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Determining the 180-year Change of Cd, Fe, and Al Concentrations in the Air by Using Annual Rings of *Corylus colurna* L

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Abstract Heavy metals (HMs), among the components of air pollution that is one of the utmost critical concerns our world has faced, are one of the biggest threats to living organisms. The plants, as a biomonitor, offer the most effective solution in tracking the change of HM concentration on earth and taking them under control. This paper aimed to evaluate the differences in cadmium (Cd), iron (Fe), and aluminum (Al) concentrations by using the annual rings of a 180-year-old *Corylus colurna* L. tree, which was cut in late 2020. Moreover, HMs in outer and inner bark were also compared to the values found in wood, and the direction-based change in the concentrations of these HMs was examined. As a result, the concentrations statistically differed between wood and barks for all three elements only in the north side ($p < 0.001$), and bark samples had higher Cd, Fe, and Al element concentrations than wood. When examining the annual rings, the highest values were commonly observed in the western and northern sides, and there were notable differences between the directions in the same term. The difference is thought to be the effects of highway and steel and iron facility located at the nearest point. In conclusion, the results showed that the use of the species and monitoring method employed in this study were very appropriate for tracking the variation in Cd, Fe, and Al concentrations, and these HMs have almost no transfer between organs and cells of the *Corylus colurna*.

Keywords Aluminum · Annual tree ring · Cadmium · Iron · Turkish hazelnut

1 Introduction

The earth has been faced many calamities such as climate change (Canturk & Kulaç, 2021; Koç, 2019; Koç et al., 2021; Koç, 2021a, 2021b), global warming, drought (Koç & Nzokou, 2022), and air pollution (Ghoma et al., 2022; Jo et al., 2020; Koç, 2021c), affecting all ecosystems. In the recent century, industrial activities have increased because of the economic development in the world and the increase in human welfare. Increasing industrial activities cause high levels of pollutant emissions, negatively affecting the environment (Edusei et al., 2021).

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Furthermore, the need for meeting the raw materials required for industrial activities also increased the mining activities (Alaqouri et al., 2020; Atienza et al., 2021; Varol et al., 2022). As a consequence of the increasing mining activities, also increases were observed in concentrations of various elements, which are extracted from underground and most of which are harmful to organic life, in soil (Long et al., 2021; Wei et al., 2022), water (Rajendran et al., 2022; Ucun Ozel et al., 2020), and air (Cui et al., 2022), as well as various organs of different animals (Coffin et al., 2022) and plants (Iqbal et al., 2021) living in these environments.

Increasing pollution in habitats of organisms can result in deteriorating health status and deaths. Polluted air in the environment creates the most critical risk to organisms, including humans. Considering that approximately 55% of the world's population lived in cities in 2018 (UN, 2018), and this rate is estimated to increase to 70% in 2050 (Uçar et al., 2021), as a result, it is not difficult to predict that many harmful effects of air pollution on people will occur. It was reported that, besides the fact that it caused mass deaths in the past, air pollution nowadays results in severe health problems such as lung cancer, stroke, and cardiac diseases and leads to the death of 7 million individuals annually worldwide (Cetin et al., 2019; Ghoma et al., 2022; Jo et al., 2020).

Many factors deteriorating the typical composition of air, including CO_2, particle matters, and various gases, are called pollutants (Elsunousi et al., 2021). Among these pollutants, heavy metals (HMs) are considered the most dangerous and harmful ones because they threaten living organisms (Aricak et al., 2019; Sevik et al., 2020a). HMs bioaccumulate within organisms and can be poisonous, carcinogenic, and lethal even at low amounts, but some of them both are structural components for living beings and can even be unsafe when at high concentrations (Bozdogan Sert et al., 2019; Turkyilmaz et al., 2020). Besides that, since the half-life of HMs is very long, they cannot be easily degraded in nature (Cesur et al., 2021). Thus, it is vital to track the alterations in HM concentrations in the air.

However, the HMs in the air are more defined, and it is complicated and expensive to measure them directly. Furthermore, direct and instant measurement of the concentration of heavy metals (HMs) in the air does not provide information about their accumulation in media and their effects on the environment. For these reasons, biomonitors are used in tracking the differences of HMs concentrations in air, and plants are among the most useful biomonitors (Cetin et al., 2020; Karacocuk et al., 2022; Cetin & Jawed, 2021).

