Determination of Sixteen Woody Species' Ability to Sequester Sr, Mo, and Sn Pollutants

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This study aimed to determine the most suitable woody species that can be used to reduce the pollution of Sr, Mo, and Sn, which are heavy metals that are harmful to the ecosystem and human and environmental health. Within the study's scope, samples were taken from the wood parts of 16 woody species growing under similar conditions in Düzce province, which is among the five cities with the most polluted air in Europe. The wood part is the largest organ of higher plants in terms of mass; it traps heavy metals within itself for many years and can remove heavy metals to a great extent. Therefore, plants with a high potential for heavy metal accumulation in the wood part are among the most suitable plants for phytoremediation studies. The study determined Sr, Mo, and Sn concentrations in the wood parts of 16 tree species *via* inductively coupled plasma optical emission spectroscopy and compared them using statistical methods. Results indicate that *Robinia pseudoacacia* and *Cedrus atlantica* species were suitable for reducing pollution by Mo and Sn, while *Platanus orientalis* and *Populus alba* species were suitable for reducing Sr pollution.

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INTRODUCTION

It is frequently stated that many of today's most important problems worldwide have emerged due to industrial and technological advancements in the last century. Global climate change, urbanization, and pollution, which are now defined as the most significant and irreversible problems on a global scale, have emerged because of this process. Specifically, the workforce required in the industrial field has caused the population to gather in certain areas, which has given rise to the problem of urbanization (Dogan *et al.* 2023; Erturk *et al.* 2024). Excessive use of fossil fuels to generate the energy needed to meet the needs of industry and people has led to an increase in various gases in the atmosphere, impaired atmospheric gas balance, and ultimately global climate change (Tekin *et al.* 2022; Özel *et al.* 2024). Mining activities to provide the raw materials required for industrial activities and the processing of products have led to a rapid increase in environmental pollution (Istanbullu *et al.* 2023; Kuzmina *et al.* 2023).

Among the above-mentioned problems, urbanization and global climate change are now considered irreversible (Gur *et al.* 2024). Pollution has become a global problem that threatens all living beings and ecosystems.

Air pollution, in particular, has reached such serious dimensions that it is stated that approximately 2.5 million living spaces across Europe are polluted, 90% of the world's population breathes polluted air, and air pollution causes more than 4 million premature births and approximately 7 million deaths worldwide every year (Ghoma *et al.* 2023; Isinkaralar *et al.* 2023; WHO 2024). Among the air pollution components, those that pose the most serious threat to human and environmental health are heavy metals. It is indicated that heavy metals, some of which can be harmful, toxic, and fatal to humans even at low concentrations, can be harmful at high concentrations, albeit they are necessary as nutrients for living things (Ucun Ozel *et al.* 2019; Key *et al.* 2022). Recent studies reveal that the concentrations of heavy metals have increased significantly in soil (Rashid *et al.* 2023; Xiang *et al.* 2024), water (Uncuosmanoglu and Mutlu 2021; Mutlu 2021), and air (Guney *et al.* 2023) as a result of anthropogenic activities. Moreover, releasing heavy metals into nature causes pollution throughout the receiving environments. For example, heavy metals released into the air descend to the soil with the effect of gravity, and after a while, heavy metals in the air mix with rainwater into soil and water resources. Heavy metals in water and soil are exchanged between receiving environments (Adnan *et al.* 2024; Swain 2024). Thus, all living things and ecosystems in nature are affected by this pollution. Moreover, this situation is shown to be responsible for processes affecting all living things in the world, such as global climate change (Tekin *et al.* 2022; Canturk *et al.* 2024; Dogan *et al.* 2024). Some of the heavy metals can be extremely harmful and fatal for living organisms, even at very low concentrations (Key *et al.* 2022; Sevik *et al.* 2024).

Strontium (Sr) is one of the most toxic heavy metals for the environment and human health. Some compounds of Sr, which is harmful to human health even at low concentrations, can cause lung cancer and accumulate in the body throughout life, causing serious problems that may even result in sudden death (NIH 2024). Tin (Sn), one of the elements threatening human health, is a potential clastogen. When inhaled, it causes shortness of breath, coughing, and wheezing, may lead to dizziness, balance disorder, amnesia, and headache in the nervous system, and may cause vasodilation, hypotension, and heart failure. While it causes diarrhea, vomiting, muscle weakness and paralysis, anemia, and severe damage to the liver and kidneys in humans, fatal cases have been reported after its ingestion in large amounts (Sharma and Kumar, 2020). Molybdenum (Mo) is a micronutrient and an essential trace element that acts as a cofactor for more than 50 enzymes. However, it is stated that coal combustion wastes are very rich in Mo, and Mo toxicity poses a potential risk for humans due to the widespread use of Mo in ceramics, glass, contact lens solutions, metallurgy, lubricants, pigments, catalysts, electronics, and cosmetic products (Tambat *et al.* 2023). Moreover, it is stressed that the heavy metals in question can be much more harmful and fatal if taken into the body through inhalation (Jaishankar *et al.*, 2014). Hence, reducing heavy metal pollution in the air is one of the priority research topics.

