Changes in Strontium Levels in Bark and Over the Past 40 Years in the Wood of Trees Exposed to High Levels of Air Pollution

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The present study aims to identify the most suitable tree species for monitoring and reducing strontium (Sr) pollution. Strontium is a heavy metal that is extremely harmful to human and environmental health even at low concentrations and is listed as a priority pollutant by the Agency for Toxic Substances and Disease Registry due to its potential harm. Samples were taken from *Pinus pinaster*, *Cupressus arizonica*, *Picea orientalis*, *Cedrus atlantica*, and *Pseudotsuga menziesii* species grown in Düzce, a location reported as one of the top 5 cities having the most polluted air in Europe by the World Air Pollution Report. The changes in Sr concentration over the last 40 years were evaluated by species, organ, direction, and age range. The results indicate that Sr pollution significantly increased due to traffic sources. This study also showed that the transfer of Sr within the wood is limited in all the species under consideration; hence, all these species can be used in monitoring the changes in Sr pollution. The most suitable species for reducing Sr pollution were *Cupressus arizonica* and *Picea orientalis*, which have the highest capacity to accumulate the most Sr in their wood.

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INTRODUCTION

The industrial revolution over the past century has caused irreversible problems, such as climate change and urbanization, on a global scale (Tekin *et al.* 2022; Cetin *et al.* 2023). During this period, the increase in environmental pollution is considered to be one of the most important threats to human health worldwide (Elsunousi *et al.* 2021). Today, almost the entire global population (99%) breathes air that exceeds WHO air quality limits and threatens their health (WHO 2022). Air pollution is estimated to contribute to 6 million preterm births each year and is stated to result in the death of approximately 7 million people annually (Jo *et al.* 2020; WHO 2023). Moreover, this change in the atmosphere's composition also contributes to global climate change, which is considered the most critical issue worldwide (Cobanoglu *et al.* 2023a; Isinkaralar *et al.* 2023a,b).

The most harmful and deadly components of air pollution, which is important in terms of causing human death, are heavy metals. Nowadays, air concentrations of heavy metals have increased significantly, especially in urban areas, due to industrial activities and traffic (Istanbullu *et al.* 2023). These metals can stay undegraded in nature for a long period and bioaccumulate in living organisms; some are toxic and carcinogenic even at low concentrations and their concentrations in the air are constantly increasing (Sulhan *et al.* 2022; Yayla *et al.* 2022). Studies revealed that the concentrations of many heavy metals in the air, such as Mn, Cr, Ni, Cu, Zn, Al, Cd, and Fe, have increased significantly in recent years (Isinkaralar *et al.* 2023b,c). Some of these elements are much more harmful than others regarding human and environmental health. Therefore, they are defined as priority pollutants by international organizations such as ATSDR and EPA (Isinkaralar *et al.* 2022). One of the most toxic heavy metals in terms of environment and human health is strontium (Sr). Compounds of strontium (Sr), even small amounts of which can be harmful to human health, can cause lung cancer and accumulate in the body over a lifetime, leading to significant problems that can even result in sudden death (Cobanoglu *et al.* 2022). Moreover, studies show that Sr may be radioactive (Burger and Lichtscheidl 2019; Ivanets *et al.* 2020; Kwon *et al.* 2021). For this reason, monitoring and reducing the concentrations of these elements in the air is critical for human health.

In the present study, by reviewing the previous studies on the use of annual rings as biomonitors, gaps in the literature were determined. In the literature to date, many species such as *Cupressus arizonica, Platanus orientalis, Robinia pseudoacacia*, *Corylus colurna,* and *Cedrus atlantica* have been used to monitor the change of more known elements such as Pb, Cr, Ni, Co, Mn (Koc *et al.* 2023). However, the number of studies on elements such as Tl, V, As, and Sr, which have been proven extremely dangerous for human and environmental health, is much more limited (Canturk 2023). In this study, considering the gaps identified, the changes in the concentrations of Sr, one of the most harmful heavy metals for human and environmental health, were determined by species, year range, organ, and direction. Within the scope of the study, it is aimed to compare the Sr accumulation potential of the species examined here and determine how the accumulation in the trunk organs (outer bark, inner bark, and wood) of the tree varies with the concentrations in the air, how the concentrations in the annual rings change by the year range, the level of transition between organs after being taken into the plant body, and which sources are responsible for the accumulation in the trees. Thus, it was aimed to gather information about both the pollutants with Sr origin and the most suitable species that can be used for monitoring and reducing this pollution.

MATERIALS AND METHODS

This study was carried out in Düzce, a province in the Western Black Sea region of Türkiye, where the level of air pollution is very high. According to the 2021 World Air Pollution Report, Düzce is one of the top five cities with the highest level of air pollution in Europe (IQAir 2021). Within the scope of this study, the trunks of *Pinus pinaster* (Pp), *Cupressus arizonica* (Cpa), *Picea orientalis* (Po), *Cedrus atlantica* (Cda), and *Pseudotsuga menziesii* (Pm) species marked on their north sides were cut at approximately 10 cm thickness and approximately 50 cm above the ground. These log samples were then brought to the laboratory, and their surfaces were planed to clearly reveal the annual rings. As a result of the count and investigation, it was determined that the trees were approximately 40 years old. Considering the widths of the annual rings, they were grouped into five-year groups, and, using a steel drill, samples were taken from the outer bark, inner bark, and wood of each age group. The process was carried out in triplicate. The collected samples, in the form of shaving, were placed in glass Petri dishes and left with their lids open for 15 days to air dry. Then, the samples were dried in an oven at 45 °C for a week. From the dried samples, 0.5 g was taken, added with 6 mL of 65% HNO_3 and 2 mL of 30% H_2O_2, and then placed in a microwave oven designed for such analyses. The solution samples were transferred to volumetric flasks and diluted with ultrapure water to 50 mL. The samples prepared were analyzed using an ICP-OES device, and the values obtained were multiplied by the dilution factor to calculate Sr concentrations. The method used in the study has been commonly used in recent studies on this subject (Sevik *et al.* 2020).