The first living things used as biomonitors in monitoring HM pollution in the air are mosses and lichens. In the 1960s, lichens were determined to be sensitive to gases such as SO_2 and tend to accumulate many elements in amounts much higher than their physiological needs. Mainly algae and bryophytes, which are plant groups that include mosses, liverworts, and hornworts, have been used since the 1970s as biomonitors in monitoring HM pollution (Sulhan, 2021). In the following years, organs such as bark and wood, especially the leaves of perennial plants, were used as biomonitors for many years, and many studies were conducted (Isinkaralar et al., 2022). However, it is difficult to determine how long non-evergreen plants and bryophytes are exposed to the pollutant (Savas et al., 2021; Sulhan, 2021). Deciduous plants can provide information about only one year of accumulation (Cetin & Jawed, 2021), while studies on needles of species such as Picea and Abies provide a maximum of 8–10 years of historical information (Cesur et al., 2022). These have led to studies on new opinions that can be used as a biomonitor (Cetin et al., 2022).

It is stated that reliable and longest-lasting information on this subject can be obtained through studies on the annual rings of trees (Isinkaralar, 2022a, 2022b). Dendrochronological approaches have been used for more than a century, providing us with a chronology of climate, fire, floods, human activities (archaeology), mudslides, and other biological and geological events (Balouet et al., 2009). Dendrochemical approaches have been used to observe historical changes in atmospheric and soil chemistry since the early 1970s (Watmough, 1997). Lepp (1975) stated many years ago that annual tree rings are a potential use for observing temporal alterations in environmental trace metal levels. Fritts (1976) stated that it is possible to use tree rings as temporal observers of environmental adjustment.

In the past years, devices such as spectrophotometer (Matusiewicz & Barnes, 1985) and then atomic absorption spectrometry were used to determine the HM concentrations in woody parts such as annual tree rings (Ehsan & Marshall, 2001; Martin et al., 2018). However, since the HM concentrations in the woody parts are quite low, inductively coupled plasma (ICP) devices have been used in the following years, which can determine the metal levels in more sensitive and lower concentrations. In recent years, ICP-AES (Eberhardt & Pan, 2013), IPC-OES (Isinkaralar, 2022a, 2022b), and ICP-MS (Nechita et al., 2021; Traxler et al., 2022) devices have been used in studies on this subject.

One of the most useful methods used in tracking the variation in HM concentrations in the air is the use of annual rings of plants. Previous studies reported a correlation between environmental pollution and the element concentrations in annual rings (Sevik, 2021; Sevik et al., 2020a, 2020b; Turkyilmaz et al., 2020). Thus, the use of the annual rings, especially in observing the chemical pollution, is considered a confirmed and reliable method (Lee et al., 2015; Liu et al., 2018; Perone et al., 2018). However, although studies on the use of annual tree rings as biomonitors have been carried out for a while, the amount of information on the speciation of HMs in the plant and their transition between organs is quite limited (Cesur et al., 2022; Isinkaralar, 2022a, 2022b). The current study aimed to determine the usability of annual tree rings of Turkish hazelnut in tracking the variation in Cd, Fe, and Al concentrations among the HMs in the air that are critical for environmental and human health.

2 Material and Method

The present study was conducted on a *Corylus colurna* L. (Turkish hazelnut) tree, which was grown in Müsellimler Village of Ağlı district in Kastamonu region (coordinates—41°38′13.14'' N, 33°30′13.60'' E) (Fig. 1) and found to be 180-year-old (19.3 m in height and 69.7 cm dbh) by counting the annual rings (Fig. 2). In the year 2020, the directions were marked in the tree's trunk, and a 10 cm-thick cross-sectional log sample was taken from approx. 50 cm height from the ground. The sample was taken to the laboratory, and its surface was sanded. When examining the widths of annual rings, it was determined that it would be appropriate to perform the examinations by clustering the annual rings into 10-year groups. Then, the samples were collected from barks (inner and outer bark) and wood by making use of a steel drill.

In studies on using annual rings as biomonitors, annual tree rings are generally combined for evaluation because of their widths. Annual tree rings can easily determine which year they are formed, but it is risky and challenging to take wood chips from the narrow annual rings due to mixing them. Therefore, annual tree rings are evaluated by grouping them according to their widths. For example, annual rings are grouped as five.

(Yigit, 2019), three (Isinkaralar, 2022b; Koç, 2021a, 2021b, 2021c; Savas et al., 2021), and two (Turkyilmaz et al., 2019) years. They determined the change in HM concentrations by grouping them and using the average values in these studies. As the tree's age and the annual ring width increase, the grouping spacing also increases. Key and Kulaç (2022) analyzed HM concentrations in the annual tree rings of a 180-year-old tree by grouping them over ten years. Therefore, considering the tree's age in the current study and annual ring widths, they were grouped as ten years, and samples were taken.

