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Original Article

Change in Some Heavy Metal Concentrations in Forest Trees by Species, Organ, and Soil Depth

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ABSTRACT

Heavy metal pollution is one of the most important environmental problems nowadays, and studies on monitoring and reducing heavy metal pollution are among the popular and high-priority study subjects. It was stated that the most effective instrument in monitoring heavy metal pollution and reducing pollution is the plants. However, the heavy metal accumulation potential remarkably differs among the organs of plants. Within the scope of this study, the concentrations of Cu, Mn, and Al, which are among the most dangerous and important heavy metals for human health, in the soils in which forest tree species *Pinus nigra* Arnold., *Pinus silvestris* L., *Fagus orientalis* Libsky., and *Abies nordmanniana* subsp. *bornmülleriana* Mattf. are grown and analyzed at different soil depths and in leaf, bark, wood, cone, and root organs. As a result, the highest concentrations were found in cone and bark for Cu, leaf for Mn, and root for Al. For this reason, among the elements examined here, it is estimated that Mn is taken into the plant body mainly from the air through leaves, and Al is mainly taken from the soil via roots. The results obtained here suggest that the transfer of all three elements between organs was very limited and that species utilize elements in the soil at different levels. Study results might provide important information about which species can be used in reducing heavy metal pollution in which environment.

Keywords: Aluminum, copper, heavy metal, manganese, plant

Introduction

Natural disasters (earthquakes, floods, fires, hurricanes, tsunamis, tornadoes, volcanic eruptions, landslides, drought, etc.) have been hitting the earth. However, global warming and climate change have been gaining more importance in the twenty-first century. For instance, due to global warming and climate change, plant species have faced increased temperatures in many regions (Çakır & Makineci, 2018; Koç, 2022), resulting in drought stress in plants (Hodzic et al., 2021; Koç & Nzokou, 2022; Koç et al., 2022a). However, human activities, such as generating power, manufacturing goods, deforestation, and increased usage of fossil fuels, are the most significant contributors to the cause of climate change (Lee et al., 2016; Tekin et al., 2022). These activities lead to environmental pollution worldwide.

Environmental pollution, which increased in the last century because of the increasing population, the concentration of population in urban areas, and industrial advancements, has become one of the most important problems worldwide (Elsunousi et al., 2021; Mutlu & Aydın Uncumusaoğlu, 2017). One of the most dangerous and harmful factors in pollution is the heavy metals increasing due to industrial activities (Cesur et al., 2022), mining activities (Abdalmoula et al., 2019; Akburak et al., 2020; Isinkaralar et al., 2022a), traffic (Aricak et al., 2019; Çobanoğlu et al., 2022), and human activities in urban areas (Mutlu & Aydın Uncumusaoğlu, 2018; Turkyilmaz et al., 2020). Chen and Lu (2018) reported that heavy metal pollution in soil increased due to four main sources. Those sources for Xi'an in China were found to be natural sources by 25.04%, traffic by 24.71%, mixed sources by 24.99%, and industrial sources by 25.26%. Similar studies showed that the heavy metal pollution in water (Tokatli et al., 2021; Ucun Ozel et al., 2020), soil (Elajail et al., 2022), and air (Ghoma et al., 2022; Koç et al., 2022b) increased mainly due to human activities.

Heavy metals pose a significant danger to ecosystems and organisms, especially humans (Koç, 2021). Thus, monitoring and reducing heavy metal pollution is among the primary research subjects (Key et al., 2022). It is stated that the most effective instrument used in monitoring the change of heavy metal pollution and reducing

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the pollution was the plants (Karacocuk et al., 2022). The plants grown in locations where the level of heavy metal pollution is high might accumulate the heavy metals from the soil, water, and air in their bodies. Thus, they contribute to reducing heavy metal pollution in such environments (Ancona et al., 2020; Jin et al., 2019; Wei et al., 2021). However, plants have different potentials in terms of heavy metal accumulation in their organs (Sevik et al., 2020; Turkyilmaz et al., 2020). For plants to be effectively used in reducing heavy metal pollution, it is necessary to fill the lack of information in this field. The level of knowledge in subjects such as which metals the plants, which are grown in the same soil, accumulate in which organs, through which ways heavy metals are taken into plant body, and how the heavy metal concentrations vary by depth in soils, where different plants are grown.

