95	1.80	0.17	0.27	0.18
Leaf	197.81	1.95	0.22	0.26	0.24
Flower	233.50	1.75	0.23	0.18	0.38
TF	1.46	1.00	1.54	1.27	1.47
***Descurainia sophia* (L.) W.ex P.**					
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	129.76^{ns}	1.78a**	0.21a*	0.33^{ns}	0.08b*
Stem	144.60	1.52b	0.13ab	0.26	0.08b
Leaf	96.28	1.55b	0.16ab	0.37	0.18a
Flower	130.45	1.34b	0.12b	0.27	0.16a
TF	0.95	0.83	0.63	0.90	1.86

*:p<0.05, **:p<0.01, ns: non significant.

Table 4. Distribution of Fe, Cr, As, Cd and Pb concentrations (mg kg^{-1}) in organs and TF values (continued)

			***Fumaria asepala* Boiss.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	179.23c**	1.24c**	0.06d**	0.08ab*	0.11^{ns}
Stem	313.26b	1.92a	0.14b	0.11a	0.14
Leaf	366.78a	1.79ab	0.17a	0.08ab	0.17
Flower	222.56c	1.64b	0.10c	0.02b	0.14
TF	1.68	1.44	2.10	0.92	1.39
			***Fumaria officinalis* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	240.91b**	1.00c**	0.11c**	0.08a**	0.05^{ns}
Stem	227.66b	1.32b	0.15b	0.04c	0.27
Leaf	335.03a	1.31b	0.22a	0.05b	0.12
Flower	93.36c	1.53a	0.09d	0.02d	0.05
TF	0.91	1.39	1.39	0.44	2.65
			***Matricaria chamomilla* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	236.56b**	1.58b**	0.12b**	0.18a**	0.06b*
Stem	190.84bc	1.84a	0.10b	0.10b	0.08ab
Leaf	327.29a	1.88a	0.20a	0.09bc	0.10ab
Flower	160.92c	1.86a	0.09b	0.06c	0.12a
TF	0.96	1.18	1.09	0.46	1.58
			***Papaver dubium* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	222.46a**	2.91a**	0.08^{ns}	0.07^{ns}	0.16^{ns}
Stem	50.39b	1.41b	0.19	0.28	0.30
Leaf	91.04b	1.49b	0.14	0.20	0.10
Flower	72.44b	1.16b	0.08	0.03	0.12
TF	0.32	0.47	1.81	2.31	1.10
			***Scrophularia canina* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	302.79a**	0.88a**	0.08b**	0.14b**	0.53a*
Stem	139.41bc	0.42b	0.02c	0.25a	0.02b
Leaf	191.99b	0.75a	0.09a	0.10c	0.24ab
Flower	113.07c	0.30b	0.03c	0.09c	0.07ab
TF	0.49	0.56	0.61	1.03	0.21
			***Trifolium repens* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	315.79b**	0.57b**	0.05b**	0.02a**	0.10ab*
Stem	185.72c	0.49bc	0.02c	0.01b	0.08b
Leaf	331.65a	0.68a	0.06a	0.00c	0.19a
Flower	156.46b	0.45c	0.02c	0.00c	0.09ab
TF	0.71	0.95	0.65	0.19	1.23
			***Ziziphora capitata* L.**		
	Fe	**Cr**	**As**	**Cd**	**Pb**
Root	279.36a**	0.75a**	0.07a**	0.05a**	0.06a**
Stem	132.28c	0.48b	0.02b	0.02ab	0.02b
Leaf	288.10a	0.69a	0.08a	0.01b	0.10a
Flower	166.37b	0.47b	0.03b	0.00c	0.08a
TF	0.70	0.73	0.57	0.17	1.00

*:p<0.05, **:p<0.01, ns: non significant.

3.3. Fe concentration of species (mg kg^{-1})

The distribution of Fe concentrations (mg kg^{-1}) in plant organs of plant species collected from the garbage area are shown in Table 5.

The values obtained in each organ and their averages were found to be statistically very significant ($p<0.01$). In all organs (root, stem, leaf, and flower), *Fumaria asepala* accumulated the highest (270.46 mg kg^{-1}) Fe, while *Alyssum simplex* accumulated the least (81.41 mg kg^{-1}). Among the species, *Scrophularia canina* and *Trifolium repens* accumulated the most iron (Fe) in roots, *Fumaria asepala* accumulated the most in stems, *Fumaria asepala, Fumaria officinalis*, *Trifolium repens* and *Matricaria chamomilla* accumulated the most in leaves and *Cirsium libanoticum* accumulated the most in flowers (Table 5).