The samples were taken into petri dishes and kept at room temperature for a 15-day period. The air-dried sawdust samples were dried in an oven at 45 °C for a week. The samples weighed at 0.5 g were added with 2 ml 30% H_2O_2 and 6 ml 65% HNO_3. Then, they were placed into a specially designed microwave oven and combusted (at 180ºC temperature -under 280 PSI pressure) for about 20 min. After the completion of the procedure, the tubes were removed from the microwave and sat for cooling. Cool tubes were completed to 50 ml by using ultrapure water, and the analysis was performed using an ICP-OES device (GBC Scientific Equipment Pty Ltd., Melbourne, Australia). The results were multiplied by the dilution factor, and the concentrations of Cd, Fe, and Al were calculated.

This method is widely used in recent studies in HMs (Cesur et al., 2022; Sevik et al., 2019; Turkyilmaz et al., 2019). The results were analyzed using variance analysis (ANOVA) and Duncan's test in SPSS 21.0 software package program.

3 Results

3.1 Change in Elements by Organ and Direction

The data and analysis results regarding the change in Cd concentrations by direction and organ are given in Table 1.

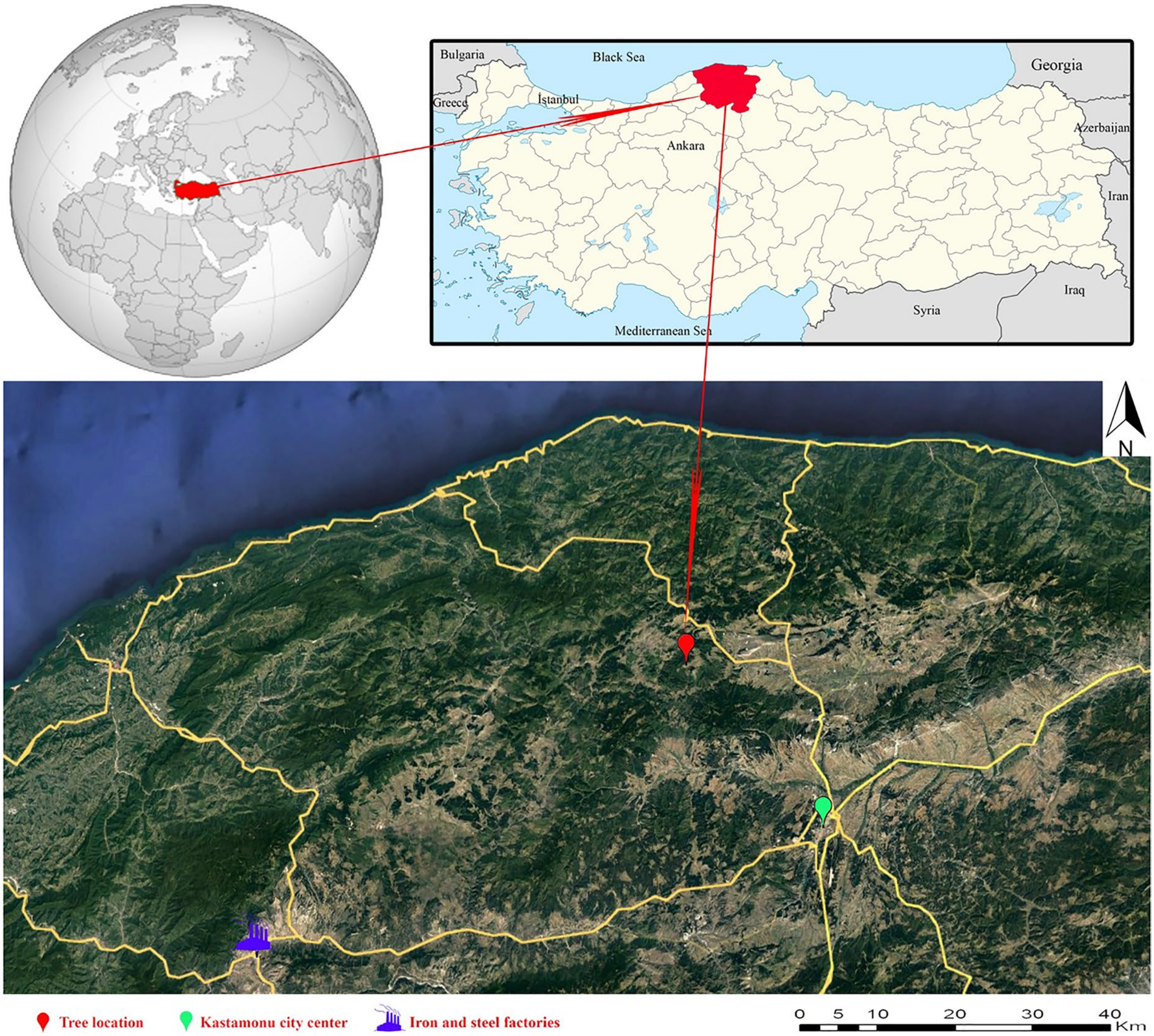

Fig. 1 Location of Turkish hazelnut tree and iron & steel factories

As seen in Table 1, Cd concentration levels were significant only in the organs in the north direction ($p < 0.01$). The organs in the north gathered in two groups that wood had lower Cd concentration values than bark samples. The variation in Cd concentration based on the direction was significant in all the tree organs ($p < 0.001$). Given the results obtained from Duncan's test, it can be seen that all the values obtained from all the organs in the east were in the first group. The highest values were found in the south in inner bark and west in wood and outer bark. The variations in the concentration of Fe by organ and direction and Duncan's test results are presented in Table 2.

Examining the changes in Fe concentrations, it was found that there was no considerable difference by the organs in the south ($p > 0.05$). However, the changes by organs in all other directions and changes by directions in all other organs were statistically significant. Duncan's test results indicated that wood samples had the lowest Fe concentration than barks in all directions. The highest values were observed from outer bark in the east and west and inner bark in the north. Considering the direction, there were two groups: the west was in the first group, and the other directions were in the second group. In outer bark, the lowest concentration was obtained in the south and the