In the present study, it was aimed to contribute to making up for the deficiency of information. Within this study's scope, it aimed to determine the change of concentrations of Cu, Mn, and Al, which are widely used in different fields in daily life and might be very dangerous for human and environmental health in different organs of different plants and soil.

Methods

Within the scope of this study, the change of the concentrations of Cu, Mn, and Al elements, which are widely used in different fields and have an increasing concentration for this reason, in plant organs and soils, where different plants are grown, was determined. For this purpose, leaf, bark, wood, cone, and root samples were collected from *Pinus nigra* Arnold., (Pni), *Pinus silvestris* L. (Psi), *Fagus orientalis* Libsky., (Fo), and *Abies nordmanniana* subsp. *bornmülleriana* Mattf. (Abo) species that are grown in a limited region in the Araç district of Kastamonu province (Figure 1), which has similar soil and climate conditions. Since it has no cone, *Fagus orientalis* Libsky. was not included in the study. Branch samples were collected from 1-year-old shoots of species at the end of vegetation season. They were packed and taken to the laboratory. Then, these branches were divided into organs without using metal instruments. Then, all the samples were labeled.

Moreover, under every single tree and by cleaning the litter layer, soil samples were collected from 0–5 cm (upper soil), 20–30 cm (medium depth), to 50–60 cm (deep soil) depths. The study was carried out in three replications for all of the samples. Soils taken to the laboratory were dried in a dry environment for 2 weeks under room conditions. Then, after sieving, they were dried for 2 weeks at 45°C. The same procedure was followed for plant samples, except for the sieving process.

Dried specimens were analyzed for Cu, Mn, and Al by using the ICP-OES device, and the concentrations were determined at the ppb (plant samples) or ppm (soil samples) level. This method has been widely used in the recent period of time in elemental analysis for soil (Cetin et al., 2022) and plant organs (Isinkaralar et al., 2022b). The data obtained were analyzed using Statistical Package for Social Sciences 22.0 package software with Variance Analysis and Duncan's test. The data were interpreted by simplifying and tabularizing.