Many studies have determined that heavy metals accumulate at different levels in different plant organs (Aricak *et al.* 2019; Ghoma *et al.* 2022; Karacocuk *et al.* 2022; Guney *et al.* 2023; Öztürk Pulatoğlu 2024). It was generally determined that heavy metals accumulated most in the outer bark, roots, and leaves and least in the wood (Karacocuk *et al.* 2022; Erdem *et al.* 2023). This situation is primarily related to the entry route of heavy metals into the plant and their transportation within the plant. Heavy metals can enter the plant body directly from the soil through the roots, from the air through the leaves, or from the stem parts (Cobanoglu *et al.* 2023). Therefore, heavy metals in the air primarily contact the leaves or bark, and heavy metals in the soil contact the roots. On the other hand, the wood part does not have direct contact with soil or air and heavy metals must be transported and accumulated within the plant structure. Therefore, the wood is generally the organ with the lowest concentration of heavy metals (Şevik *et al.* 2024). This may be due to different ion exchange capacities of xylem in different tree species. The amount of metal ions adsorbed onto biomaterials is governed by the ion exchange capacity (IEC) (Hubbe *et al.* 2011). For one mole of metal (Sr or Cd) sorbed, there is one mole of Ca displaced (Crist *et al.* 2003). In other words, each adsorbed metal ion is predicted to displace a number of other ions, such as sodium or hydrogen, corresponding to the valence of the metal species (Hubbe 2013). Most cellulosic materials have the ability to bind with positively charged ions (Hubbe *et al.* 2022). The plant cell wall, which is a part of the apoplast, is a complex and multifunctional system. Due to the presence of ion-exchange groups, the plant cell wall controls the composition of periplasmic medium as well as transport of ions and metabolites across the plasma membrane. Primary plant cell walls are composed mostly of polysaccharides (cellulose, hemicelluloses, and pectins) which account for up to 90% plant cell wall dry weight (Meychik *et al.* 2017). In general, hardwoods contain more hemicellulose than softwoods (Baeza and Freer 2000). Softwoods are those woods that come from gymnosperms, and hardwoods are woods that come from angiosperms (Popescu *et al.* 2011). Therefore, different species have different levels of heavy metal accumulation capacity and this has been demonstrated in numerous studies (Karacocuk *et al.* 2021; Koc *et al.* 2024).

Species that can accumulate these heavy metals, particularly in the wood part, are the most suitable for this purpose because the wood part is the largest organ of higher plants in terms of mass; it traps heavy metals within itself for many years and can remove heavy metals from the air to a significant extent (Key *et al.* 2023). Heavy metals can accumulate more in organs such as leaves and bark than in wood. However, these organs dry up and fall off in a short time, and the heavy metals trapped in them are released back into nature as a result of decay. By contrast, the heavy metals accumulated in the trunk wood are kept away from nature as long as the trees live, which can be thousands of years for some species. In addition, after the trees are cut down, the heavy metals accumulated in the wood are kept away from nature for many years by using the wood in furniture, construction, *etc*. Therefore, species that can accumulate heavy metals in the wood are beneficial in phytoremediation studies (Ateya *et al.* 2023; Key *et al.* 2023).

However, the most suitable species that can be used for this purpose should be determined separately for each element. This study aimed to determine the potential of some tall trees grown frequently in urban areas to accumulate Sr, Sn, and Mo heavy metals in their wood parts.

Until now, many studies have been conducted to determine heavy metal concentrations both in different organs of trees (Koc *et al.* 2024) and in other parts of the wood of the same tree (Sevik *et al.* 2024). However, these studies do not provide sufficient information on using high-structure trees for phytoremediation. Because the most suitable organ for phytoremediation studies is the trunk wood and studies on trunk wood have generally been conducted on a single or a few species. The determination of heavy metal concentrations in the stem wood of as many species as possible growing in similar ecological conditions in the same area will provide much more helpful information to the field of application. In this respect, this study has a special importance in terms of the information it provides to the application.

EXPERIMENTAL

Materials and Methods

The present study used wood samples taken from the main trunks of woody species growing in Düzce city center. Düzce is one of the five cities with the most polluted air in Europe (Koc *et al.* 2024). The tree species subject to the study are frequently used in landscape surveys, especially in Türkiye and Europe. Table 1 lists the species used in the study. In the region where the study was conducted, the trees used in the study can thrive. The species to reduce heavy metal pollution should have two important features. The first is that the trees are not damaged by heavy metal pollution and continue their healthy growth. The trees used in the study were selected because of these characteristics. The other feature that should be present in the species to reduce heavy metal pollution is the ability to accumulate as much heavy metals as possible. These characteristics of the trees were also evaluated within the scope of the study.

Table 1. Tree Species Used in the Study

No.	Species
1	*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe
2	*Juglans nigra* L.
3	*Gleditsia triacanthos* L.
4	*Cupressus arizonica* Greene
5	*Prunus avium* L.
6	*Populus alba* L.
7	*Platanus orientalis* L.
8	*Abies nordmanniana* (Steven) Spach
9	*Tilia tomentosa* Moench
10	*Robinia pseudoacacia* L.
11	*Fraxinus excelsior* L.
12	*Pinus pinaster* Aiton
13	*Cupressus sempervirens* L.
14	*Picea orientalis* (L.) Peterm.
15	*Pseudotsuga menziesii* Franco
16	*Cedrus atlantica* G.Manetti

The materials used in the study were obtained during a harvest in the region, and the trees not foreseen to be cut were not harmed. The trees were felled entirely on the same day during this harvest. However, although this method provides the healthiest sample, it is not a sustainable method that can be used at all times. Therefore, in similar studies, taking samples from the trees with the help of a drill is recommended. However, samples must be taken from the main trunk because the main trunk is the largest part of the tree by volume, much larger than all other parts of the trunk combined, and the structure of the trunk wood and, therefore, the potential for heavy metal accumulation is different from that of the branch wood.