Table 5. Fe concentrations in organs of species (mg kg^{-1})

	Fe Concentration (mg kg^{-1})					
	Species	**Root**	**Stem**	**Leaf**	**Flower**	**Mean**
1.	*Alyssum simplex*	79.88f**	92.50de**	52.65d**	100.62c**	81.41D**
2.	*Cirsium libanoticum*	132.13ef	146.95cd	197.81bc	233.50a	177.60BC
3.	*Descurainia sophia*	129.76ef	144.60cd	96.28cd	130.45bc	125.27CD
4.	*Fumaria asepala*	179.23de	313.26a	366.77a	222.56ab	270.46A
5.	*Fumaria officinalis*	240.91bc	227.66b	335.03a	93.36c	224.24AB
6.	*Matricaria chamomilla*	236.56bc	190.84bc	327.29a	160.92abc	228.90AB
7.	*Papaver dubium*	222.46cd	50.39e	91.04cd	72.44c	109.08CD
8.	*Scrophularia canina*	302.79a	139.41cd	191.99bc	113.07c	186.81BC
9.	*Trifolium repens*	315.79a	185.72bc	331.65a	156.46abc	247.41AB
10.	*Ziziphora capitata*	279.36ab	132.28cd	288.10ab	166.37abc	216.53AB
	Mean	211.89A**	162.36B	227.86A	144.97B	

**:$p<0.01$, level of significance; capital letters show significant differences between the average concentrations of species and the average concentrations of organs; small letters show significant differences between the concentrations in each organ.

When all species are considered together, it is observed that the most iron accumulated in roots (211.89 mg kg^{-1}) and leaves (227.86 mg kg^{-1}), followed by stems (162.36 mg kg^{-1}) and flowers (144.97 mg kg^{-1}) (Table 5).

3.4. Cr concentration of species (mg kg^{-1})

The distribution of Cr concentrations (mg kg^{-1}) in plant organs of plant species collected from the garbage area are shown in Table 6. The values obtained in each organ and their averages were found to be statistically very significant ($p<0.01$). *Cirsium libanoticum*, *Matricaria chamomilla*, and *Papaver dubium* accumulated the highest (1.84, 1.79, and 1.74 mg kg^{-1}) Cr in all organs, while *Scrophularia canina*, *Trifolium repens* and *Ziziphora capitata* accumulated the least (0.59, 0.55 and 0.59 mg kg^{-1}). Among the species, *Papaver dubium* accumulated the most chromium (Cr) in its roots, *Fumaria asepala*, *Matricaria chamomilla* and *Cirsium libanoticum* accumulated it in its stems, *Cirsium libanoticum*, *Fumaria asepala* and *Matricaria chamomilla* accumulated it in their leaves, while *Cirsium libanoticum* and *Matricaria chamomilla* accumulated it in their flowers (Table 6).

Table 6. Cr concentrations in organs of species (mg kg^{-1})

	Cr Concentration (mg kg^{-1})					
	Species	**Root**	**Stem**	**Leaf**	**Flower**	**Mean**
1.	*Alyssum simplex*	1.56c**	1.44b**	1.27b**	1.09b**	1.34B**
2.	*Cirsium libanoticum*	1.84b	1.80a	1.95a	1.75a	1.84A
3.	*Descurainia sophia*	1.78b	1.52b	1.55ab	1.34ab	1.55AB
4.	*Fumaria asepala*	1.24d	1.92a	1.79a	1.64ab	1.65AB
5.	*Fumaria officinalis*	1.00e	1.32b	1.31b	1.53ab	1.29B
6.	*Matricaria chamomilla*	1.58c	1.84a	1.88a	1.86a	1.79A
7.	*Papaver dubium*	2.91a	1.41b	1.49ab	1.16b	1.74A
8.	*Scrophularia canina*	0.88ef	0.42c	0.75c	0.30c	0.59C
9.	*Trifolium repens*	0.57fg	0.49c	0.68c	0.45c	0.55C
10.	*Ziziphora capitata*	0.75f	0.48c	0.69c	0.47c	0.59C
	Mean	1.41A**	1.26AB	1.34AB	1.16B	

**:$p<0.01$, level of significance; capital letters show significant differences between the average concentrations of species and the average concentrations of organs; small letters show significant differences between the concentrations in each organ.

When all species are considered together, it is observed that most chromium accumulated in the roots (1.41 mg kg^{-1}) followed by leaves (1.34 mg kg^{-1}) and stems (1.26 mg kg^{-1}) (Table 6).

3.5. As concentration of species (mg kg^{-1})

The distribution of As concentrations (mg kg^{-1}) in plant organs of plant species collected from the garbage area are shown in Table 7. The values obtained in each organ and their averages were found to be statistically very significant (p<0.01). *Cirsium libanoticum* accumulated the highest (0.19 mg kg^{-1}) As in all organs, while *Scrophularia canina*, *Trifolium repens* and *Ziziphora capitata* accumulated the least (0.06, 0.04 and 0.05 mg kg^{-1}). Among the species, *Descurainia sophia* accumulated the most arsenic (As) in its roots, *Papaver dubium* and *Cirsium libanoticum* in its stems, *Alyssum simplex*, *Cirsium libanoticum*, *Fumaria officinalis*, and *Matricaria chamomilla* in its leaves and *Cirsium libanoticum* in its flowers (Table 7).