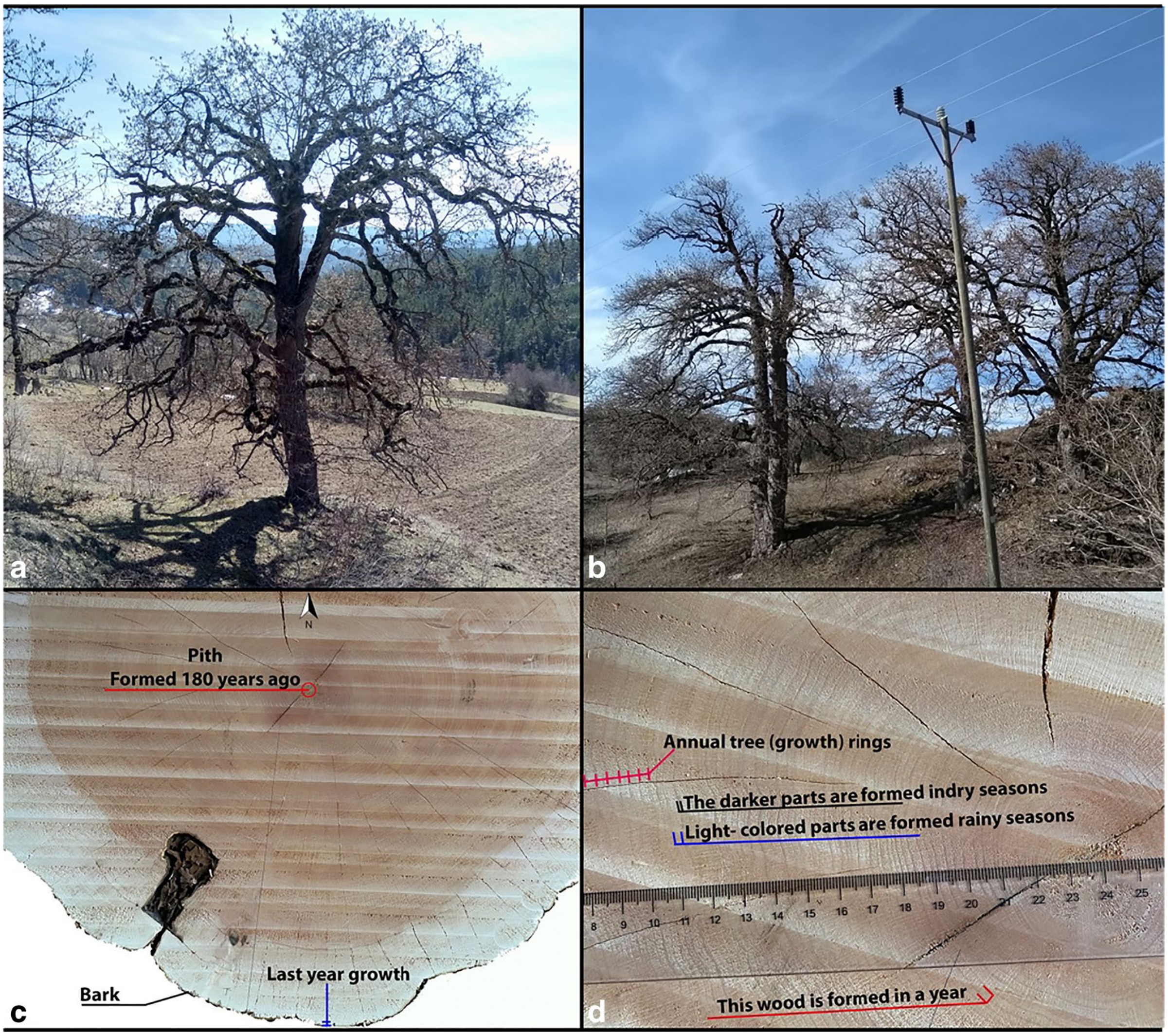

Fig. 2 **a)** Turkish hazelnut tree, **b)** its environment, **c)** log sample, and **d)** cross section of log

Table 1 Changes in Cd concentrations (ppb) by direction and organ

Organ	South	West	North	East	F value
Outer Bark	409.1 B	412.4 C	405.0 Bb	195.1 A	4540.1***
Inner Bark	418.8 D	392.5 B	401.0 Cb	188.4 A	3166.5***
Wood	435.2 B	460.3 B	275.8 Aa	265.8 A	38.0***
F value	0.2 ns	0.3 ns	5.4**	1.7 ns	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions. ns: not significant. $** = p < 0.01$; $*** = p < 0.0.001$

highest one in the east, whereas the lowest value in inner bark was obtained in the east and the highest concentration levels in the north. The Al concentration changes by organ, and direction and the statistical analysis results are shown in Table 3.

Given the changes in Al concentrations, it can be seen that all the changes by organ in all directions and all the changes by directions in all the organs were statistically significant. The results of Duncan's test showed that the change in Al concentration was in the order of wood < inner bark < outer bark. Considering the directions, there were two groups in wood; the west was in the first group, and all other directions

Table 2 Fe concentration changes (ppm) by direction and organ

Organ	South	West	North	East	F value
Outer Bark	16.0 A	248.6 Db	30.4 Ba	123.9 Cb	9121.3***
Inner Bark	23.6 B	147.4 Cab	200.6 Db	9.9 Aa	301,126.3***
Wood	44.2 A	71.8 Ba	20.6 Aa	40.8 Aa	4.7**
F value	0.665 ns	3.9*	91.8***	3.8*	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions. ns: not significant. * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Table 3 Al concentration changes (ppm) by direction and organ