Trunk stump samples were taken from the main trunks of the trees subject to the study at a height of approximately 50 cm from the ground. Samples were taken from five points in three directions on the stumps. Samples taken in the form of sawdust were placed in glass Petri dishes and left to dry for 15 days, then dried in an oven at 45 °C for a week. A total of 0.5 g of the dried samples were then mixed with 6 mL of 65% HNO_3 and 2 mL of 30% H_2O_2 were added and placed in a microwave oven. The samples that became a solution were taken into volumetric flasks and completed to 50 mL with ultrapure water, then analyzed with the Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES) device (Spectro, Kleve, Germany), and Sr, Mo, and Sn concentrations were calculated by multiplying the obtained values by the dilution factor. The method employed in the study has been frequently used in studies carried out on this subject in recent years (Çebi Kilicoglu 2024; Şevik *et al.* 2024).

Variance analysis was applied to the data obtained, and Duncan's test was applied for the factors with statistically significant differences at least at a 95% confidence level ($P < 0.05$), and the obtained data were simplified, tabulated, and interpreted.

RESULTS

Variation in Sr (ppb) concentrations on a tree species basis are shown in Table 2.

Table 2. Variation in Sr (ppb) Concentrations on a Tree Species Basis

Species	Minimum	Maximum	St Deviation	Average
Pinus nigra	2760	4240	530	3420
Juglans nigra	6260	45200	15500	14700
Gleditsia triacanthos	5320	9630	1440	7420
Cupressus arizonica	7700	9880	816	8560
Prunus avium	7970	12000	1490	10100
Populus alba	8570	19700	3780	14300
Platanus orientalis	24000	42500	6450	33600
Abies nordmanniana	4440	5090	218	4670
Tilia tomentosa	6210	9140	1070	7110
Fraxinus excelsior	6600	13300	1690	8710
Pseudotsuga menziesii	3020	5290	494	4090

As can be seen from the tabulated values, the Sr concentration remained below the detectable limits in *Robinia pseudoacacia*, *Pinus pinaster*, *Cupressus sempervirens*, *Picea orientalis*, and *Cedrus atlantica* woods. When other species are evaluated, it is apparent that Sr concentration ranged between 3420 ppb and 33600 ppb on a species basis. In all species, the lowest value was obtained in *Pinus nigra* wood, whereas the highest value was obtained in *Platanus orientalis* wood. The next highest values were obtained in *Populus alba* wood with 14700 ppb and *Prunus avium* wood with 10100 ppb. From the results, it is noteworthy that the lowest Sr concentrations were obtained in coniferous species. Furthermore, the species in which Sr level remains below detectable limits were coniferous or scale-leaved species, except for *Robinia pseudoacacia*. Table 3 shows the variation in Mo concentrations on a species basis.

As can be seen from the values in the table, Mo concentration in *Picea orientalis* wood remained below the detectable limits. In other species, the lowest values were obtained in *Fraxinus excelsior* with 106 ppb and *Tilia tomentosa* with 278 ppb. The highest values were acquired in *Robinia pseudoacacia* wood with 14100 ppb and *Cedrus atlantica* wood with 6490 ppb. The Mo concentration determined in the wood of species other than these species was in a very narrow range (2130 ppb to 4650 ppb). Table 4 presents the variation in Sn concentrations on a species basis.

Table 3. Variation in Mo (ppb) Concentrations Based on Tree Species

Species	Minimum	Maximum	St Deviation	Average
Pinus nigra	2360	2650	90	2470
Juglans nigra	1930	2330	160	2130
Gleditsia triacanthos	2420	3180	250	2700
Cupressus arizonica	2340	2620	80	2510
Prunus avium	2450	2600	50	2520
Populus alba	2500	2860	110	2680
Platanus orientalis	3080	3660	190	3440
Abies nordmanniana	2500	2680	40	2610
Tilia tomentosa	200	330	40	278
Robinia pseudoacacia	13200	14700	460	14100
Fraxinus excelsior	30	170	50	106
Pinus pinaster	540	5730	2030	2920
Cupressus sempervirens	850	6520	1940	4650
Pseudotsuga menziesii	1600	4930	1110	2660
Cedrus atlantica	6170	6810	190	6490

Table 4. Variation in Sn (ppb) Concentrations Based on Tree Species

Species	Minimum	Maximum	St Deviation	Average
Pinus nigra	2990	4170	370	3550
Juglans nigra	2180	3310	320	2940
Gleditsia triacanthos	2870	3540	180	3280
Cupressus arizonica	2810	3610	270	3230
Prunus avium	3640	4600	330	4000
Populus alba	3350	3840	160	3640
Platanus orientalis	3690	4320	190	4040
Abies nordmanniana	3100	3930	250	3390
Tilia tomentosa	270	550	90	430
Robinia pseudoacacia	15200	16500	470	16000
Fraxinus excelsior	68	270	56	140
Pinus pinaster	800	2340	590	1700
Cupressus sempervirens	590	6390	2250	4110
Picea orientalis	1850	2070	110	1950
Pseudotsuga menziesii	1870	7770	2800	4230
Cedrus atlantica	6860	7700	220	7330

Sn concentration accumulated within detectable limits in all species subject to study. The lowest average values were obtained in *Fraxinus excelsior* (140 ppb), *Tilia tomentosa* (430 ppb), and *Pinus pinaster* (1700 ppb) wood, whereas the highest values were acquired in *Robinia pseudoacacia* (16000 ppb), *Cedrus atlantica* (7330 ppb), and *Pseudotsuga menziesii* (4230 ppb) wood. There was a difference of approximately 115 times between the lowest and highest values.

CONCLUSION AND DISCUSSION

This study determined that all three heavy metals examined varied at a statistically significant level on a tree species basis. This is an expected result because numerous studies conducted to date have revealed that heavy metal accumulation potential can vary significantly based on tree species (Cobanoglu *et al.* 2023; Sulhan *et al.* 2023).