Data were analyzed using the SPSS software package. A variance analysis was conducted for the data, and the Duncan test was applied for factors that had statistically significant differences at a confidence level of at least 95% ($P < 0.05$). Data were interpreted by simplifying and tabularizing them. Thus, the changes in Sr concentration were separately determined and evaluated by species, direction, organ, and year range.

FINDINGS

The changes in Sr concentration by species and organ are presented in Table 1.

Table 1. Changes in Sr (ppb) Concentration by Species and Organ

Species	OB	IB	Wood
Pp	7629.3^{ab}	2157.2^{a}	1881.4^{ab}
Cpa	68616.1^{d}	54351.6^{c}	3205.5^{c}
Po	23612.6^{c}	32259.6^{b}	5323.3^{d}
Cda	16347.7^{bc}	243.5^{a}	2335.0^{bc}
Pm	7629.3^{ab}	2725.0^{a}	1204.6^{a}
F-value	65.2***	13.8***	18.7***

According to Duncan's test results, numbers followed by the same letters (a, b, c, or d) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions; ***$P \le 0.001$

Table 2. Changes in Sr (ppb) Concentration by Directions and Species

Species	North	East	South	West	Avg.
Pp	2374.2^{a}	334.5^{a}	3439.0	3613.8^{a}	2660.7^{a}
Cpa	16296.1^{b}	9969.9^{b}	8630.1	2454.8^{b}	14861.2^{c}
Po	8597.5^{a}	2829.7^{a}	6926.1	21030.0^{b}	9845.8^{b}
Cda	3335.3^{a}	109.1^{a}	3640.4	6578.6^{a}	3589.9^{a}
Pm	1307.1^{a}	2617.6^{a}	680.4	3756.8^{a}	1922.4^{a}
F-value	5.5***	4.3**	2.3 ns	7.7***	16.7***

According to Duncan's test results, numbers followed by the same letters (a, b) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions, ns = not significant; ***$P \le 0.001$; **$P \le 0.01$

Results of the variance analysis revealed that the Sr concentration was significant in all organs by species. The highest values in the outer and inner bark were found in the Cpa and those in wood were observed in the Po. The lowest average value was found in wood and the highest in the outer bark. Therefore, the results can be ranked as wood <

inner bark < outer bark. The changes in Sr concentration by species and direction is shown in Table 2.

Given the results presented in Table 2, it was determined that the changes in Sr concentration were significant in all directions, except for the south. The highest concentrations in the north, south, and east were found in the Cpa, whereas the highest concentration in the west was observed in Cpa and Po. The lowest average values were obtained in the Pp, Cda, and Pm species. The changes in Sr concentration by period and direction are given in Table 3.

Table 3. Changes in Sr (ppb) Concentration by Period and Direction

AGE	North	East	South	West	F	Avg.
2018 to 2022	3684.3^{bc}	2541.1	3564.0	4584.3	0.9 ns	3648.8^{bc}
2013 to 2017	1964.0^{Aabc}	1956.8^{bc}	1331.7^{A}	6863.8^{B}	15.8***	2875.2^{abc}
2008 to 2012	2121.8^{ABabc}	101.1^{Aa}	2575.5^{B}	7373.5^{C}	16.6***	2815.1^{abc}
2003 to 2007	1859.7^{Aab}	71.7^{Aa}	1577.2^{A}	5200.1^{B}	10.2***	2177.2^{ab}
1998 to 2002	486.6^{Aa}	142.8^{Aa}	485.9^{A}	6012.7^{B}	21.5***	1868.3^{a}
1993 to 1997	2081.0^{Aabc}	1145.9^{Aab}	3048.4^{A}	7294.6^{B}	6.6**	3427.2^{abc}
1988 to 1992	466.2^{Aa}	468.9^{Aa}	3111.7^{AB}	4966.1^{B}	4.8**	2412.8^{abc}
1983 to 1987	4260.7^{ABc}	1152.8^{Aab}	363.9^{AB}	6858.5^{B}	11.8***	3973.5^{c}
F-value	3.2**	4.6***	1.8 ns	0.8 ns		2.1*

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; ns = not significant; ***P ≤ 0.001; **P ≤ 0.01; *P ≤ 0.01

Given the values presented in Table 3, the changes in Sr concentration by directions were significant in all periods, except for the period 2018 to 2022. The Sr concentration by period was insignificant in directions other than the north and east. The lowest concentration was found in the period 1998 to 2002, whereas the highest concentration was found in the period 1983 to 1987. The lowest concentration in the north was obtained in the periods 1988 to 1992 and 1998 to 2002, while the highest in the east was obtained in the period 2018 to 2022. The changes in Sr concentration by organ and direction are presented in Table 4.

Table 4. Changes in Sr (ppb) Concentration by Organ and Direction

Organ	North	East	South	West	F-Value
OB	29120.5^{c}	14567.5^{b}	19512.0^{b}	34536.9^{b}	1.9 ns
IB	17525.5^{ABb}	10581.1^{Ab}	7725.3^{Aa}	38037.6^{Bb}	3.3*
Wood	2162.9^{Ba}	920.8^{Aa}	2398.3^{Ba}	6038.3^{Ca}	48.4***
F-value	38.7***	18.5***	19.5***	37.7***	
Avg.	6571.3^{C}	3569.3^{A}	4688.2^{B}	12314.1^{D}	9.8***

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. Ns = not significant; ***P ≤ 0.001; *P ≤ 0.01

When examining the results shown in Table 4, it was determined that the changes in Sr concentration in all organs, except the outer bark, by direction were significant. The changes in Sr concentration by organ were significant in all directions. The lowest value in the north was found in wood, whereas the highest value was seen in the outer bark. In the east, the highest value was found in the inner and outer bark and the lowest in the wood. The highest concentration in the south was obtained in the outer bark, whereas the highest concentration in the west was obtained in the outer and inner barks. The changes in Sr concentration in Pp by organ and direction are presented in Table 5.