Organ	South	West	North	East	F value
Outer Bark	7.1 Ab	199.8 Dc	17.4 Bb	77.5 Cb	116,998.6***
Inner Bark	6.1 Bb	31.1 Cb	4.9 Aa	5.0 Aa	90,135.6***
Wood	3.7 Aa	8.5 Ba	5.2 Aa	8.8 Ba	5.227**
F value	7.4**	2226.2***	5.4**	38.8***	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions. ns: not significant. ** = $p < 0.01$; *** = $p < 0.001$

were in the second group. While the lowest value was found to be in the south and the highest one in the west in outer bark, the lowest concentrations were obtained to be in north and east and the highest one in the west in the inner bark.

4 Changes in the Concentrations of Elements in Annual Rings by Periods and Directions

The changes in Cd concentrations in annual rings by periods and directions and the statistical analysis results are shown in Table 4.

The results of ANOVA showed that there were significant differences between Cd concentrations by the period in whole directions and by direction in all year periods ($p < 0.001$). Given the results achieved, it can be seen that the maximum value was obtained to be 1203.8 ppb in the oldest period in the west, and it was much higher than the other values. When examining the results without considering this finding that seems to be an anomaly, it can be seen that the concentrations of Cd in west and south directions ranged within a narrow range in general. Cd concentration, which coursed within a narrow range in the north until 1970 and did not exceed 226.1 ppb, almost doubled since the 1971–1980 period and then coursed horizontally. A completely contrary finding was achieved for the east. Cd concentration, which did not go down below 393 ppb in the period 1861–1920, decreased almost to its half since then and did not exceed 200 ppb to date since then.