Table 7. As concentrations in organs of species (mg kg^{-1})

	As Concentration (mg kg^{-1})					
	Species	**Root**	**Stem**	**Leaf**	**Flower**	**Mean**
1.	*Alyssum simplex*	0.16b**	0.14ab**	0.22a*	0.10ab**	0.15AB**
2.	*Cirsium libanoticum*	0.14bc	0.17a	0.22a	0.23a	0.19A
3.	*Descurainia sophia*	0.21a	0.13ab	0.16abc	0.12ab	0.15AB
4.	*Fumaria asepala*	0.06f	0.14ab	0.17ab	0.10ab	0.12BC
5.	*Fumaria officinalis*	0.11cde	0.15ab	0.22a	0.09ab	0.14AB
6.	*Matricaria chamomilla*	0.12cd	0.10ab	0.20a	0.09ab	0.13AB
7.	*Papaver dubium*	0.08ef	0.19a	0.14abc	0.08b	0.12B
8.	*Scrophularia canina*	0.08def	0.02b	0.09bc	0.03b	0.06CD
9.	*Trifolium repens*	0.05f	0.02b	0.06c	0.02b	0.04D
10.	*Ziziphora capitata*	0.07ef	0.02b	0.08bc	0.03b	0.05D
	Mean	0.11B**	0.11B	0.16A	0.09B	

*:p<0.05, **:p<0.01, level of significance; capital letters show significant differences between the average concentrations of species and the average concentrations of organs; small letters show significant differences between the concentrations in each organ.

When all species are considered together, it is seen that the most arsenic is accumulated in the leaves (0.16 mg kg^{-1}) and that As is accumulated in other organs, although less than the leaves, at similar concentrations (0.09-0.11 mg kg^{-1}) (Table 7).

3.6. Cd concentration of species (mg kg^{-1})

The distribution of Cd concentrations (mg kg^{-1}) in plant organs of plant species collected from the garbage area are shown in Table 8.

Table 8. Cd concentrations in organs of species (mg kg^{-1})

	Cd Concentration (mg kg^{-1})					
	Species	**Root**	**Stem**	**Leaf**	**Flower**	**Mean**
1.	*Alyssum simplex*	0.40a**	0.34a**	0.36a**	0.22b**	0.33A**
2.	*Cirsium libanoticum*	0.19b	0.27ab	0.26ab	0.18b	0.22B
3.	*Descurainia sophia*	0.33a	0.26ab	0.37a	0.27a	0.31A
4.	*Fumaria asepala*	0.08bcd	0.11ab	0.08d	0.02de	0.07CDE
5.	*Fumaria officinalis*	0.08bcd	0.04b	0.05d	0.02e	0.05DE
6.	*Matricaria chamomilla*	0.18b	0.10ab	0.09cd	0.06cd	0.11CD
7.	*Papaver dubium*	0.07bcd	0.28ab	0.20bc	0.03de	0.15BC
8.	*Scrophularia canina*	0.14bc	0.25ab	0.10cd	0.09c	0.15BC
9.	*Trifolium repens*	0.02d	0.01b	0.00d	0.00e	0.01E
10.	*Ziziphora capitata*	0.05cd	0.02b	0.01d	0.00e	0.02E
	Mean	0.16A**	0.17A	0.15A	0.09B	

**:p<0.01, level of significance; capital letters show significant differences between the average concentrations of species and the average concentrations of organs; small letters show significant differences between the concentrations in each organ.

The values obtained in each organ and their averages were found to be statistically very significant (p<0.01). *Alyssum simplex* and *Descurainia sophia* accumulated the highest (0.33 and 0.31 mg kg^{-1}) Cd in all organs, while *Trifolium repens* and *Ziziphora capitata* accumulated the least (0.01 and 0.02 mg kg^{-1}). Among the species, *Alyssum simplex* and *Descurainia sophia* accumulated the most arsenic (As) in roots, *Alyssum simplex* accumulated the most in stems, *Alyssum simplex* and *Descurainia sophia* accumulated the most in leaves, and *Descurainia sophia* accumulated the most in flowers (Table 8).

When all species are considered together, it is seen that the highest cadmium accumulates in similar concentrations in the roots, stems and leaves (0.15-0.17 mg kg^{-1}), and the least accumulates in the flowers (0.09 mg kg^{-1}) (Table 8).