As a result of the analyses, the highest Sr concentration was obtained in *Platanus orientalis* wood with 33600 ppb and *Populus alba* wood with 14700 ppb. These values are quite high compared to studies conducted to date. Erdem (2023) determined Sr concentration in different species and found that the average Sr concentration in wood was 1880 ppb in *Pinus pinaster*, 3210 ppb in *Cupressus arizonica*, 5320 ppb in *Picea orientalis*, 2340 ppb in *Cedrus atlantica*, and 1200 ppb in *Pseudotsuga menziesii*. Karacocuk (2021) found that Sr concentrations in the woods of plants collected from areas with heavy traffic were 10900 ppb in *Robinia pseudoacacia*, 47100 ppb in *Platanus orientalis*, 14900 ppb in *Acer negundo*, 7480 ppb in *Ulmus minor*, and 18800 ppb in *Nerium oleander*. The present study also demonstrates that *Platanus orientalis* is a good phytoremediation plant for Sr.

The highest Mo concentrations in this study were obtained in *Robinia pseudoacacia* wood with 14100 ppb and *Cedrus atlantica* wood with 6490 ppb. Molybdenum is one of the least studied heavy metals. Hence, no literature information could be found to compare the study results.

Tin is one of the most harmful elements to human and environmental health. Within the study's scope, the highest Sn concentrations were obtained in the wood of *Robinia pseudoacacia* (16000 ppb), *Cedrus atlantica* (7330 ppb), and *Pseudotsuga menziesii* (4230 ppb). Cetin *et al.* (2023) found that the average Sn concentration in wood was 1410 ppb in *Pinus pinaster*, 2110 ppb in *Cupressus arizonica*, 1530 ppb in *Picea orientalis*, 1880 ppb in *Cedrus atlantica*, and 2070 ppb in *Pseudotsuga menziesii*. The Sn concentrations obtained in this study are considerably higher.

The most harmful and dangerous element evaluated in this study is Sr, and it is an element on ATSDR's substance priority list due to its potential harms (Savas *et al.* 2021). The highest Sr concentrations were found in broad-leaved species, while Sr concentrations in coniferous species were quite low. Furthermore, Sr concentrations remained below detectable limits in the wood of *Pinus pinaster*, *Cupressus sempervirens*, *Picea orientalis* and *Cedrus atlantica*, which are coniferous or scale-leaved species. The amount of metal ions adsorbed onto biomaterials is governed by the ion exchange capacity (Hubbe *et al.* 2011). Softwoods are those woods that come from gymnosperms (Popescu *et al.* 2011). Softwoods generally contain less hemicellulose than softwoods (Baeza and Freer 2000). In this case, the potential for Sr accumulation in the wood of species may be related to the IEC and hence the amount of hemicellulose.

The highest Mo and Sn concentrations were obtained in *Robinia pseudoacacia* and *Cedrus atlantica* wood. These results demonstrate that plants have different levels of heavy metal accumulation potential. This situation has been frequently emphasized in studies conducted to date, and it has been stressed that the appropriate species should be determined separately on a heavy metal basis to monitor variation in the pollution of each heavy metal and reduce its content (Yayla *et al.* 2022).

As a result of the study, it was determined that heavy metal accumulation was quite high, especially in species such as *Robinia pseudoacacia*, *Cedrus atlantica*, and *Platanus orientalis*. This situation is primarily related to the anatomical and morphological structure of species. Especially the leaf and bark structure is one of the most important factors in the entry of heavy metals into the air into the plant body. Heavy metals can enter the plant body from the soil *via* roots, from the air *via* leaves, and by direct adsorption from the stem sections (Wani *et al.* 2018; Chen *et al.* 2021). Heavy metals in the air enter the leaves through stomata or adhere to stem sections such as leaves and bark through particulate matter. Studies show that heavy metals in the air adhere to particulate matter and infect particulate matter with heavy metals. Particulate matter containing heavy metals can adhere to plant organs and enter the plant body through stem parts. The fact that the leaves are large, hairy, and dense and the bark is rough causes a large amount of particulate matter to adhere to these organs and infect the organs with heavy metals (Cesur *et al.* 2022). Here the word "dense" has the meaning used in forestry to denote dense packing and the ability to block air movement. As a result of the study, it was determined that the highest heavy metals were found in trees with these characteristics.

Within the scope of the study, the aim was to determine suitable species to reduce heavy metal pollution in the air. Heavy metals can enter the plant body from air, soil or water through roots. The area where the study was conducted is an area that can be considered quite homogeneous in terms of soil and, therefore, water. In addition, Sr, Mo and Sn concentrations were below the detectable limits as a result of heavy metal analysis in soils. This result can be interpreted as the trees effectively draw water into their root systems, which reduces the metal content of the soil. This combination may explain the low ion levels in the soil. This indicates that the accumulation of Sr, Mo, and Sn in plants is airborne. In addition, studies conducted in the region showed that there were large differences between the concentrations of heavy metals such as Cr (Koc *et al.* 2024), Pd (Sevik *et al.* 2024), Sn (Cetin *et al.* 2023), and Tl (Canturk *et al.* 2023) in wood annual rings formed in different periods. It was stated that these differences were due to the change in heavy metal pollution in the air during the process.

The transport of elements within the wood part is largely related to the cell structure and especially the cell wall (apoplastic pathway) (Wani *et al.* 2018). The wood part is the plant's organ that lacks direct contact with the air, and therefore, heavy metal accumulation in wood is considerably lower than in other organs (Koç *et al.* 2024). This can be attributed to different ion exchange capacities of different tissues in the tree. The amount of ion-exchange groups in the cell wall differs not only between plant species but also between tissues within the same plant (Meychik *et al.* 2021). However, in regions where annual rings are formed, wood is the most suitable biomonitoring for checking the change in heavy metal pollution from past to present (Cesur *et al.* 2022). Furthermore, because it is the largest organ of plants in terms of mass, trees species that can accumulate heavy metals in the wood part are very suitable for phytoremediation (Koc *et al.* 2024; Şevik *et al.* 2024). Nevertheless, plants that can be used for phytoremediation purposes must be able to accumulate heavy metals in the wood part; in other words, heavy metals must be able to enter the wood part.