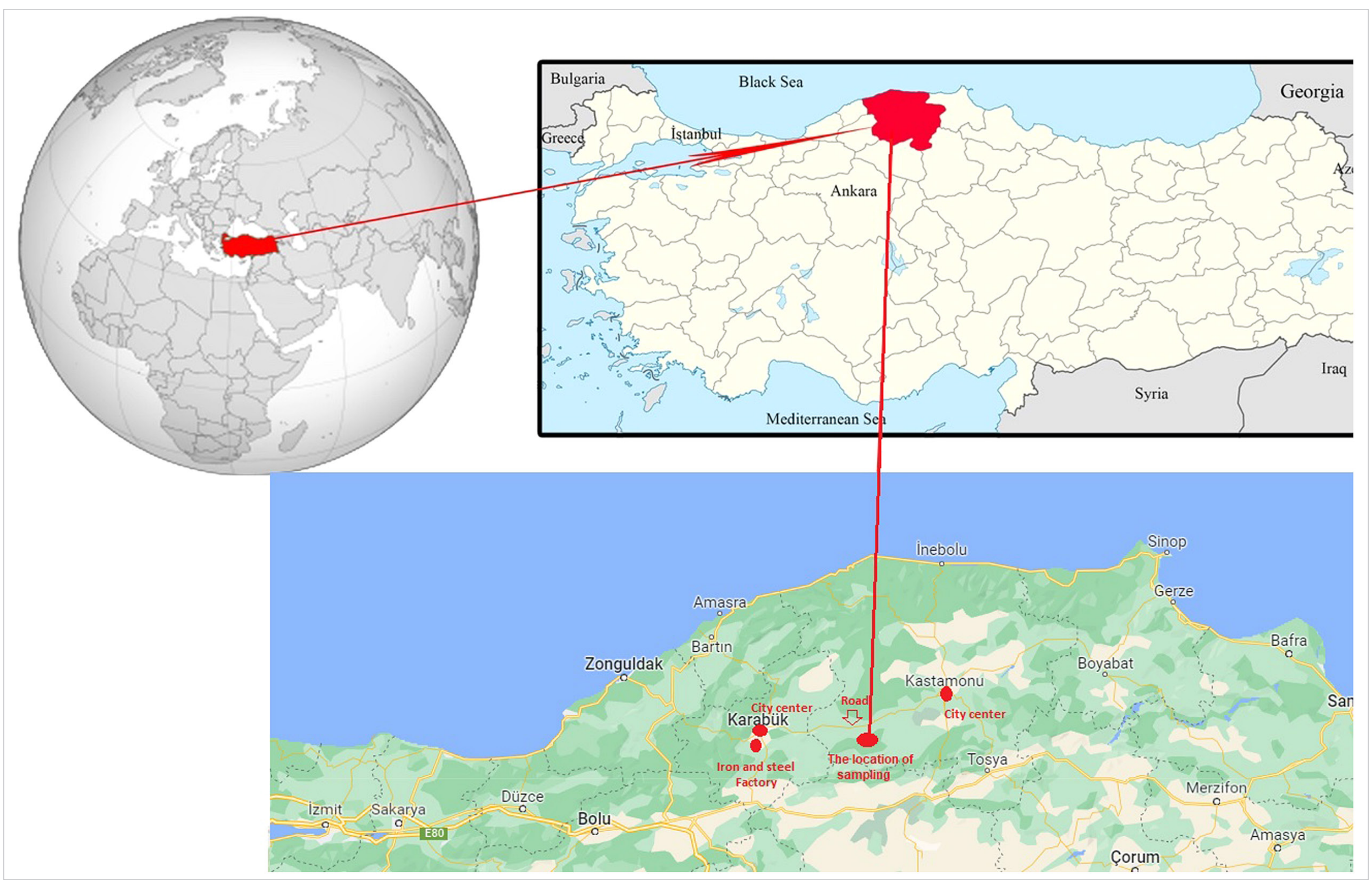

Figure 1.
The Location of Sampling, Iron and Steel Factories, and Main Roads Nearby the Area.

Table 1.
Change of Cu Concentration (ppm) in Soil

	Soil Depth				
Species	Upper	Medium	Lower	*F* Values	Average
Abo	24.11^{ab}	22.75^{ab}	31.12^{a}	2.99^{ns}	25.99^{a}
Pni	26.26^{b}	19.27^{a}	23.05^{a}	0.85^{ns}	22.86^{a}
Psi	44.07^{c}	44.26^{c}	43.90^{b}	0.004^{ns}	44.08^{b}
Fo	13.79^{Aa}	25.72^{Bb}	24.90^{Ba}	5.97**	21.47^{a}
F values	11.12***	33.50***	8.94***		32.83***
Average	27.06	28.00	30.74	0.76^{ns}	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. ***$P \leq .001$; ns = not significant. ppm; parts per million, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

Table 3.
Change of Mn Concentration (ppm) in Soils

	Soil Depth				
Species	Upper	Medium	Lower	*F* Values	Average
Abo	672.94^{c}	630.69^{c}	853.86^{b}	1.66^{ns}	719.16^{c}
Pni	502.41^{b}	380.08^{a}	428.22^{a}	1.37^{ns}	436.90^{b}
Psi	538.44^{bc}	515.08^{b}	502.50^{a}	0.73^{ns}	518.67^{b}
Fo	282.33^{a}	310.13^{a}	378.63^{a}	2.15^{ns}	323.70^{a}
F values	11.65***	12.62***	8.04***		24.91***
Average	499.03	459.00	540.80	1.20^{ns}	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. ***$p \leq .001$; ns = not significant. ppm; parts per million, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

Results

Among the elements examined here, the change of Cu concentration by species and soil depth is presented in Table 1.

Examining the change of Cu concentration in soil specimens, it can be seen that the change by species was statistically significant for all soil depth levels. For all soil depths, Duncan's test showed that the soils where Abo was grown were in the first group, whereas soils where Psi was grown were in the last group. Considering the mean values, soils where Psi was grown were in the first group, and the soils where other species were grown were in the second group. Except for the soils where Fo was grown, there was no statistically significant difference between depth levels in terms of Cu concentration. The change in Cu concentration in plants is presented in Table 2.