3.7. Pb concentration of species (mg kg^{-1})

The distribution of Pb concentrations (mg kg^{-1}) in plant organs of plant species collected from the garbage area are shown in Table 9. The values obtained in each organ and their averages were found to be statistically very significant (p<0.01). The species that accumulated Pb in all organs was *Cirsium libanoticum*. Among the species, *Scrophularia canina* accumulated the most lead (Pb) in its roots, *Papaver dubium* accumulated it in its trunk, and *Cirsium libanoticum* accumulated it in its flowers. The concentration of Pb accumulated in leaves did not differ significantly between species (Table 9).

Table 9. Pb concentrations in organs of species (mg kg^{-1})

	Pb Concentration (mg kg^{-1})					
	Species	**Root**	**Stem**	**Leaf**	**Flower**	**Mean**
1.	*Alyssum simplex*	0.27ab**	0.11bc*	0.14^{ns}	0.07b**	0.15AB**
2.	*Cirsium libanoticum*	0.18b	0.18abc	0.24	0.38a	0.25A
3.	*Descurainia sophia*	0.08b	0.08c	0.18	0.16b	0.12AB
4.	*Fumaria asepala*	0.11b	0.14abc	0.17	0.14b	0.14AB
5.	*Fumaria officinalis*	0.05b	0.27ab	0.12	0.05b	0.12AB
6.	*Matricaria chamomilla*	0.06b	0.08c	0.10	0.12b	0.09B
7.	*Papaver dubium*	0.16b	0.30a	0.10	0.12b	0.17AB
8.	*Scrophularia canina*	0.53a	0.02c	0.24	0.07b	0.21AB
9.	*Trifolium repens*	0.10b	0.08c	0.19	0.09b	0.11AB
10.	*Ziziphora capitata*	0.06b	0.02c	0.10	0.08b	0.06B
	Mean	0.16^{ns}	0.13	0.16	0.13	

**:p<0.01, level of significance; ns: non significant, capital letters show significant differences between the average concentrations of species and the average concentrations of organs; small letters show significant differences between the concentrations in each organ.

When all species are considered together, it is seen that there is no statistically significant difference between plant organs for Pb accumulation.

4. Discussion

Among the plant species, *Alyssum simplex* accumulated the least iron (Fe) and the most cadmium (Cd) in all its organs. Plants such as *Alyssum, Thlaspi, Urtica*, and *Polygonum* have a high ability to accumulate heavy metals such as cadmium, copper, lead, nickel, and zinc (Ozay and Mammadov, 2013). It has been reported that some plant species such as *Alyssum murale, Thlaspi vaerulescens, Nicotiana tabacum, Zea mays, Salix viminalis, Helianthus annuus* and *Viola baoshanensis* are used for phytoremediation purposes (Kabata-Pendias, 2011). Similar to this study, in the study conducted by Celiktas (2020), *Alyssum oxycarpum* species accumulated iron in its roots, stems, and leaves at concentrations close to each other. Although there was no Pb pollution in the area, *Alyssum simplex* preferred to accumulate the available lead in its roots. Similarly, in a study conducted around Adana Cr mine, *Alyssum alyssoides* preferred to accumulate lead mostly in its roots (root: 4.86, stem: 1.22, leaf: 3.01, mg kg^{-1}) (Celiktas, 2020).

Cirsium libanoticum tended to accumulate Cr and As in its aboveground organs compared to other species. Dokmeci and Adiloglu (2020) reported that *Cirsium vulgare* offers the potential for use in the removal of chromium from the soil. In this study, TF>1 was found for Cr. Sajad et al. (2020)

reported a similar result as TF>1 for Cr in *Cirsium vulgare* plant in their study. In this study, Pb TF >1 was calculated for *Cirsium libanoticum*. Sajad et al. (2019) also reported TF >1 for Pb in *Cirsium vulgare* species in their study.

Descurainia sophia accumulated the most Cd in all organs compared to other plant species. While the TF value for Cd was 0.90, it was 1.86 for Pb. Moameri et al. (2017) found that the TF value for Pb (TF>1) was higher than 1 in *Descurainia sophia, Stachys lavandulifolia*, and *Echium amoenum* plants. They also reported Cd translocation factor value as TF>1 for *Brassica juncea, Scariola orientalis, Descurainia sophia, Achillea millefolium, Centaurea virgata* and *Stachys lavandulifolia* plants.

Fumaria asepala accumulated the most iron (276.46 mg kg^{-1} Fe) in all organs compared to other plant species. *Fumaria officinalis* accumulated an average of 224.24 mg kg^{-1} Fe in all plant organs. Zokaei et al. (2018) reported the Fe concentration of plants collected in Shiraz, including *Fumaria officinalis* species, as 187.24 mg kg^{-1}. The researchers also reported that the same species had Cd concentration in the range of 0.01-0.08 mg kg^{-1} and Pb concentration in the range of 0.02-0.3 mg kg^{-1}. These results are parallel for both *Fumaria* species examined in this study (Cd: 0.02-0.11 mg kg^{-1} and Pb: 0.05-0.3 mg kg^{-1}).