Table 5. Changes in Sr (ppb) Concentration in Pp by Organ and Direction

Organ	North	East	South	West	F-Value	Avg.
OB	10646.2^{Dc}	261.2^{A}	10523.0^{Cc}	9086.9^{Bc}	51879.4***	7629.3^{b}
IB	107.6^{Ba}	62.2^{A}	3925.1^{Cb}	6934.0^{Db}	147697.6***	2757.2^{a}
Wood	1516.2^{Bb}	420.9^{A}	2357.5^{Ca}	2514.6^{Ca}	40.8***	1881.4^{a}
F-value	293.8***	0.6 ns	259.6***	459.1***		43.6***
Avg.	2374.2^{B}	334.5^{A}	3439.0^{B}	3613.8^{B}	7.9***	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. Ns = not significant; ***P ≤ 0.001

Table 6. Changes in Sr (ppb) Concentrations in Pp by Period and Direction

AGE	North	East	South	West	F-Value	Avg.
2018 to 2022	1395.0^{Ab}	LA	1382.6^{Aa}	1726.2^{Ba}	705.8***	1501.2^{ab}
2013 to 2017	LA	31.9^{Aa}	1657.0^{Bb}	2346.0^{Cc}	48737.9***	1345.0^{a}
2008 to 2012	24.8^{Aa}	135.6^{Bb}	2536.2^{Cd}	2882.8^{Df}	280030.6***	1394.8^{a}
2003 to 2007	1990.3^{Be}	147.0^{Ab}	3006.9^{Df}	2617.7^{Cd}	41795.6***	1940.5^{abc}
1998 to 2002	1964.6^{Ad}	LA	2051.1^{Ac}	2827.9^{Be}	1834.7***	2281.2^{bc}
1993 to 1997	2254.6^{Af}	LA	2773.0^{Be}	2254.6^{Ab}	1809.8***	2427.4^{c}
1988 to 1992	1501.6^{Bc}	1369.1^{Ac}	LA	2266.2^{Cb}	17074.7***	1712.3^{abc}
1983 to 1987	1482.8^{Ac}	LA	3096.1^{Bg}	3195.3^{Bg}	43254.7***	2591.4^{c}
F-value	8218.1***	25003.9***	8468.8***	10273.6***		2.9*
Avg.	1516.2^{B}	420.9^{A}	2357.5^{C}	2514.6^{C}	40.8***	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. LA: Under limits; ***P ≤ 0.001

Examining the results of the variance analysis, it was found that the change in Sr concentration in Pp was significant in all organs by direction and in all directions, except the east, by organ. The highest values in the north, south, and west were found in the outer bark. The lowest average value was found in the east and the highest value was in the north, south, and west. The changes in Sr concentration in Pp by period and direction are given in Table 6.

Given the results presented above, the changes in Sr concentration in all woods were significant in all periods by direction and in all directions by period. The highest average values were found in the periods 1983 to 1987 and 1993 to 1997. Considering the average values by direction, the lowest value was obtained in the east and the highest value in the south and west. The changes in Sr concentration in the north for the period 2013 to 2017 and in the south for the period 1988 to 1992 were below the detectable limits. In the east, the changes in Sr concentration in the 1983 to 1987, 1993 to 1997, 1998 to 2002, and 2018 to 2022 periods were also lower than the detectable limits. The changes in Sr concentration in Cpa by organ and direction are presented in Table 7.

Table 7. Changes in Sr (ppb) Concentration in Cpa by Organ and Direction

Organ	North	East	South	West	F-Value	Avg.
OB	73736.4^{Cc}	56924.0^{Ac}	73003.5^{Cb}	70800.5^{Bb}	331.4***	68616.1^{c}
IB	67652.5^{Cb}	41642.7^{Bb}	822.8^{Aa}	107288.2^{Dc}	43676.1***	54351.6^{b}
Wood	2696.6^{Ba}	141.5^{Aa}	1559.3^{Ba}	8424.6^{Ca}	68.3***	3205.5^{a}
F-value	1164.5***	44726.7***	1228.4***	23971.8***		194.6***
Avg.	16296.1	9969.9	8630.1	24548.5	2.5 ns	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; Ns = not significant; ***P ≤ 0.001

Table 8. Changes in Sr (ppb) Concentration in Cpa Woods by Period and Direction

AGE	North	East	South	West	F-value	Avg.
2018 to 2022	230.9^{Bd}	93.8^{Ab}	5890.6^{Cc}	7918.6^{Dc}	47746.4***	3533.5
2013 to 2017	189.4^{Bc}	58.1^{Aa}	95.9^{Aa}	7453.0^{Cb}	100087.3***	1949.1
2008 to 2012	6525.4^{Ce}	118.1^{Abc}	5931.3^{Bd}	7276.7^{Da}	33167.2***	4962.9
2003 to 2007	6991.7^{Bf}	54.4^{Aa}	113.7^{Aab}	10072.0^{Ch}	65479.6***	4307.9
1998 to 2002	204.5^{Bcd}	275.2^{Cf}	96.8^{Aa}	8360.1^{Dd}	49715.9***	2234.1
1993 to 1997	73.0^{Aa}	224.0^{Be}	108.4^{Aab}	8497.2^{Ce}	49531.9***	2225.6
1988 to 1992	123.7^{Ab}	182.1^{Bd}	96.5^{Aa}	8693.5^{Cf}	104605.2***	2274.0
1983 to 1987	7234.0^{Bg}	126.1^{Ac}	141.5^{Ab}	9125.5^{Cf}	118411.4***	4156.8
F-value	75778.6***	72.4***	54759.1***	1129.6***		1.1 ns
Avg.	2696.6^{B}	141.5^{A}	1559.3^{B}	8424.6^{C}	68.3***	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; ns = not significant; ***P ≤ 0.001

Examining the results presented in Table 7, the changes in Sr concentration at T5 were significant in all directions based on the organ and in all organs based on direction. The lowest value in the north, east, and west is seen in wood, while the lowest value in the south is seen in wood and inner bark. The highest values were obtained in the outer bark in the north, east, and south, while the highest value in the west was obtained from the inner bark. Therefore, the average results can be ranked as wood < inner bark < outer bark. The changes in Sr concentration in Cpa by period and direction are shown in Table 8.