The Fe concentration changes in annual rings by period and direction, and the statistical analysis results are presented in Table 5. Examining the variations in Fe concentration by period and direction, it was determined that there were significant changes by the period in four directions and direction in all year periods ($p < 0.001$). Given the changes, it can be stated that Fe concentrations ranged irregularly; they sometimes abnormally increased (in the west direction in period 2001–2010, the east direction in period 1911–1920 and 1891–1900). However, it cannot be stated that the change in Fe concentration either by period or direction is regular.

The Al concentration changes in annual rings by period, and direction and the statistical analysis results are presented in Table 6. As in Cd and Fe concentrations, the results of variance analysis showed that Al concentrations statistically significantly ranged by the period in four directions and by direction in all year periods ($p < 0.001$). Examining the changes by period, it can be seen that they

Table 4 Cd concentration changes (ppb) in annual rings by periods and directions

Periods	South	West	North	East	F value
1841–1850	393.6 Cab	1203.8 Dk	188.4 Aa	201.6 Bb	29,237.3***
1851–1860	396.3 Bb	423.6 Ch	224.5 Ade	217.6 Ad	2262.0***
1861–1870	394.3 Bab	396.5 Bcd	222.6 Ade	395.3 Be	4871.5***
1871–1880	392.6 Bab	402.2 Cdef	224.1 Ade	407.6 Cf	1756.1***
1881–1890	406.4 Bc	456.8 Di	226.1 Ae	416.8 Cg	1839.0***
1891–1900	397.6 Cb	386.2 Ba	223.4 Ade	393.2 Ce	1707.2***
1901–1910	426.4 Dgh	385.3 Ba	220.6 Acd	395.5 Ce	2221.9***
1911–1920	392.2 Cab	384.1 Ba	221.7 Acde	398.5 Ce	1426.9***
1921–1930	417.0 Def	404.3 Cef	224.2 Bde	193.7 Aa	8100.0***
1931–1940	452.6 Di	397.2 Ccde	223.0 Bde	191.2 Aa	5850.6***
1941–1950	388.4 Ca	413.0 Dg	220.1 Bcd	197.5 Aab	2380.6***
1951–1960	679.8 Ck	394.2 Bbc	217.1 Abc	211.6 Ac	7732.9***
1961–1970	430.4 Ch	427.0 Ch	214.2 Bb	193.7 Aa	5112.2***
1971–1980	418.2 Bef	412.0 Bg	414.9 Bh	197.0 Aab	2283.4***
1981–1990	422.6 Cfg	404.9 Bf	436.4 Di	193.1 Aa	7381.1***
1991–2000	414.0 Cde	388.8 Bab	409.8 Cg	196.6 Aab	3405.8***
2001–2010	602.6 Cj	620.8 Dj	453.2 Bj	192.1 Aa	6658.7***
2011–2020	408.9 Dcd	384.7 Ba	401.1 Cf	192.9 Aa	2461.4***
F value	1115.5***	6689.6***	3599.7***	2598.7***	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions.
ns: not significant.
$*** = p < 0.001$

Table 5 Fe concentration changes (ppm) in annual rings by direction and period

Periods	South	West	North	East	F value
1841–1850	111.1 Cl	122.5 Dk	6.1 Ad	62.2 Bn	131,576.8***
1851–1860	5.0 Aa	18.9 Cef	8.0 Bh	31.5 Dk	15,849.9***
1861–1870	11.2 Bc	126.0 Dl	7.1 Afg	13.6 Ce	165,567.6***
1871–1880	119.2 Cm	19.5 Bf	3.3 Aa	148.4 Do	35,911.9***
1881–1890	11.0 Ac	111.5 Dj	60.8 Cö	27.2 Bj	290,652.4***
1891–1900	212.1 Dn	21.4 Bg	39.1 Co	16.2 Af	38,433.4***
1901–1910	22.6 De	12.9 Bb	7.2 Ag	21.4 Ch	24,464.6***
1911–1920	26.8 Cg	17.1 Bd	4.2 Ab	231.6 Dö	42,569.1***
1921–1930	20.3 Dd	18.7 Bef	6.6 Ae	19.2 Cg	26,390.8***
1931–1940	29.3 Dh	12.2 Bb	12.7 Cj	11.2 Ad	3860.6***
1941–1950	9.1 Ab	169.8 Cm	32.5 Bn	9.6 Ac	68,943.0***
1951–1960	24.8 Cf	15.6 Bc	10.6 Ai	42.5 Dm	67,828.0***
1961–1970	38.0 Ci	50.3 Di	23.5 Am	24.4 Bi	13,221.1***
1971–1980	10.9 Ac	24.1 Ch	22.6 Bl	11.4 Ad	450.9***
1981–1990	26.9 Dg	19.2 Cf	5.4 Ac	7.1 Bb	31,159.2***
1991–2000	20.2 Ad	17.9 Cde	20.6 Ak	40.9 Bl	118,839.8***
2001–2010	54.7 Dk	510.4 Cn	6.7 Aef	10.0 Bc	15,804.6***
2011–2020	42.5 Cj	4.5 Aa	93.5 Dp	5.9 Ba	30,162.9***
F value	3370.4***	91,309.7***	33,604.3***	51,791.3***	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions.
ns: not significant.
$*** = p < 0.001$