As a result of the variance analysis, it was determined that the changes in Cu concentration between all organs (except for wood) by species and between species (except for Fo) by organ were statistically significant ($p < .05$). Examining the mean values, the results achieved using Duncan's test yielded two groups; Abo was in the second group, and the other species were in the first group. Examining by organs, the lowest Cu values were found in wood, whereas the highest values were generally found in cones. It was determined that Cu concentration was remarkably high in Abo cones. The change in Mn concentration by species and soil depth levels is presented in Table 3.

As seen in Table 3, the results obtained from the variance analysis showed that the change of Mn concentration by soil depth was statistically non-significant ($p > .05$). The change of Mn concentration between soils, where different species were grown, was statistically significant at the confidence level of 99.9% ($p < .001$). By examining the values, for all soil depth levels, it was found that the lowest concentrations were found in soils where Fo was grown, whereas the highest values were found in soils where Abo was grown. The change in Mn concentration in plants is presented in Table 4.

The change in Mn concentration was found to be statistically significant (in all species by organ and all organs by species). By examining the values, it can be stated that the highest values were found in Abo as a specie and leaves as an organ. On the other hand, Mn levels found in wood and cone samples were at very low levels. The change in the concentrations of Al, the last element examined here, in soil samples by species and depth level is presented in Table 5.

Table 2.
Change of Cu Concentration (ppb) in Plants

	Organ						
Species	Leaf	Bark	Cone	Wood	Root	*F* Values	Average
Abo	947.80^{Ab}	4194.08^{Cb}	4728.77^{Cc}	467.00^{A}	2876.04^{Bc}	18.24***	2977.47^{b}
Pni	265.26^{Aa}	1102.43^{Aa}	2672.26^{Bb}	242.86^{A}	1011.19^{Aab}	6.04**	1259.99^{a}
Psi	748.86^{ab}	437.66^{a}	182.53^{a}	UnLim	1987.86^{bc}	10.76***	1103.80^{a}
Fo	1820.13^{bc}	2001.63^{a}	–	577.66	874.00^{ba}	2.59^{ns}	1407.03^{a}
F values	9.34***	10.87***	16.28***	4.31^{ns}	7.24**		12.34***
Average	1081.56^{AB}	2403.50^{CD}	3285.56^{D}	429.17^{A}	1748.73^{BC}	9.83***	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. **$p < .01$; ***$p \leq .001$; ns = not significant. ppb; parts per billion, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

Table 4.
Change of Mn Concentration (ppb) in Plants

	Organ						
Species	Leaf	Bark	Cone	Wood	Root	*F* Values	Average
Abo	382 402.06^{Bb}	147 514.42^{Ab}	101 968.44^{Ab}	42 518.66^{Ab}	110 275.00^{Ab}	11.80***	156 935.72^{b}
Pni	41 463.84^{Ba}	8504.17^{Aa}	13 979.55^{Aa}	5842.62^{Aa}	9570.24^{Aa}	17.83***	15 872.08^{a}
Psi	94 182.20^{Ba}	29 933.37^{Aa}	9576.66^{Aa}	12 344.71^{Aa}	90 435.44^{Bb}	36.59***	47 294.47^{a}
Fo	79 271.13^{Ca}	22 170.28^{Ba}		7689.17^{Aa}	26 351.55^{Ba}	41.50***	33 870.53^{a}
F values	16.93***	22.47***	10.38**	47.77***	26.44***		23.46***
Average	149 329.81^{B}	52 030.56^{A}	41 841.55^{A}	17 098.79^{A}	59 158.06^{A}	10.28***	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. **$p < .01$; ***$p \leq .001$; ns = not significant. ppb; parts per billion, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

As a result of the variance analysis, it was determined that the change in Al concentrations by plant species was statistically non-significant in deep soils but statistically significant in other depth levels. The results of Duncan's test showed that the soils where Fo was grown were in the first group, whereas the soils where Psi was grown were in the last group. The change by depth level was found to be statistically significant only in soils where Abo and Fo were grown; in those samples, the lowest values were found in upper soil, and the highest values were found in deep soil. The change in Al concentration in plants is presented in Table 6.