Considering the results, it was determined that the changes in Sr concentration in Cpa wood were significant in all periods by directions and in all directions by periods. The highest concentration was observed in the north in the period 2008 to 2012, while the highest value in the east was observed during the 1998 to 2002 period. The highest value in the south was found in the period 2018 to 2022 and the one in the west was found in the period 2003 to 2007. Comparing the average values, the lowest one was found in the east and the highest one in the west. There was no significant difference between the periods by average values. The changes in Sr concentration at Po by organ and direction are presented in Table 9.

Table 9. Changes in Sr (ppb) Concentration in Po by Organ and Direction

ORGAN	North	East	South	West	F-Value	Avg.
OB	39021.8^{Cc}	14876.3^{Bb}	589.6^{Aa}	39962.7^{Db}	11649.7***	23612.6^{b}
IB	19481.5^{Bb}	543.0^{Aa}	33530.6^{Cb}	75483.5^{Dc}	375734.6***	32259.6^{c}
Wood	3434.0^{ABa}	1609.7^{Aa}	4392.7^{Ba}	11856.8^{Ca}	27.6***	5323.3^{a}
F-value	93.4***	42.0***	41.5***	1133.7***		38.6***
Avg.	8597.5^{A}	2829.7^{A}	6926.1^{A}	21030.0^{B}	10.5***	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. ***P ≤ 0.001

Given the results of variance analysis, it was determined that the changes in Sr concentration in Po were significant in all organs by direction and in all directions by organ. The highest concentration in the north and east was found in the outer bark and those in the south and west were found in the inner bark. The lowest average value was observed in the north, east, and south, whereas the highest one was found in the west. The average concentration results for organs can be ranked as wood < inner bark < outer bark. The changes in Sr concentration at T6 by period and direction are presented in Table 10.

Table 10 shows that changes in Sr concentration in Po wood were significant in all periods and all directions. The highest value in the north was in the period 1983 to 1987, whereas the highest value in the east was in the period 2018 to 2022. The highest value in the south was obtained in the period 1983 to 1987 and the one in the west was found in the period 1993 to 1997. Comparing the average values, the lowest value was found in the east and the highest in the west. The changes in Sr concentration in Cda by organ and direction are shown in Table 11.

Table 10. Changes in Sr (ppb) Concentration in Po Woods by Period and Direction

Age	North	East	South	West	**F-Value**	**Avg.**
2018 to 2022	10050.4^{Dc}	6243.4^{Bf}	112.9^{Aa}	8703.8^{Ca}	15964.2***	6277.6^{abc}
2013 to 2017	106.0^{Aa}	5805.6^{Be}	120.6^{Aa}	9053.0^{Cb}	29046.8***	3771.3^{ab}
2008 to 2012	126.4^{Aa}	132.6^{Ab}	125.3^{Aa}	14057.8^{Bg}	2014366.4***	3610.5^{ab}
2003 to 2007	106.1^{Aa}	81.0^{Aa}	103.2^{Aa}	9195.9^{Bc}	124450.0***	2371.5^{a}
1998 to 2002	114.3^{Ba}	38.0^{Aa}	169.3^{Ca}	12215.6^{Dd}	256681.3***	3134.3^{ab}
1993 to 1997	4348.6^{Bb}	83.6^{Aa}	9768.8^{Cb}	15619.0^{Dh}	119928.7***	7455.0^{bc}
1988 to 1992	140.6^{Aa}	309.3^{Bd}	9852.0^{Cc}	13680.4^{Df}	66098.7***	5995.6^{abc}
1983 to 1987	12479.5^{Cd}	184.1^{Ac}	14889.1^{Dd}	12328.7^{Be}	45676.3***	9970.4^{c}
F-value	101384.7***	35040.3***	58103.8***	6608.4***		2.7*
Avg.	3434.0^{AB}	1609.7^{A}	4392.7^{B}	11856.8^{C}	27.6***	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; ***P ≤ 0.001; *P ≤ 0.01

Table 11. Changes in Sr (ppb) Concentration in Cda by Organ and Direction

Organ	**North**	**East**	**South**	**West**	**F-Value**	**Avg.**
OB	21594.2^{Cb}	248.4^{Ab}	12761.9^{Bc}	30786.5^{Dc}	38643.3***	16347.7^{b}
IB	293.4^{Ca}	243.8^{Bb}	144.8^{Aa}	292.0^{Ca}	79.9***	243.5^{a}
Wood	1433.2^{Ba}	63.4^{Aa}	2937.1^{Cb}	4338.5^{Db}	21.1***	2335.0^{a}
F-value	215.8***	31.1***	47.4***	191.8***		60.7***
Avg.	3335.3^{B}	109.1^{A}	3640.4^{BC}	6578.6^{C}	5.5**	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; ***P ≤ 0.001; **P ≤ 0.01

Considering the results presented in Table 11, it was determined that the changes in Sr concentration were significant in all organs by direction and in all directions by organ. The highest concentration in the outer bark was in the west and the lowest concentration in the east. The highest value in the inner bark was obtained in the west and north, whereas the highest value in wood was obtained in the west. Comparing the average values, the lowest average value was found in the east and the highest value in the west. The changes in Sr concentration in Cda woods by period and direction are presented in Table 12.