Matricaria chamomilla accumulated the most Cr in all organs compared to other species. In addition, in the evaluation within the organs, stem, leaves, and flowers accumulated more Cr than roots (root: 1.58 mg kg^{-1}, stem: 1.84 mg kg^{-1}, leaf: 1.88 mg kg^{-1}, and flower: 1.86 mg kg^{-1}). Glišić et al. (2021) reported that the leaves and stem of *Matricaria inodora* can be used in the phytoextraction of chromium (Cr). *Matricaria chamomilla* preferred to accumulate cadmium in its roots and this aspect weakened its usability in phytoremediation (root: 0.18 mg kg^{-1}, stem: 0.10 mg kg^{-1}, leaf: 0.09 mg kg^{-1} and flower: 0.06 mg kg^{-1}). Kováčik et al. (2006) reported that *Matricaria chamomilla* cannot be classified as a hyperaccumulator due to the preferential accumulation of Cd in the roots and is therefore not suitable for phytoremediation.

Papaver dubium preferred to accumulate iron and chromium in the roots than in the above-ground organs. The difference in the distribution of As, Pb and Cd in plant organs was not statistically significant.

Alizadeh et al. (2022) found that *Papaver dubium*, *Trifolium fragiferum* and *Achillea vermicularis* species collected from a mine and waste dumpsite did not exceed the hyperaccumulation thresholds for the relevant trace elements (As, Ca, Co, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Zn). The researchers also determined concentrations of Cr 0.72 mg kg^{-1}, Pb 4.39 mg kg^{-1}, and As 2.14 mg kg^{-1} for *Papaver dubium*. According to the results of Alizadeh et al. (2022), Cr was determined higher in our study, while As and Pb were determined lower. Ghaderian and Ravandi (2012) reported Pb concentration in the leaf dry matter of *Papaver dubium* collected from copper mining area as 11 mg kg^{-1}. The concentration in the plant collected from the mining area was higher than the plant collected from the garbage area, as expected.

It appears that the *Scrophularia canina* plant prefers to accumulate Pb and Fe elements in its roots. The TF of the plant for Pb was calculated to be TF<1, which limits the usability of the species for phytoremediation in Pb-polluted areas. Cd concentration in the *Scrophularia canina* plant was determined as 0.14 mg kg^{-1} in the roots, 0.25 mg kg^{-1} in the stem, 0.10 mg kg^{-1} in the leaf, and 0.09 mg kg^{-1} in the flower. Boularbah et al. (2006) found that the *Scrophularia canina* plant collected from the mining area had a Cd concentration of 0.25 mg kg^{-1}, which is similar to the study findings. Shallari et al. (1998) heavy metal contents (1 mg kg^{-1} Cd, 4 mg kg^{-1} Cr, and 8 mg kg^{-1} Pb) of the *Scrophularia canina* plant collected from serpentine areas are higher than our study findings.

In the *Trifolium repens* plant, TF<1 for Fe, Cr, As, and Cd, while TF>1 was determined only for Pb. In addition, it accumulated the elements Cr, Cd, and As in the least concentration in all its organs compared to other plant species. Wen et al. (2018) reported in their study that *Trifolium repens* and *R. nepalensis* plants could increase the phytoremediation efficiency of Pb-Zn-contaminated areas when planted together. Matanzas et al. (2021) found TF <1 for As (TF: 0.38) and Pb (TF: 0.31) in the *Trifolium repens* plant. TF <1 for arsenic was similar to the study findings.

Ziziphora capitata was the species that accumulated Cr, As, and Cd elements the least in all plant tissues compared to other species. The TF value was found to be 1.00 only for Pb, but it still did not exceed the concentration limit value allowed in plants. Cd and Pb were found to be higher than the permissible limit values in the *Ziziphora persica* plant (Alinia-Ahandani et al., 2021). Cd, Pb, and Cr were found to be <0.05 mg kg^{-1} in the *Ziziphora tenuior* plant (Hajihashemi et al., 2021).

When all species were considered together, it was observed that the most iron, chromium, and cadmium accumulated in the roots, arsenic was distributed in the leaves, and lead was distributed in all plant organs in similar proportions. Nouri et al. (2009) reported that metals accumulated by plants were mostly distributed in root tissues. It has been reported that in contaminated soils, cadmium is especially concentrated in the roots of plants (Kabata-Pendias, 2011).