Table 5.
Change of Al Concentration (ppm) in Soils

	Soil Depth				
Species	Upper	Medium	Lower	*F* Values	Average
Abo	6091.77^{Aa}b	6082.27^{Aa}	6941.52^{B}	4.40*	6371.86^{ab}
Pni	6729.36^{b}	6299.36^{a}	6053.25	0.74^{ns}	6360.65^{ab}
Psi	7015.30^{b}	6943.75^{b}	6711.30	0.76^{ns}	6890.12^{b}
Fo	4920.69^{Aa}	6306.27^{Ba}	6415.41^{B}	6.99**	5880.79^{a}
F values	4.89**	11.56***	2.10^{ns}		5.07**
Average	6189.28	6407.91	6530.37	1.06^{ns}	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. **$p < .01$; ***$p \leq .001$; ns = not significant. ppm; parts per million, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

As a result of the variance analysis, the change in Al concentration was found to be statistically significant (in all species by organ and all organs by species). Given the values, the highest values were found in Abo and Fo as species and roots as an organ. The lowest values were found in wood and, contrary to the other elements, the values found in leaves were much lower in comparison to the other elements.

Discussion, Conclusion, and Recommendations

At the end of the present study, the change of elements examined here by soil depth was found to be statistically non-significant in general. However, the element concentrations obtained from the soils where different species are grown were found to be statistically significant. Considering the soil specimens, the lowest values were found in samples, where Psi was grown, for Cu and Al, and in samples, where Abo was grown, for Mn. Considering the organs, the lowest Cu and Al concentrations were found in wood samples, while the highest Cu concentration was found in cones and that of Al in roots. The concentrations found in leaves were at very low levels. Analyzing the Mn concentrations, the highest values were found in Abo as a species and leaves as organs.

Table 6.
Change of Al Concentration (ppb) in Plants

	Organ						
Species	Leaf	Bark	Cone	Wood	Root	*F* Values	Average
Abo	91 964.55^{Ab}	185 692.62^{Bc}	60 712.75^{Ab}	7183.84^{Aa}	362 019.08^{Cb}	21.21***	141 514.57^{b}
Pni	63 692.46^{Bc}a	99 555.84^{Cb}	65 030.68^{BC}b	11 595.35^{Ab}	44 644.40^{Ab}a	4.05**	56 903.75^{a}
Psi	60 274.22^{Aa}	26 855.28^{Aa}	29 465.68^{Aa}	13 238.59^{Ab}	243 982.62^{Ba}b	6.20**	74 763.28^{ab}
Fo	98 449.40^{Ab}	34 501.62^{Aa}b	–	8692.08^{Aa}	408 684.86^{Bb}	9.46***	137 581.99^{b}
F values	20.69***	9.78***	9.54**	8.06***	4.16*		3.36*
Average	78 595.16^{B}	86 651.34^{B}	51 736.37^{B}	10 177.47^{A}	264 832.74^{C}	19.58***	

Different letters, such as a, b, and c, mean that Cu concentration significantly ($p < .05$) differed between soil depth and species. Lowercase letters indicate vertical direction, whereas uppercase letters represent horizontal direction. *$p \leq .05$; **$p < .01$; ***$p \leq .001$; ns = not significant. ppb; parts per billion, Pni; *Pinus nigra. Psi; Pinus silvestris. Fo; Fagus orientalis* Abo; *Abies nordmanniana* subsp. *bornmülleriana*

The intake of heavy metals into the plant body occurs through absorption via roots, from the air via leaves, and directly into the body parts (Chen et al., 2021). Plant leaves are the organs having the highest level of contact and interaction with air. In leaves, the air exchange occurs through stomas and, thus, air metals in the air might be taken into the plant body (Karacocuk et al., 2022). In the case of heavy metal intake via leaves, it would be normal if the highest concentration was found in leaves (Sulhan et al., 2022). However, the heavy metals absorbed from the soil are expected to be at higher concentrations in roots and body parts, which have no contact with air. As a result of the present study, the highest concentrations were found in cones and bark for Cu, leaves for Mn, and roots for Al. Thus, it is thought that a higher level of Mn intake occurred from the air via leaves, and a higher level of Al intake occurred from the soil via roots.