In this study, the highest values were obtained for Sr (33600 ppb) in *Platanus orientalis* wood, Mo (14100 ppb), and Sn (16000 ppb) in *Robinia pseudoacacia* wood. These values are quite high compared to the values obtained in similar studies. Erdem (2023) obtained the highest average Sr concentrations in *Picea orientalis* with 5320 ppb in his research on 5 different species. Cetin *et al.* (2023) reported that the average Sn concentration in the wood of five different species varied between 1410 ppb and 2110 ppb, and the highest concentrations were obtained in *Cupressus arizonica.* However, the values obtained in some species evaluated in this study are much higher than the values obtained in other studies. In addition, heavy metal concentrations in some species in this study were below the determinable limits. This situation reveals the importance of evaluating many species in similar studies.

The potential of plants to absorb and accumulate heavy metals depends on numerous factors, such as organ structure, weather conditions, and plant habitus, in addition to the heavy metal's structure and its interaction with the plant (Savas *et al.* 2021). These factors are also linked to other factors. For example, plant physiology is shaped under the influence of genetic structure (Yigit *et al.* 2021; Hrivnak *et al.* 2024) and environmental conditions (Yigit *et al.* 2023; Özdikmenli *et al.* 2024). Hence, all factors impacting plant physiology also influence the entry of heavy metals into the plant and their accumulation, and plant physiology is shaped by the interaction of many inter-influencing factors, such as genetic structure (Kurz *et al.* 2024), edaphic (Kravkaz Kuscu *et al.* 2018), and climatic factors (Varol *et al.* 2022; Aricak *et al.* 2024), and stress factors (Ozel *et al.* 2021; Koc and Nzouko 2022). Therefore, many of these factors directly and indirectly impact the heavy metal accumulation potential of plants. However, information about this complex mechanism is still limited (Isinkaralar *et al.* 2022).

RECOMMENDATIONS

This study has determined that *Robinia pseudoacacia* and *Cedrus atlantica* were suitable for reducing Mo and Sn pollutions, and *Platanus orientalis* and *Populus alba* were suitable for reducing Sr pollution. Among these species, *Platanus orientalis* and *Cedrus atlantica* are particularly suitable for use because they can be grown in a wide area, grow very quickly, branch and reach large masses, are very long-lived, and can preserve heavy metals for hundreds or even thousands of years. *Robinia pseudoacacia*, on the other hand, is a species known for its durability and can be used in areas where there is Mo and Sn pollutions and where edaphic and climatic conditions are not very favorable, particularly in drought.

The heavy metals analyzed in the study are extremely harmful and dangerous for human and environmental health, and therefore, reducing heavy metal pollution is very important. However, this study found that suitable tree species should be determined separately to reduce the pollution levels of each heavy metal. In contrast, the number of studies on reducing Sn and Mo pollutions is negligibly low, and the number of studies on reducing Sr pollution is inadequate. It is recommended that comprehensive studies be conducted on the subject.

REFERENCES CITED

Adnan, M., Xiao, B., Ali, M. U., Xiao, P., Zhao, P., Wang, H., and Bibi, S. (2024). "Heavy metals pollution from smelting activities: A threat to soil and groundwater," *Ecotoxicology and Environmental Safety* 274, article 116189. DOI: 10.1016/j.ecoenv.2024.116189

Aricak, B., Çetin, M., Erdem, R., Sevik, H., and Cometen, H. (2019). "The change of some heavy metal concentrations in Scotch pine (*Pinus sylvestris*) depending on traffic density, organelle and washing," *Applied Ecology & Environmental Research* 17(3), 6723-6734 DOI: 10.15666/aeer/1703_67236734

Arıcak, B., Canturk, U., Koc, I., Erdem, R., and Sevik, H. (2024). "Shifts that may appear in climate classifications in Bursa due to global climate change," *Forestist* 74, 129-137. DOI: 10.5152/ forestist.2024.23074

Ateya, T. A. A., Bayraktar, O. Y., and Koc, I. (2023). "Do *Picea pungens* Engelm. organs be a suitable biomonitor of urban atmosphere pollution?," *Cerne* 29, article e-103228.

Baeza, J., and Freer, J. (2000). "Chemical characterization of wood and its components," *Wood and Cellulosic Chemistry*, Marcel Dekker Inc. New York, USA

Canturk, U., Koç, İ., Özel, H. B., and Şevik, H. (2024). "Possible changes of *Pinus nigra* distribution regions in Türkiye with the impacts of global climate change," *BioResources* 19(3), 6190-6214. DOI: 10.15376/biores.19.3.6190-6214

Çebi Kılıçoğlu, M. (2024). "Effects of heavy metal contamination on fungal diversity in *Pinus brutia* shoots," *BioResources* 19(2), 2724-2735. DOI: 10.15376/biores.19.2.2724-2735

Cesur, A., Zeren Cetin, I., Cetin, M., Sevik, H., and Ozel, H. B. (2022). "The use of *Cupressus arizonica* as a biomonitor of Li, Fe, and Cr pollution in Kastamonu," *Water Air Soil Pollution* 233, article 193. DOI: 10.1007/s11270-022-05667-w

Cetin, M., Cebi Kilicoglu, M., and Kocan, N. (2023). "Usability of biomonitors in monitoring the change of tin concentration in the air," *Environmental Science and Pollution Research* 30(52), 112357-112367. DOI: 10.1007/s11356-023-30277-2