Table 12. Changes in Sr (ppb) Concentration in Cda Wood by Period and Direction

Age	North	East	South	West	F-Value	Avg.
2018 to 2022	3166.5^{Be}	35.1^{Ab}	4819.9^{Dh}	4434.6^{Cd}	35545.6***	3114.0^{bc}
2013 to 2017	3983.2^{Bg}	30.2^{Aab}	4720.4^{Cg}	8603.1^{Dg}	36802.5***	4334.2^{c}
2008 to 2012	127.5^{Bc}	21.9^{Aa}	4239.5^{Ce}	5276.9^{De}	47749.7***	2416.4^{abc}
2003 to 2007	186.4^{Bd}	23.8^{Aab}	4619.2^{Df}	4068.6^{Cc}	385023.3***	2224.5^{ab}
1998 to 2002	126.8^{ABc}	160.6^{Bd}	74.2^{Ab}	6606.7^{Cf}	22517.3***	1742.1^{ab}
1993 to 1997	3701.2^{Cf}	LA	2545.6^{Ad}	2807.6^{Bb}	5571.0***	3018.1^{bc}
1988 to 1992	98.9^{Ab}	LA	2447.7^{Cc}	125.8^{Ba}	79065.1***	890.8^{a}
1983 to 1987	75.3^{Ba}	108.8^{Cc}	30.5^{Aa}	2784.4^{Db}	92528.6***	749.7^{a}
F-value	58925.0***	227.4***	65757.8***	14277.0***		3.3**
Avg.	3335.3^{B}	109.1^{A}	3640.4^{BC}	6578.6^{C}	5.5**	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. LA: Under limits; ***$P \leq 0.001$; **$P \leq 0.01$

Considering the results of the variance analysis, it was determined that the changes in Sr concentration in Cda wood were significant in all periods and all directions. A comparison of average values revealed that the lowest value was found in the east and the highest was found in the west. A further comparison found that the lowest average concentration was obtained in the periods 1983 to 1987 and 1988 to 1992. In the east, the changes in Sr concentration during the periods 1988 to 1992 and 1993 to 1997 were found to be lower than the detectable limits. The changes in Sr concentration in Pm by organ and direction are shown in Table 13.

Table 13. Changes in Sr (ppb) Concentration in Pm by Organ and Direction

Organ	North	East	South	West	F-Value	Avg.
OB	604.1^{B}	527.5^{Aa}	681.9^{C}	22048.0^{Dc}	226069.8***	5965.4^{b}
IB	92.5^{A}	10413.6^{Cb}	203.2^{B}	190.6^{Bb}	79688.6***	2725.0^{a}
Wood	1581.1^{B}	1904.4^{Ba}	739.8^{A}	75.6^{Aa}	3.8*	1204.6^{a}
F-value	1.3 ns	33.7***	0.1 ns	313929.7***		8.1**
Avg.	1307.1	2617.6	680.4	3756.8	2.6 ns	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at $p > 0.05$. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions; ns = not significant; ***$P \leq 0.001$; **$P \leq 0.01$; *$P \leq 0.01$

Considering the results, the changes in Sr concentration in Pm were significant in all organs by direction. The changes in Sr concentration in all directions, except the east and west, were insignificant. The highest value in the east was observed in the inner bark and the lowest one in the wood and outer bark. In the west, the highest concentration was obtained from the outer bark, whereas the lowest concentration was found in the wood. The changes in Sr concentration in Pm by period and direction are presented in Table 14.

Table 14. Changes in Sr (ppb) Concentration in Pm Woods by Period and Direction

Age	North	East	South	West	F-Value	Avg.
2018 to 2022	3578.7^{Bb}	3792.1^{Cd}	5614.0^{Dd}	138.3^{Ac}	10597.2***	3280.7^{c}
2013 to 2017	3577.4^{Bb}	3858.1^{Ce}	64.6^{Ac}	LA	16330.0***	2500.0^{bc}
2008 to 2012	3805.1^{Cc}	97.7^{Bb}	45.2^{Ab}	LA	279605.9***	1316.0^{ab}
2003 to 2007	24.1^{Aa}	52.1^{Cab}	42.9^{Bb}	46.2^{Bca}	35.4***	41.3^{a}
1998 to 2002	22.8^{Aa}	97.6^{Db}	37.9^{Bb}	53.0^{Ca}	137.1***	52.8^{a}
1993 to 1997	27.4^{Aa}	3130.1^{Cc}	46.3^{Bb}	LA	123449.0***	1067.9^{a}
1988 to 1992	LA	15.0^{Aa}	50.7^{Bbc}	64.7^{Cb}	276.6***	43.4^{a}
1983 to 1987	32.1^{Aa}	4192.2^{Bf}	17.2^{Aa}	LA	27633.4***	1413.9^{ab}
F-value	86197.3***	10480.4***	124814.1***	217.7***		7.4***
Avg.	1581.1^{B}	1904.4^{B}	739.8^{AB}	75.6^{A}	3.8*	

According to Duncan's test results, numbers followed by the same letters (A, B, or a, b) are not statistically different at p > 0.05. Lowercase letters illustrate vertical directions, while capital letters indicate horizontal directions. LA: Under limits; ***P ≤ 0.001; *P ≤ 0.01

Given the results presented in Table 14, the changes in Sr concentration were significant in all periods by direction and in all directions by period. The highest values were obtained in the period 2008 to 2012 for the north, in the period 1983 to 1987 for the east, in the period 2018 to 2022 for the south, and in the period 2018 to 2022 for the west. Furthermore, the changes in Sr concentration were lower than detectable limits in the north for the period 1988 to 1992 and in the east for the periods 1983 to 1987, 1993 to 1997, 2008 to 2012, and 2013 to 2017.

DISCUSSION AND CONCLUSION

In the present study, the highest Sr values were generally found in *Cupressus arizonica* (Cpa) and *Picea orientalis* (Po) species. This result agrees with the data reported by many studies conducted on heavy metals. It has been noted in many studies that the accumulation levels of heavy metals varied among different species, and it has also been emphasized that plant type was the main factor influencing heavy metal accumulation (Karacocuk *et al.* 2022). This is a result of different physicochemical reactions of species to heavy metals (Isinkaralar *et al.* 2023c). For instance, when the same species are compared, the highest Cr concentration was obtained in *Cupressus arizonica* and *Pseudotsuga menziesii* (Koc *et al.* 2023), the highest Bi concentration was obtained in

Pseudotsuga menziesii (Isinkaralar *et al.* 2023c), and the highest Tl concentration was obtained in *Cupressus arizonica* (Canturk 2023).