Conclusion

It was determined that the heavy metal contents (Fe, Cr, As, Cd and Pb) of the soil samples taken from the study area (former garbage area) did not exceed the heavy metal limit values allowed in soils (WHO/FAO, 2007; Sonmez and Kılıc, 2021). The reason for this is that although the area has been used for garbage storage for approximately 18 years, it may not have encountered a new pollution factor in the last 10 years. It is thought that the existing pollution may have been removed by the effect of climatic factors such as rainfall. The potential of the plant species distributed and identified in the area to carry heavy metals to the above-ground organs was evaluated. It has been observed that *Alyssum simplex, Cirsium libanoticum, Descurainia sophia, Fumaria asepala, Fumaria officinalis, Matricaria chamomilla*, and *Papaver dubium* species accumulate arsenic (As) above the allowed limit values by WHO/FAO. It has been observed that cadmium (Cd) *Alyssum simplex, Cirsium libanoticum, Descurainia sophia, Papaver dubium*, and *Scrophularia canina* species accumulate, and lead (Pb) *Cirsium libanoticum* and *Papaver dubium* species accumulate above the limit values allowed in plants by WHO/FAO. It is not recommended to use these plants in the area for human and animal nutrition. When the use of phytoremediation purposes (TF>2) for soil with this pollution is evaluated, it can be said that *Fumaria asepala* for As, *Fumaria officinalis* for Pb, and *Papaver dubium* species for Cd have potential.

References

Agbeshie, A. A., Adjei, R., Anokye, J., & Banunle, A. (2020). Municipal waste dumpsite: Impact on soil properties and heavy metal concentrations, Sunyani, Ghana. *Scientific African, 8*, e00390.

Alinia-Ahandani, E., Malekirad, A. A., Nazem, H., Fazilati, M., Salavati, H., & Rezaei, M. (2021). Assessment of Some Toxıc Metals in Ziziphora (*Ziziphora persica*) obtained from local market in Lahijan, Northern Iran. *Annals of Military and Health Sciences Research*, *19*(4), e119991.

Alizadeh, A., Ghorbani, J., Motamedi, J., Vahabzadeh, G., Edraki, M., & van Der Ent, A. (2022). Metal and metalloid accumulation in native plants around a copper mine site: implications for phytostabilization. *International Journal of Phytoremediation*, *24*(11), 1141-1151.

Anonymous, (2013a). https://dogruhaber.com.tr/haber/83514-bingol-sehir-coplugu-tehlike-saciyor/, Access date: 03.07.2022.

Anonymous, (2013b). https://www.haberler.com/yerel/bingolde-kati-atik-bertaraf-tesisi-faaliyete-gecti-5038907-haberi/, Access date: 21.06.2022.

Awokunmi, E. E., Asaolu, S. S., & Ipinmoroti, K. O. (2010). Effect of leaching on heavy metals concentration of soil in some dumpsites. *African Journal of Environmental Science and Technology*, *4*(8), 495-499.

Boularbah, A., Schwartz, C., Bitton, G., Aboudrar, W., Ouhammou, A., & Morel, J. L. (2006). Heavy metal contamination from mining sites in South Morocco: 2. Assessment of metal accumulation and toxicity in plants. *Chemosphere*, *63*(5), 811-817.

Boysan Canal, S., Bozkurt, M., & Yilmaz, H. (2022). The effect of humic acid on plant growth, phytoremediation and oxidative stress in rapeseed (*Brassica napus* L.) grown under heavy metal stress. *Yuzuncu Yil University Journal of Agricultural Sciences*, *32*(2), 237-248.

Campbell, C. R., & Plank, C. O. (1998). Preparation of plant tissue for laboratory analysis, Y. Kalra (Ed.), *Reference Methods for Plant Analysis* (37).

Chanu, L. B., & Gupta, A. (2016). Phytoremediation of lead using Ipomoea aquatica Forsk. in hydroponic solution. *Chemosphere*, *156*, 407-411.

Clemens, S. (2006). Toxic metal accumulation, responses to exposure and mechanisms of tolerance in plants. *Biochimie*, *88*(11), 1707-1719.

Celiktas, V. (2020). The determination of the phytoremediation characteristics of plants which found in chromium mining areas in Aladağ district of Adana province. (Master's thesis, Çukurova University).

Davis, P. H. (1965-1985). Flora of Turkey and the East Aegean Islands. Vol. 1-9. Edinburgh University Press., Edinburgh.

Davis, P. H., R. R. Mill and K. Tan. (1988). Flora of Turkey and the East Aegean Islands. Vol. 10. Supplement I. Edinburgh University Press., Edinburgh.

Dokmeci, A. H., & Adiloglu, S. (2020). The Phytoremediation of chromium from soil using Cirsium vulgare and the health effects. *Biosciences Biotechnology Research Asia*, *17*(3), 535-541.

Doku, E. T., Sylverken, A. A., & Belford, J. E. (2024). Rhizosphere microbiome of plants used in phytoremediation of mine tailing dams. *International Journal of Phytoremediation*, 1-9. doi: 10.1080/15226514.2024.2301994.