Chen, S., Yao, Q., Chen, X., Liu, J., Chen, D., Ou, T., Liu, J., Dong, Z., Zheng, Z., and Fang, K. (2021). "Tree-ring recorded variations of 10 heavy metal elements over the past 168 years in southeastern China," *Elementa: Science of the Anthropocene* 9(1), article 00075. DOI: 10.1525/elementa.2020.20.00075

Cobanoglu, H., Sevik, H., and Koç, İ. (2023). "Do annual rings really reveal Cd, Ni, and Zn pollution in the air related to traffic density? An example of the cedar tree," *Water, Air, and Soil Pollution* 234(2), article 65. DOI: 10.1007/s11270-023-06086-1

Crist, D. R., Crist, R. H., and Martin, J. R. (2003). "A new process for toxic metal uptake by a kraft lignin," *J. Chem. Technol. Biotech*. 78(2-3), 199-202. DOI: 10.1002/jctb.735

Dogan, S., Kilicoglu, C., Akinci, H., Sevik, H., and Cetin, M. (2023). "Determining the suitable settlement areas in Alanya with GIS-based site selection analyses," *Environmental Science and Pollution Research* 30(11), 29180-29189. DOI: 10.1590/01047760202329013282

Dogan, S., Kilicoglu, C., Akinci, H., Sevik, H., Cetin, M., and Kocan, N. (2024). "Comprehensive risk assessment for identifying suitable residential zones in Manavgat, Mediterranean Region," *Evaluation and Program Planning* 106, article 102465. DOI: 10.1016/j.evalprogplan.2024.102465

Erdem, R. (2023). "Changes in strontium levels in bark and over the past 40 years in the wood of trees exposed to high levels of air pollution," *BioResources* 18(4), 8020-8036. DOI: 10.15376/biores.18.4.8020-8036

Erdem, R., Aricak, B., Cetin, M., and Sevik, H. (2023). "Change in some heavy metal concentrations in forest trees by species, organ, and soil depth," *Forestist,* 73(3), 257-263. DOI: 10.5152/forestist.2023.22069

Erturk, N., Aricak, B., Sevik, H., and Yigit, N. (2024). "Possible change in distribution areas of *A*bies in Kastamonu due to global climate change," *Kastamonu University Journal of Forestry Faculty* 24(1), 81-91. DOI: 10.17475/kastorman.1460616

Ghoma, W. E. O., Sevik, H., and Isinkaralar, K. (2023). "Comparison of the rate of certain trace metals accumulation in indoor plants for smoking and non-smoking areas," *Environmental Science and Pollution Research* 30(30), 75768-75776. DOI: 10.1007/s11356-023-27790-9

Ghoma, W., Sevik, H., and Isinkaralar, K. (2022). "Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke," *Air Quality, Atmosphere and Health* 15, 415-424 DOI: 10.1007/s11869-021-01146-z

Guney, D., Koc, I., Isinkaralar, K., and Erdem, R. (2023). "Variation in Pb and Zn concentrations in different species of trees and shrubs and their organs depending on traffic density," *Baltic Forestry,* 29(2), id661-id661. DOI: 10.46490/BF661

Gur, E., Palta, S., Ozel, H. B., Varol, T., Sevik, H., Cetin, M., and Kocan, N. (2024). "Assessment of climate change impact on highland areas in Kastamonu, Turkey," *Anthropocene* 46, article 100432. DOI: 10.1016/j.ancene.2024.100432

Hrivnák, M., Krajmerová, D., Paule, L., Zhelev, P., Sevik, H., Ivanković, M., Goginashvili, N., Paule, J., and Gömöry, D. (2024). "Are there hybrid zones in *Fagus sylvatica* L. sensu lato?," *European Journal of Forest Research* 143, 451-464. DOI: 10.1007/s10342-023-01634-0

Hubbe, M. A. (2013). "New horizons for use of cellulose-based materials to adsorb pollutants from aqueous solutions," *Lignocellulose* 2(2), 386-411.

Hubbe, M. A., Hasan, S. H., and Ducoste, J. J. (2011). "Cellulosic substrates for removal of pollutants from aqueous systems: A review. 1. Metals," *BioResources* 6(2), 2161-2287.

Hubbe, M. A., Szlek, D. B., and Vera, R. E. (2022). "Detergency mechanisms and cellulosic surfaces: A review," *BioResources*, *17*(4). 7167-7249. DOI: 10.15376/biores.17.4.Hubbe

Isinkaralar, K., Isinkaralar, O., Koç, İ., Özel, H. B., and Şevik, H. (2023). "Assessing the possibility of airborne bismuth accumulation and spatial distribution in an urban area by tree bark: A case study in Düzce, Türkiye," *Biomass Conversion and Biorefinery* Online, 1-12. DOI: 10.1007/s13399-023-04399-z

Isinkaralar, K., Koc, I., Erdem, R., and Sevik, H. (2022) "Atmospheric Cd, Cr, and Zn deposition in several landscape plants in Mersin, Türkiye," *Water, Air, & Soil Pollution* 233, article 120. DOI: 10.1007/s11270-022-05607-8

Istanbullu, S. N., Sevik, H., Isinkaralar, K., and Isinkaralar, O. (2023). "Spatial distribution of heavy metal contamination in road dust samples from an urban environment in Samsun, Türkiye," *Bulletin of Environmental Contamination and Toxicology* 110(4), article 78. DOI: 10.1007/s00128-023-03720-w

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2014). "Toxicity, mechanism and health effects of some heavy metals," *Interdisciplinary Toxicology* 7(2), 60-72. DOI: 10.2478/intox-2014-0009

Karaçocuk, T. (2021). *Changes in Heavy Metal Concentrations Depending on Traffic Density in Some Plants Grown in Samsun City Center*, Master's Thesis, University of Kastamonu University, Kastamonu, Türkiye.