The results achieved in this study indicated that the Sr concentrations in the organs ranked as wood < inner bark < outer bark. It was reported in previous studies that heavy metal concentrations in the outer bark were high (Cesur *et al.* 2021). This is generally related with the structure of the outer bark and the adhesion of particulate matter contaminated with heavy metals to the outer bark. Particulates in the air are first contaminated with heavy metals and these particles can adhere to the bark surface because of the rough and cracked surface of the outer bark (Yayla *et al.* 2022). It was determined in the present study that Sr concentrations in the inner bark were higher than in the wood. This is related to the intake of heavy metals into the plant body.

The heavy metals are taken into the plant body primarily from roots, leaves, and stem parts (Chen *et al.* 2021). Stemwood, the largest reservoir of aboveground tree biomass, was identified in numerous positions as the primary long-term pool for radiocaesium in forest vegetation despite the relatively low concentration of radiocaesium in woody parts (Calmon *et al.* 2009). The statistically noteworthy correlation between the transfer elements of Sr to stem wood (sapwood, heartwood) and its vertical allocations in soil profiles have not been observed (Golyaka *et al.* 2020). As a result of the present study, it can be said that the Sr in the inner bark enters from the stem parts and, therefore, the concentrations in the inner bark, which has no contact with air, were lower than in the outer bark but in comparable to the wood. Kudzin *et al.* (2019) narrated that the ability of tree organs and tissues of pine plantations to accumulate Sr was declining in the subsequent order: bark > roots > wood. Holiaka *et al.* (2023) noted that Sr was reasonably stable in the entire trunk except in the oldest annual tree rings, which expanded sharply, likely revealing active radionuclide transport to senescing tissues.

The element transfer in the tree timber part is predominantly associated with the cell wall and structure. The CWPM (cell wall–plasma membrane) interface describes an apoplastic mechanical barrier, and a flexible design takes part in stress signaling, sensing, and perceiving the metalloid and metal stress (Wani *et al.* 2018; Key *et al.* 2023). Ion exchange is the primary tool for the adsorption of Sr (II) ions on carboxymethyl groups of the carboxymethylcellulose. At low pH (<2.0), the excess H+ ions compete to the Sr (II) ions, to attach with carboxylate ion (-COO). As the pH of the medium increases, carboxylate sites are unrestricted for exchange with strontium ions (II) due to an increase in polymer hydrolysis. The ionic power of the solution rises with the concentration of KCl, and Sr (II) adsorption in carboxymethylcellulose declines. This indicates that ions' adsorption is also affected by ionic force from the medium (Jain *et al.* 2022).

It was also determined in the present study that the Sr concentrations in the wood of the species were different; there were remarkable differences between Sr concentrations in the same period in different directions and in the same direction in different periods. For instance, in *Cedrus atlantica* (Cda), the Sr concentration determined in the north in the period 2008 to 2012 was 127.5 ppb, whereas the Sr concentration measured in the same direction in the period 2003 to 2007 was 3983.2 ppb. The Sr concentration measured in the east in the period 2003 to 2007 was 30.2 ppb. These results show that there were significant differences in Sr concentration between adjacent wood masses and, thus, the transfer of Sr within the wood was limited.

This finding is important because the main lack of knowledge regarding the usability of biomonitors in monitoring heavy metal pollution has been emphasized to be the transfer of elements within the wood. In fact, it has been reported in previous studies that the transfer potentials of different elements in the wood of different species were different. Thus far, in some studies, it has been determined that *Cedrus deodara* is suitable for monitoring Cu pollution (Zhang 2019), *Cedrus atlantica* for Ni, Cr, and Mn (Koç 2021; Savas *et al.* 2021), *Cupressus arizonica* for Cd, Ni, Fe, and Zn (Cesur *et al.* 2021, 2022; Cobanoglu *et al.* 2023b), and *Corylus colurna* for Cd, Ni, Zn, Pb, Cr, and Zn (Key *et al.* 2022; Key and Kulaç 2022), indicating that the transfer of these elements in the wood of these species is limited. However, in the same studies, it has also been stated that Pb and Zn in *Cedrus deodara* (Zhang 2019), Co in *Cedrus atlantica* (Koç 2021), and Bi, Li, and Cr in *Cupressus arizonica* could be transferred within the wood (Zhang 2019; Cesur *et al.* 2021, 2022; Cobanoglu *et al.* 2023b).

The transport of elements within the wood part of plants is largely related to cell structure, particularly the cell wall (apoplastic route). In plants, the apoplast between the cell wall and plasma membrane (CWPM) is not only an apoplastic membrane barrier but also a flexible structure that acts as a sensor and signal generator in case of metal/metalloid stress. Cell wall proteins (CWP) that are activated under various abiotic stresses have been extensively identified and characterized among different types of plants (Wani *et al.* 2018). The tree-related materials studied show a relatively clear selectivity for distinct metal ions. The results from several sorption experiments using various metal ion loading solutions show that the affinity ranking of metal ions to the tree-related materials is altering (Su 2012).

Plants frequently face abiotic stress factors throughout their life cycles. The most common stresses that plants face are drought and frost stress factors, which are related to climatic parameters (Sevik and Karaca 2016; Dogan *et al.* 2023; Koç and Nzokou 2023). This is because plant development depends on the mutual interaction of genetic structure (Kurz *et al.* 2023; Tandogan *et al.* 2023) and environmental conditions (Erdem *et al.* 2023; Yiğit *et al.* 2023). Therefore, factors that cause significant and permanent changes in climatic parameters, such as global climate change trigger the stress mechanisms of plants (Varol *et al.* 2022). In addition, the increase of UV-B stress due to climate change (Ozel *et al.* 2021a), radiation originating from anthropogenic factors (Ozel *et al.* 2021b), and heavy metal pollution (Cesur *et al.* 2022; Erdem 2023) are also significant sources of stress for plants. These stress sources are likely to affect plant metabolism and hence the potential of plants to accumulate heavy metals.