Ebin, G. C. (2004). Katı atık depo sahalarının rehabilitasyonu. Yüksek Lisans Tezi, Yıldız Teknik Üniversitesi Fen Bilimleri Enstitüsü, İstanbul.

FAO/ITPS, (2015). Status of the world's soil resources (SWSR)–main report, in: Food and agriculture organization of the United Nations and intergovernmental technical panel on soils, Rome, Italy, 2015, p. 650. https://www.fao.org/3/i5199e/I5199E.pdf, Access date:18.06.2022.

Ghaderian, S. M., & Ravandi, A. A. G. (2012). Accumulation of copper and other heavy metals by plants growing on Sarcheshmeh copper mining area, Iran. *Journal of Geochemical Exploration*, *123*, 25-32.

Glišić, R., Simić, Z., Grbović, F., Rajičić, V., & Branković, S. (2021). Phytoaccumulation of metals in three plants species of the Asteraceae family sampled along a highway.

Gokce, G., & Hasanoglu, P. (2015). Plantation and Rehabilitation of Solid Waste Storage Areas and Open Dump Areas. *Düzce University Journal of Science and Technology*, *3*(1), 258-271.

GSP, (2017). Report of the Fifth Meeting of the Plenary Assembly (PA) of the Global Soil Partnership (GSP), Food and Agriculture Organization of the United Nations, Rome, Italy,. https://www.fao.org/3/bs973e/bs973e.pdf, Access date:18.06.2022.

Guner, A., Aslan, S., Ekim, T., Vural, M. & Babac, M.T. (edlr.). (2012). List of Plants of Türkiye (Vascular Plants). Nezahat Gökyiğit Garden and Flora Research Association Publication. Istanbul.

Guner, A.,Ozhatay N., Ekim T., Bafler K. H. C. (2000). Flora of Turkey and the East Aegean Islands, Second Supplement. Vol. 11. P. 656. Edinburgh: Edinburgh University Press.

Gurbuz, M. A., Kardes, T. A., & Cebi U. (2016). Assessment of the Availability of the Multinutrient Extraction Methods for Wheat Plant for the Determining Phosphorus by Soil and Plant Analysis, *Çukurova Journal of Agricultural and Food Sciences*, *31*(3), 229-233.

Hajihashemi, S., Rajabpoor, S., & Brestic, M. (2021). Introduction to the native plant species with phytoremediation potential growing in a high Fe and Zn contaminated site in the copper mine of Dehmadan, Iran. 09 November 2021, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-1058712/v1].

Holleman, A. F. E. (1985). Sayfa 868. Wiberg: Lehebuch du Anoranischen chemie. Water de Gruyter, Berlin.

JMP, (2018). Statistical Discovery from SAS, USA.

Kabata-Pendias A. (1994). Maintaining soil micronutrient status In: *Soil Resilience and Sustainable Land use, eds.* D.J. Greenland, I. Szabolcs, 199–214, CAB Int., Wallington.

Kabata-Pendias, A. (2011). 4th edn CRC Press, Trace elements in soils and plants. Boca Raton.

Kacar, B., Inal, A. 2008. Page 892, Plant analysis, Nobel Publication No: 1241.

Kalay, M., Canlı, M. (2000). Elimination of essential (Cu, Zn) and non-essential (Cd, Pb) metals from tissues of a freshwater fish Tilapia zilli. *Turkish Journal of Zoology*, *24*(4), 429-436.

Kováčik, J., Tomko, J., Bačkor, M., & Repčák, M. (2006). Matricaria chamomilla is not a hyperaccumulator, but tolerant to cadmium stress. *Plant Growth Regulation*, *50*, 239-247.

Kuzu, M., Comaklı, V., Akkemik, E., Ciftci, M., & Kufrevioglu, Ö. İ. (2018). Inhibitory properties of some heavy metals on carbonic anhydrase I and II isozymes activities purified from Van Lake fish (*Chalcalburnus Tarichi*) gill. *Fish physiology and biochemistry*, *44*, 1119-1125.

Lagerkvist, A., & Dahlén, L. (2019). Solid Waste Generation and Characterization, in: Recovery of Materials and Energy from Urban Wastes: A Volume in the Encyclopedia of Sustainability Science and Technology, Second ed., pp. 7–20.

Matanzas, N., Afif, E., Díaz, T. E., & Gallego, J. R. (2021). Phytoremediation potential of native herbaceous plant species growing on a paradigmatic brownfield site. *Water, Air, & Soil Pollution*, *232*, 1-14.

Moameri, M., Jafari, M., Tavili, A., Motasharezadeh, B., & Zare Chahouki, M. A. (2017). Rangeland plants potential for phytoremediation of contaminated soils with lead, zinc, cadmium and nickel (Case study: Rangelands around national lead & zinc factory, Zanjan, Iran). *Journal of Rangeland Science*, *7*(2), 160-171.