generally coursed within a narrow band in the south and yielded the lowest values, whereas the concentrations remained relatively high until the period 1890 but then started decreasing and coursed almost horizontal track. In the north, it did not exceed 10 ppm except for the periods 1881–1890 and 1941–1950 and

Table 6 Al concentration changes (ppm) in annual rings by period and direction

Periods	South	West	North	East	F value
1841–1850	3.8 Bj	10.7 Dj	2.9 Ad	8.0 Ci	11,296.4***
1851–1860	1.8 Bb	2.0 Cb	0.8 Aa	10.1 Dl	9525.8***
1861–1870	2.0 Ac	5.5 Ce	2.6 Bc	11.4 Dm	72,864.1***
1871–1880	2.5 Be	4.0 Cd	0.8 Aa	63.2 Dn	3,260,413.3***
1881–1890	2.1 Ad	3.0 Bc	26.4 Dm	10.1 Cl	414,217.4***
1891–1900	2.6 Bf	15.2 Dl	9.8 Ck	1.9 Aa	68,666.4***
1901–1910	4.6 Cl	1.8 Ba	0.9 Aa	8.6 Dj	44,766.2***
1911–1920	4.5 Bl	12.8 Dk	3.8 Ag	9.9 Ck	13,309.9***
1921–1930	8.9 Dn	7.4 Cf	0.8 Aa	3.8 Bf	79,143.4***
1931–1940	3.4 Bh	8.9 Dh	4.6 Ci	2.6 Ad	3786.6***
1941–1950	1.6 Aa	10.7 Cj	17.2 Dl	6.9 Bh	4229.2***
1951–1960	4.3 Ak	7.3 Df	4.4 Bh	4.9 Cg	5893.6***
1961–1970	3.4 Bh	19.0 Dn	2.8 Ad	4.8 Cg	49,049.8***
1971–1980	3.7 Bi	9.6 Di	5.1 Cj	3.4 Ae	9201.7***
1981–1990	3.8 Cj	8.4 Dg	3.5 Bf	2.0 Ab	24,315.2***
1991–2000	4.6 Cl	16.9 Dm	3.3 Be	2.5 Ad	8285.8***
2001–2010	6.8 Cm	8.4 Dg	1.7 Ab	2.3 Bc	79,092.9***
2011–2020	2.8 Dg	2.1 Bb	1.7 Ab	2.1 Cb	3286.7***
F value	3370.4***	14,184.2***	18,673.7***	222,025.2***	

Different letters indicate significant differences. Lower case letter represents vertical directions, whereas capital letter represents horizontal directions.
ns: not significant.
***=$p < 0.001$

coursed a fluctuating track. In the west, even though it generally followed the fluctuating track, it increased since 1891, and, since then, the maximum values were generally detected in the western direction.

5 Discussion

The earth's crust consists of approximately 0.1–0.2 mg/kg of Cd (Masih et al., 2009). Cd is a dangerous element that causes several health problems, such as cardiovascular, respiratory, and skeletal systems, besides cancers of the kidneys, stomach, prostate, and lung (US EPA, 2010; WHO, 2011). In this study, the Cd concentrations showed a narrow range of change in the Turkish hazelnut tree's organs and annual rings. It was found that there was slightly more than 2 times the difference between the lowest and highest values detected from outer bark, inner bark, and wood in different directions. This finding suggests that Cd can be transferred within and between the organs. Cd is an element that is fairly mobile within the plants and accumulates in roods and leaf tissues (Kaur et al., 2021). Hence, Martin et al. (2018) reported that the source of Cd concentrations in annual rings of trees was the soil and Cd taken from oil moved from wood toward the bark. Seven et al. (2018) emphasized that, since Cd is a water-soluble element, it can be easily taken from the soil into and accumulated within the bodies of plants.