As a result of this study, the highest Sr concentrations were obtained in the west and north. There is a residential area to the north of the study area and a highway to the west. It is stated that Sr is largely released into the atmosphere from anthropogenic sources (Cobanoglu *et al.* 2022; Cong *et al.* 2023). This situation is actually valid for many heavy metals. Studies show that the main sources of heavy metals are human activities such as traffic, urbanization, industry, and mining activities (Kuzmina *et al.* 2023).

SUGGESTIONS

Within the scope of this study, the highest concentrations of strontium (Sr) in the air were generally found in the outer bark of the trees examined. The concentrations of heavy metals in the outer bark usually originate from the heavy metal-contaminated particles. Therefore, it can be stated that there is a high level of Sr pollution in the air in the study area.

Changes in the Sr concentrations in different directions were determined and the highest concentrations were found in the west and north, where the traffic density is high, in almost all species. Therefore, it can be said that the primary sources of Sr pollution are anthropogenic activities, particularly urbanization and traffic.

Within the scope of this study, it was determined that the Sr concentration in all the species examined here significantly varied both between different directions within the same year range and between consecutive year ranges. This finding indicates that the transfer of Sr within the wood of the species examined here is limited. Given this conclusion, it can be said that the species and method used in the present study can effectively be used in monitoring the changes in Sr concentrations.

The usability of plants in phytoremediation studies aiming to reduce heavy metal pollution depends on their capacity to accumulate heavy metals in their bodies. The organ with the highest volume in trees is the wood. Therefore, the most suitable species for phytoremediation studies are the ones that accumulate the most Sr in the wood part. In the present study, the highest Sr concentrations were found in the wood parts of *Picea orientalis* (Po) and *Cupressus arizonica* (Cpa) species. Thus, it can be said that these species are the most suitable ones for reducing Sr pollution.

REFERENCES CITED

Burger, A., and Lichtscheidl, I. (2019). “Strontium in the environment: Review about reactions of plants towards stable and radioactive strontium isotopes,” *Science of the Total Environment* 653, 1458-1512.

Calmon, P., Thiry, Y., Zibold, G., Rantavaara, A., and Fesenko, S. (2009). “Transfer parameter values in temperate forest ecosystems: A review,” *Journal of Environmental Radioactivity* 100(9), 757-766.

Cantürk, U. (2023). “Determining the plants to be used in monitoring the change in thallium concentrations in the air,” *Cerne* (in press).

Cesur, A., Zeren Cetin, I., Abo Aisha, A. E. S., Alrabiti, O. B. M., Aljama, A. M. O., Jawed, A. A., Cetin, M., Sevik, H., and Ozel, H. B. (2021). “The usability of *Cupressus arizonica* annual rings in monitoring the changes in heavy metal concentration in air,” *Environmental Science and Pollution Research* 28(27), 35642-35648. DOI: 10.1007/s11356-.021-13166-4

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(6), article 193. DOI: 10.1007/s11270-022-05667-w

Cetin, M., Sevik, H., Koc, I., and Cetin, I. Z. (2023). “The change in biocomfort zones in the area of Muğla province in near future due to the global climate change scenarios,” *Journal of Thermal Biology* 112, article ID 103434.

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., Canturk, U., Koç, İ., Kulaç, Ş., and Sevik, H. (2023a). "Climate change effect on potential distribution of Anatolian chestnut (*Castanea sativa* mill.) in the upcoming century in Türkiye," *Forestist* 73(3), 247-256. DOI: 10.5152/forestist.2023.22065.

Cobanoglu, H., Sevik, H., and Koç, İ. (2023b). "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, & Soil Pollution* 234(2), article 65. DOI: 10.1007/s11270-023-06086-1

Cobanoglu, H., Sevik, H., Ozel, H. B., and Bozdag, S. (2022). "Usability of some woody plants in monitoring and reducing the Mn, Zn, Ba, and Sr concentrations in the air," *World Journal of Advanced Research and Reviews* 16(1), 794-802.

Cong, Y., Yu, R. L., Yan, Y., Weng, B. S., Hu, G. R., Sun, J. W., Cui, J. Y., YanYan, and Huang, Y. Y. (2023). "Source analysis of metals in the tea plant using linear correlation analysis combined with a lead-strontium isotope tracer," *CATENA* 229, article ID 107194. DOI: 10.1016/j.catena.2023.107194

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.

Elsunousi, A. A. M., Sevik, H., Cetin, M., Ozel, H. B., and Ozel, H. U. (2021). "Periodical and regional change of particulate matter and CO_2 concentration in Misurata," *Environmental Monitoring and Assessment* 193(11), article 707. DOI: 10.1007/s10661-021-09478-0

Erdem, R. (2023). "Change of Cr, Co, and V concentrations in forest trees by species, organ, and soil depth," *BioResources* 18(3), 6183-6193. DOI: 10.15376/biores.18.3.6183-6193

Erdem, R., Çetin, M., Arıcak, B., and Sevik, H. (2023). "The change of the concentrations of boron and sodium in some forest soils depending on plant species," *Forestist* 73(2), 207-212. DOI: 10.5152/forestist.2022.22061

Golyaka, D. M., Levchuk, S. J., Kashparov, V. O., Golyaka, M. A., Joshchenko, L. V., Otreshko, L. M., and Lazarjev, M. M. (2020). "Vertical distribution of 90 Sr in soil profiles and its uptake by scots pine (*Pinus sylvestris* L.) wood growing within the Chernobyl exclusion zone," *Yaderna Fyizika ta Energetika*, 21(2), 157-165.

IQAir (2021). "2021 World air quality report: Region & city PM2.5 ranking," IQAir, (https://www.iqair.com/us/world-most-polluted-cities), Accessed 15 Jan 2023.