The elements examined here can be very harmful to human and environmental health. Al is one of the important and widespread elements, and it causes Alzheimer's disease by causing allergic reactions in the body and affecting the neurologic system (Çelik, 2014; Key et al., 2022). Cu, which is a very poisonous element, might cause various symptoms in humans, such as nausea, stomachache, vomiting, and diarrhea. A low level of copper ion intake might cause liver cirrhosis, Wilson's disease, systematic rheumatic diseases, and kidney diseases, whereas a high level of intake might cause leukemia (Cetin et al., 2020). Mn might cause hallucinations, tiredness, sleeplessness, weakness, dysmnesia, and nerve injury among humans. Moreover, it can also cause Parkinson's disease, pulmonary embolism, and bronchitis (Ozel et al., 2021; Yayla et al., 2022). Because of these reasons, the elements examined here are in the primary pollutants list of ATSDR (Agency for Toxic Substances and Disease Registry) (Badea et al., 2018).

Because of their environmental effects, monitoring the concentrations of heavy metals in air and soil and reducing their concentrations (in case they exceed the damage thresholds) are among the primary research subjects (Aricak et al., 2019). Plants are used in environment-friendly biotechnology, called phytoremediation, in order to reduce heavy metal pollution in the air, water, and soil (Gawronski et al., 2017). However, plants' potential for heavy metal accumulation differs between the organs (Sevik et al., 2020), and thus, it is necessary to determine which plant species separately and organs would be the most effective in eliminating which heavy metal from which environment.

The most important problem in studies to be carried out on this subject is that the environmental conditions cannot be equalized/leveled. As it knows, plants can have desired growth in their optimum conditions. However, when plants face unfavorable growth conditions, such as lack of water or fertilization, their growth is hindered in their natural areas, plantation sites, and marginal lands (Kulaç and Özkuru, 2021; Shults et al., 2020). Plant growth and development also are differed by environmental stresses, such as cold stress (Yildiz et al., 2014), drought stress (Seleiman et al., 2021), biotic and abiotic stress (Aykan et al., 2022; Kesik and Kabakci, 2022; Özel et al., 2022), and heavy metal stress (Ghori et al., 2019). Plant development is shaped by the mutual interaction between genetic structure and environmental conditions, and many environmental factors are involved in this process (Tekin et al., 2022; Varol et al., 2022). Plants' heavy metal accumulation potential is related to plant habitus and development (Cesur et al., 2022). For this reason, all the environmental factors influencing plant development affect the heavy metal accumulation potential of plants (Savas et al., 2022). Thus, it is recommended to carry out studies on this subject in controlled environments and, if not possible, in areas having environmental conditions as similar as possible. The present study is important since it can be a model for future studies.

Using the results achieved here, it can be decided which species should be used in reducing heavy metal pollution in which environment. For instance, Abo, in which the highest Mn concentrations were found in both leaves and roots, can be used in reducing Mn pollution. Since the highest Cu concentration in leaves was found in it, Fo can be used in reducing Cu pollution in the air. Abo can be used in reducing Cu pollution in the soil since the highest Cu concentration in roots was found in this species.

In studies examining heavy metals, it is reported that there was a significant lack of knowledge about the transfer of heavy metals between the organs during the period starting from the intake into the plant body (Shahid et al., 2017). In the present study, the concentrations of all three elements differed between the organs of the same species. It suggests that the elements examined here had limited transfer between the organs.

Moreover, it was also concluded in the present study that element concentrations were at different levels in different soils where different plant species are grown. The area where the present study was carried out is a level area. Since it has formed on the same bedrock, the elemental contents of the soils were estimated to be similar. The change in the elemental content of soils where different species are grown indicates that different species use different elements at different levels. In particular, the difference between plant species' elemental concentrations in roots corroborates this conclusion.

Availability of Data and Materials: The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – H.S., B.A.; Design – H.S., R.E.; Supervision – H.S., B.A., M.C.; Resources – H.S., R.E.; Materials – R.E.; Data Collection and/or Processing – M.C., B.A., R.E., H.S.; Analysis and/or Interpretation – H.S., B.A., R.E., M.C.; Literature Search – M.C., B.A., R.E.; Writing Manuscript – H.S., R.E.; Critical Review – H.S., B.A., M.C., R.E.

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