Karacocuk, T., Sevik, H., Isinkaralar, K. Turkyilmaz, A., and Cetin, M. (2022). "The change of Cr and Mn concentrations in selected plants in Samsun city center depending on traffic density," *Landscape and Ecological Engineering* 18, 75-83. DOI: 10.1007/s11355-021-00483-6

Key, K., Kulaç, Ş., Koç, İ., and Sevik, H. (2022). "Determining the 180-year change of Cd, Fe, and Al concentrations in the air by using annual rings of *Corylus colurna* L.," *Water, Air, & Soil Pollution* 233(7), article 244. DOI: 10.1007/s11270-022-05741-3

Key, K., Kulaç, Ş., Koç, İ., and Sevik, H. (2023). "Proof of concept to characterize historical heavy-metal concentrations in atmosphere in North Turkey: Determining the variations of Ni, Co, and Mn concentrations in 180-year-old *Corylus colurna* L. (Turkish hazelnut) annual rings," *Acta Physiologiae Plantarum* 45(10), article 120. DOI: 10.1007/s11738-023-03608-6

Koc, I., and Nzokou, P. (2022). "Do various conifers respond differently to water stress? A comparative study of white pine, concolor and balsam fir," *Kastamonu University Journal of Forestry Faculty* 22(1), 1-16. DOI: 10.17475/kastorman.1095703

Koç, İ., Canturk, U., Isinkaralar, K., Ozel, H. B., and Sevik, H. (2024). "Assessment of metals (Ni, Ba) deposition in plant types and their organs at Mersin City, Türkiye," *Environmental Monitoring and Assessment* 196(3), Article Number 282. DOI: 10.1007/s10661-024-12448-x

Koc, I., Cobanoglu, H., Canturk, U., Key, K., Kulac, S., and Sevik, H. (2024). "Change of Cr concentration from past to present in areas with elevated air pollution," *International Journal of Environmental Science and Technology* 21(2), 2059-2070. DOI: 10.1007/s13762-023-05239-3

Kravkaz Kuscu, I. S., Cetin, M., Yigit, N., Savaci, G., and Sevik, H. (2018). "Relationship between enzyme activity (urease-catalase) and nutrient element in soil use," *Polish Journal of Environmental Studies* 27(5), 2107-2112. DOI: 10.15244/pjoes/78475

Kurz, M., Koelz, A., Gorges, J., Carmona, B. P., Brang, P., Vitasse, Y., Kohler, M., Rezzonico, F., Smits, T. H., Bauhus, J., *et al*. (2023). "Tracing the origin of Oriental beech stands across Western Europe and reporting hybridization with European beech–Implications for assisted gene flow," *Forest Ecology and Management* 531, article ID 120801. DOI: 10.1016/j.foreco.2023.120801

Kuzmina, N., Menshchikov, S., Mohnachev, P., Zavyalov, K., Petrova, I., Ozel, H. B., Aricak, B., Onat, S. M., and Sevik, H. (2023). "Change of aluminum concentrations in specific plants by species, organ, washing, and traffic density," *BioResources* 18(1), 792-803. DOI: 10.15376/biores.18.1.792-803

Meychik, N., Nikolaeva, Y., and Kushunina, M. (2021). "The significance of ion-exchange properties of plant root cell walls for nutrient and water uptake by plants," *Plant Physiology and Biochemistry* 166, 140-147. DOI: 10.1016/j.plaphy.2021.05.048

Meychik, N., Nikolaeva, Y., Kushunina, M., Titova, M., and Nosov, A. (2017). "Ion-exchange properties of the cell walls isolated from suspension-cultured plant cells," *Plant Cell, Tissue and Organ Culture (PCTOC)* 129, 493-500. DOI: 10.1007/s11240-017-1194-7

Mutlu, E. (2021). "Determination of seasonal variations of heavy metals and physicochemical parameters in Kildir pond (Yildizeli-Sivas)," *Fresenius Environmental Bulletin* 30(6), 5773-5780

NIH (2024), "Toxicological Profile for Strontium" (https://www.ncbi.nlm.nih.gov/books/NBK602022/) Accessed 28 July 2024.

Özdikmenli, G., Yiğit, N., Özel, H. B., and Şevik, H. (2024). "Altitude-dependent variations in some morphological and anatomical features of Anatolian chestnut," *BioResources* 19(3), 4635-4651. DOI: 10.15376/biores.19.3.4635-4651

Ozel, H. B., Abo Aisha, A. E. S., Cetin, M., Sevik, H., and Zeren Cetin, I. (2021). "The effects of increased exposure time to UV-B radiation on germination and seedling development of Anatolian black pine seeds," *Environmental Monitoring and Assessment* 193(7), 388-395. DOI: 10.1007/s10661-021-09178-9

Özel, H. B., Şevik, H., Yıldız, Y., and Çobanoğlu, H. (2024). "Effects of silver nanoparticles on germination and seedling characteristics of Oriental beech (*Fagus orientalis*) seeds," *BioResources* 19(2), 2135-2148. DOI: 10.15376/biores.19.2.2135-2148

Öztürk Pulatoğlu, A. (2024). "Variation of Ba concentration in some plants grown in industrial zone in Türkiye," *Forest Science and Technology* 20(1), 38-46. DOI: 10.1080/21580103.2023.2290500

Popescu, M. C., Popescu, C. M., Lisa, G., and Sakata, Y. (2011). "Evaluation of morphological and chemical aspects of different wood species by spectroscopy and thermal methods," *Journal of Molecular Structure* 988(1-3), 65-72. DOI: 10.1016/j.molstruc.2010.12.004