Naila, A., Meerdink, G., Jayasena, V., Sulaiman, A. Z., Ajit, A. B., & Berta, G. (2019). A review on global metal accumulators Mechanism, enhancement, commercial application, and research trend, Environmental Science and Pollution Research, *26*(26), 26449-26471.

Nouri, J., Khorasani, N., Lorestani, B., Karami, M., Hassani, A. H., & Yousefi, N. (2009). Accumulation of heavy metals in soil and uptake by plant species with phytoremediation potential. *Environmental Earth Sciences*, *59*, 315-323.

Oksuz, C. (2019). Determination of heavy metal concentration of soil and vegetation the city waste of Kastamonu (Master's thesis, Kastamonu University).

Ozay, C., & Mammadov, R. (2013). Heavy Metals and Potential Availability of Ornamental Plants for Phytoremediation. *Journal of Balıkesir University Institute of Science and Technology*, 15(1), 68-77. Retrieved from https://dergipark.org.tr/en/pub/baunfbed/issue/24792/261934

Ozbek, K. (2015). Hyperaccumulation and hyperaccumulator species in the flora of Turkey. *Soil Science and Journal of Plant Nutrition, 3*(1), 37-43.

Sajad, M. A., Khan, M. S., & Ali, H. (2019). 42. Lead phytoremediation potential of sixty-one plant species: an open field survey. *Pure and Applied Biology (PAB)*, *8*(1), 405-419.

Sajad, M. A., Khan, M. S., Bahadur, S., Naeem, A., Ali, H., Batool, F., ... & Batool, S. (2020). Evaluation of chromium phytoremediation potential of some plant species of Dir Lower, Khyber Pakhtunkhwa, Pakistan. *Acta Ecologica Sinica*, *40*(2), 158-165.

Saleem, M. H., Ali, S., Rehman, M., Hasanuzzaman, M., Rizwan, M., Irshad, S., ... & Qari, S. H. (2020a). Jute: A potential candidate for phytoremediation of metals A review. *Plants*, *9*(2), 258.

Saleem, M. H., Fahad, S., Rehman, M., Saud, S., Jamal, Y., Khan, S., & Liu, L. (2020b). Morpho-physiological traits, biochemical response and phytoextraction potential of short-term copper stress on kenaf (*Hibiscus cannabinus* L.) seedlings. *PeerJ*, *8*, e8321.

Shallari, S., Schwartz, C., Hasko, A., & Morel, J. L. (1998). Heavy metals in soils and plants of serpentine and industrial sites of Albania. *Science of The Total Environment*, *209*(2-3), 133-142.

Sharma, R. K., & Agrawal, M. (2005). Biological effects of heavy metals: an overview. *Journal of environmental Biology*, *26*(2), 301-313.

Sonmez, O., & Kılıc, F. N. (2021). Heavy metal pollution in soil and removal methods. *Turkish Journal of Agricultural Engineering Research (TURKAGER)*, *2*(2), 493-507.

Surmen, B., Kılıc, D. D., Kutbay, H. G., & Tuna, E. E. (2019). Investigation of Heavy Metal Accumulation and Biomonitoring of *Lepidium draba* L. Species Growing in Amasya (Turkey) Province. *European Journal of Science and Technology*, (17), 491-499.

Tas, R., & Demir, Y. (2022). Determination and mapping of fertility level and some heavy metal contents of agricultural soils in Bingöl plain. *Düzce University Faculty of Forestry Journal of Forestry*, *18*(2), 296-315.

TUIK, (2020). Atık İstatistikleri. https://data.tuik.gov.tr/, Access date: 25.06.2022.

UNEP, (2018). World commits to pollution-free planet at environment summit., UN Environment, [online]. https://wedocs.unep.org/bitstream/handle/20.500.11822/25435/AnnualReport2018_En.pdf?sequence=1&isAllowed=y, Access date: 18.06.2022.

Wan, X., Zeng, W., Cai, W., Lei, M., Liao, X., & Chen, T. (2023). Progress and future prospects in co-planting with hyperaccumulators: Application to the sustainable use of agricultural soil contaminated by arsenic, cadmium, and nickel. *Critical Reviews in Environmental Science and Technology*, *53*(24), 2112–2131.

Wen, W., Zhao, H., Ma, J., Li, Z., Li, H., Zhu, X., ... & Liu, Y. (2018). Effects of mutual intercropping on Pb and Zn accumulation of accumulator plants Rumex nepalensis, Lolium perenne and Trifolium repens. *Chemistry and Ecology*, *34*(3), 259-271.

WHO/FAO, (2007). Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty-Eight Session of the Codex Committee on Food Hygiene, Houston, United States of.

Zokaei, M., Sepehri, M., Zarei, A., & Jafari, F. (2018). Determination of the concentration of heavy metals in medicinal plants and assessment of the risk to health. *Amazonia Investiga*, *7*(16), 335-343.