Isinkaralar, K. (2023a). "A study on the gaseous benzene removal based on adsorption onto the cost-effective and environmentally friendly adsorbent," *Molecules* 28(8), article 3453. DOI:10.3390/molecules28083453

Isinkaralar, K. (2023b). "Improving the adsorption performance of non-polar benzene vapor by using lignin-based activated carbon," *Environ. Sci. Pollut. Res*. DOI: 10.1007/s11356-023-30046-1

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 Pollut.* 233, 120. DOI: 10.1007/s11270-022-05607-8

Isinkaralar, O., Isinkaralar, K., Sevik, H., and Kucuk, O. (2023a). "Spatial modeling the climate change risk of river basins via climate classification: A scenario-based prediction approach for Türkiye," *Nat Hazards*. DOI: 10.1007/s11069-023-06220-6

Isinkaralar, O., Isinkaralar, K., and Yilmaz, D. (2023b). "Climate-related spatial reduction risk of agricultural lands on the Mediterranean coast in Türkiye and scenario-based modelling of urban growth," *Environ Dev Sustain*. DOI:10.1007/s10668-023-03774-0

Isinkaralar, K., Isinkaralar, O., Koç, İ., Özel, H. B., and Şevik, H. (2023c). "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.

Ivanets, A., Milyutin, V., Shashkova, I., Kitikova, N., Nekrasova, N., and Radkevich, A. (2020). "Sorption of stable and radioactive Cs (I), Sr (II), Co (II) ions on Ti–Ca–Mg phosphates," *Journal of Radioanalytical and Nuclear Chemistry* 324, 1115-1123.

Jain, P., De, A., and Singh, N. B. (2022). "Cellulose-based materials for water purification," *ChemistrySelect 7*(24), e202200121.

Jo, J., Jo, B., Kim, J., Kim, S., and Han, W. (2020). "Development of an IoT-based indoor air quality monitoring platform," *Journal of Sensors* 2020, article ID 8749764. DOI: 10.1155/2020/8749764

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., and Kulaç, Ş. (2022). "Proof of concept to characterize historical heavy metal concentrations from annual rings of *Corylus colurna*: Determining the changes of Pb, Cr, and Zn concentrations in atmosphere in 180 years in North Turkey," *Air Quality, Atmosphere & Health* 15(9), 1623-1633.

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), 1-13.

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.

Koç, İ. (2021). "Using *Cedrus atlantica*'s annual rings as a biomonitor in observing the changes of Ni and Co concentrations in the atmosphere," *Environmental Science and Pollution Research* 28(27), 35880-35886.

Koç, İ., and Nzokou, P. (2023). "Combined effects of water stress and fertilization on the morphology and gas exchange parameters of 3-year-old *Abies fraseri* (Pursh) Poir," *Acta Physiologiae Plantarum* 45(3), Article Number 49.

Koç, İ., Sevik, H., Kulaç, Ş., Cantürk, U., Çobanoğlu, H., and Key, K. (2023). "Change of Cr concentration from past to present in areas with elevated air pollution," *International Journal of Environmental Science and Technology* (In press). DOI : 10.1007/s13762-023-05239-3.

Kudzin, M., Zabrotski, V., Garbaruk, D., and Uhlianets, A. (2019). "90 Sr in the components of pine forests of Belarusian part of Chernobyl NPP Exclusion Zone," *Strontium Contamination in the Environment* 2020, 159-183.

Kurz, M., Kölz, A., Gorges, J., Carmona, B. P., Brang, P., Vitasse, Y., Kohler, M., Rezzonico, F., Smits, T. H. M., 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

Kwon, S., Kim, C., Han, E., Lee, H., Cho, H. S., and Choi, M. (2021). "Relationship between zeolite structure and capture capability for radioactive cesium and strontium," *Journal of Hazardous Materials* 408, article 124419.

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

Ozel, H. B., Cetin, M., Sevik, H., Varol, T., Isik, B., and Yaman, B. (2021b). "The effects of base station as an electromagnetic radiation source on flower and cone yield and germination percentage in *Pinus brutia* Ten," *Biologia Futura* 72, 359-365.

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(39), 55446-55453. DOI: 10.1007/s11356-021-14826-1

Sevik, H., and Karaca, U. (2016). "Determining the resistances of some plant species to frost stress through ion leakage method," *FEB – Fresenius Environmental Bulletin* 25(8), 2745-2750.

Sevik, H., Cetin, M., Ozel, H. B., Akarsu, H., and Zeren Cetin, I. (2020). "Analyzing of usability of tree-rings as biomonitors for monitoring heavy metal accumulation in the atmosphere in urban area: A case study of cedar tree (*Cedrus* sp.)," *Environmental Monitoring and Assessment* 192, Article Number 23. DOI: 10.1007/s10661-019-8010-2

Su, P. (2012). "Sorption of metal ions to wood, pulp and bark materials," Åbo Akademi University, ISBN 978-952-12-2777-6 Painosalama Oy – Turku, Finland

Sulhan, O. F., Sevik, H., and Isinkaralar, K. (2022). "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/s10668-022-02647-2

Tandoğan, M., Özel, H. B., Gözet, F. T., and Şevik, H. (2023). "Determining the taxol contents of yew tree populations in western Black Sea and Marmara regions and analyzing some forest stand characteristics," *BioResources* 18(2), 3496-3508. DOI: 10.15376/biores.18.2.3496-3508

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

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 the 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., Wani, S. A., Mosa, K. A. (2018). "Engineering plants for heavy metal stress tolerance," *Rendiconti Lincei-Scienze Fisiche E Naturali* 29(3), 709-723.

WHO (2022). "Billions of people still breathe unhealthy air: New WHO data," World Health Organization, (https://www.who.int/news/item/04-04-2022-billions-of-people-still-breathe-unhealthy-air-new-who-data), Accessed 01 Feb 2023.

WHO (2023). "152 million babies born preterm in the last decade," World Health Organization, (https://www.who.int/news/item/09-05-2023-152-million-babies-born-preterm-in-the-last-decade), Accessed 30 May 2023.

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 an urban air quality," *Environmental Monitoring and Assessment* 194(10), article 687. DOI: 10.1007/s10661-022-10356-6

Yiğit, N., Öztürk, A., Şevik, H., Özel, H. B., Kshkush, F. E. R., 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

Zhang, X. (2019). "The history of pollution elements in Zhengzhou, China recorded by tree rings," *Dendrochronologia* 54, 71-77.

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