Rashid, A., Schutte, B. J., Ulery, A., Deyholos, M. K., Sanogo, S., Lehnhoff, E. A., and Beck, L. (2023). "Heavy metal contamination in agricultural soil: environmental pollutants affecting crop health," *Agronomy* 13, article 1521. DOI: 10.3390/agronomy13061521

Savas, D. S., Sevik, H., Isinkaralar, K., Turkyilmaz, A., and Cetin, M. (2021). "The potential of using *Cedrus atlantica* as a biomonitor in the concentrations of Cr and Mn," *Environmental Science and Pollution Research* 28, 55446-55453. DOI: 10.1007/s11356-021-14826-1

Sevik, H., Koç, İ., and Cobanoglu, H. (2024). "Determination of some exotic landscape species as biomonitors that can be used for monitoring and reducing Pd pollution in the air," *Water Air Soil Pollut*. 235, article 615. DOI: 10.1007/s11270-024-07429-2

Sharma, M., and Kumar, P. (2020). "Biochemical alteration of mustard grown under tin contaminated soil," *Plant Archives* 20(2), 3487-3492.

Şevik, H., Yildiz, Y., and Özel, H. B. (2024). "Phytoremediation and long-term metal uptake monitoring of silver, selenium, antimony, and thallium by black pine (*Pinus nigra* Arnold). *BioResources* 19(3), 4824-4837. DOI: 10.15376/biores.19.3.4824-4837

Sulhan, O. F., Sevik, H., and Isinkaralar, K. (2023). "Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara, Türkiye," *Environment, Development and Sustainability* 25, 4365-4384. DOI: 10.1007/s10668-022-02647

Swain, C. K. (2024). "Environmental pollution indices: a review on concentration of heavy metals in air, water, and soil near industrialization and urbanization," *Discover Environment* 2(1), 5. DOI: 10.1007/s44274-024-00030-8

Tambat, V. S., Tseng, Y. S., Kumar, P., Chen, C. W., Singhania, R. R., Chang, J. S., and Patel, A. K. (2023). "Effective and sustainable bioremediation of molybdenum pollutants from wastewaters by potential microalgae," *Environmental Technology and Innovation* 30, article ID 103091. DOI: 10.1016/j.eti.2023.103091

Tekin, O., Cetin, M., Varol, T., Ozel, H. B., Sevik, H., and Zeren Cetin, I. (2022). "Altitudinal migration of species of fir (*Abies* spp.) in adaptation to climate change," *Water, Air, & Soil Pollution* 233(9), article 385. DOI: 10.1007/s11270-022-05851-y

Ucun Ozel, H., Ozel, H. B., Cetin, M., Sevik, H., Gemici, B. T., and Varol, T. (2019). "Base alteration of some heavy metal concentrations on local and seasonal in Bartin River," *Environmental Monitoring and Assessment* 191(9), article 154. DOI: 10.1007/s10661-019-7753-0

Uncumusaoğlu, A. A., and Mutlu, E. (2021). "Water quality assessment in Karaboğaz Stream Basin (Turkey) from a multi-statistical perspective," *Polish Journal of Environmental Studies* 30(5), 4747-4759.

Varol, T., Canturk, U., Cetin, M., Ozel, H. B., Sevik, H., and Zeren Cetin, I. (2022). "Identifying the suitable habitats for Anatolian boxwood (*Buxus sempervirens* L.) for the future regarding climate change," *Theoretical and Applied Climatology* 150(1-2), 637-647. DOI: 10.1007/s00704-022-04179-1

Wani, W., Masoodi, K. Z., Zaid, A., Wani, S. H., Shah, F., Meena, V. S., Shafiq, A.W. and Mosa, K. A. (2018). "Engineering plants for heavy metal stress tolerance," *Rendiconti Lincei. Scienze Fisiche e Naturali* 29(3), 709-723.DOI: 10.1007/s12210-018-0702-y

Wani, W., Masoodi, K. Z., Zaid, A., Wani, S. H., Shah, F., Meena, V. S., Wani, S.A., and Mosa, K. A. (2018). "Engineering plants for heavy metal stress tolerance," *Rendiconti Lincei. Scienze Fisiche e Naturali* 29, 709-723. DOI: 10.1007/s12210-018-0702-y

WHO (2024). "WHO releases country estimates on air pollution exposure and health impact," (https://www.who.int/news/item/27-09-2016-who-releases-country-estimates-on-air-pollution-exposure-and-health-impact), Accessed 28 July 2024.

Xiang, Z., Wu, S., Zhu, L., Yang, K., and Lin, D. (2024). "Pollution characteristics and source apportionment of heavy metal (loid) s in soil and groundwater of a retired industrial park," *Journal of Environmental Sciences*, 143, 23-34.DOI: 10.1016/j.jes.2023.07.015

Yayla, E. E., Sevik, H., and Isinkaralar, K. (2022). "Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in urban air quality," *Environmental Monitoring and Assessment* 194(10), article 687. DOI: 10.1007/s10661-022-10356-6

Yigit, N., Mutevelli, Z., Sevik, H., Onat, S. M., Ozel, H. B., Cetin, M., and Olgun, Ç. (2021). "Identification of some fiber characteristics in *Rosa* sp. and *Nerium oleander* L. wood grown under different ecological conditions," *BioResources* 16(3), 5862-5874. DOI: 10.15376/biores.16.3.5862-5874

Yigit, N., Öztürk, A., Sevik, H., Özel, H. B., Ramadan Kshkush, F. E., and Işık, B. (2023). "Clonal variation based on some morphological and micromorphological characteristics in the boyabat (Sinop/Turkey) black pine (*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe) seed orchard," *BioResources* 18(3), 4850-4865. DOI: 10.15376/biores.18.3.4850-4865

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