Considering Fe examined within the scope of this study, significant differences were found in Fe concentration by the organ in all directions; the highest values observed in wood were found in the east direction, followed by the south. Furthermore, comparing all the organs, the highest value (248.6 ppm) was found in the outer bark in the west. The tree examined here was located relatively far from the HM sources such as urban areas, traffic, and industrial facilities. However, the main iron and stainless steel facility in Turkey is at 88 km air distance from the tree's location in the southwestern direction. Previous studies determined that HMs can be transferred over hundreds of kilometers of distances by the wind (Shahid et al., 2017; Turkyilmaz et al., 2018; Karacocuk et al., 2022). A previous study found that the dominant element in particle materials near a steel and iron facility was Fe (Dai et al., 2015). These findings justify the high concentration of Fe in both wood and outer bark in south and west directions. Thus, high Fe concentrations in the wood part in the west and south directions can explain the abovementioned facility.

As a result, the highest Al concentrations were obtained in the west side for all the organs in this study. Moreover, the value detected from the outer bark in the west side (199.8 ppm) was extremely higher than other values. Al concentration found in outer bark in the west direction was more than 11 times higher than the concentration found in the north direction. As with Fe, the highest Al concentrations were obtained from the west direction; this finding could be explained by the presence of iron and steel facilities.

HMs can accumulate in the plant body by being absorbed by the root, from the air via the leaves, and entering the stem parts directly (Cesur et al., 2022; Chen et al., 2021). Some of the HM content in the plant indeed originates from the soil. However, it should be accepted that the tree subject to the study is 180 years old, the amounts of Cd, Fe, and Al in the soil are limited and consumed in a short time, and the amount of metal absorbed from these regions is limited as the tree roots go deeper. The soil-borne HM accumulation is ignored because the element concentrations in the woods formed in different directions in the annual rings formed in the same year are at different levels. Also, there are significant differences between these concentrations. These results show that the elements in the air enter wood through the leaves or directly to the stem parts, both of which are formed depending on the amount of HMs in the air.

Interestingly, the highest values of both Fe and Al were obtained from the outer bark on the west side. As reported in many studies, industrial facilities are among the most important sources (smelters, petrochemical plants, chemical industries, untreated sewage sludge, and diffuse sources, such as traffic, metal piping, and coal-burning power plants) of HM (Jeong et al., 2021), and HMs can be conveyed hundreds of kilometers away from their sources by wind (Turkyilmaz et al., 2018). Particle matters play a critical role in the transportation of HMs. Particle materials act as a sink for HMs, and the HM-contaminated particles can be conveyed to far distances and adhere to the plant tissues (Koç, 2021c). The porous structure of bark makes it easier for HM-contaminated particles to stick on the bark surface (Koç, 2021c). Previous studies reported that HM concentrations were at a very high level in outer bark in case of a high level of HM pollution (Cesur et al., 2021; Sevik et al., 2020b, 2020c).

It was explored that the most suitable method to be used in tracking the variation in HM concentration levels in the air is the annual tree rings of plants (Koç, 2021c). The most important advantages of this method are as follows. The current method can provide information about the change within a long time, allow year-based comparisons, and minimize the potential failure to arise from genetic structure differences between different plant species (Sevik, 2021).

Thus, the annual rings of trees are among the most useful instruments in determining the variation in HM concentrations in air. However, it should be separately determined which tree species is suitable for which HM. Only very few of the previous studies examined the HMs examined here. In previous studies, the concentrations of Cd were monitored using annual rings of *Quercus* sp. (Turkyilmaz et al., 2019), *Malus floribunda* (Yigit, 2019), *Cupressus arizonica* (Cesur et al., 2021), *Pinus massoniana* (Chen et al., 2021), *Acer platanoides* (Turkyilmaz et al., 2018), those of Fe by using annual rings of *Quercus* sp. (Turkyilmaz et al., 2019), *Malus floribunda* (Yigit, 2019), *Pinus massoniana* (Chen et al., 2021), *Acer platanoides* (Turkyilmaz et al., 2018), and *Cedrus* sp. (Sevik et al., 2020a, 2020b, 2020c), and those of Al by using annual rings of *Quercus* sp. (Turkyilmaz et al., 2019), *Malus floribunda* (Yigit, 2019) and *Acer platanoides* (Turkyilmaz et al., 2018).

However, the results achieved from the studies are not satisfactory yet. First of all, we still do not have sufficient knowledge about the intake of HMs into plant organisms. Although many studies (Turkyilmaz et al., 2018) reported that many studies are influencing the intake of HM into the plant body such as plant species, HM structure, organ structure (surface area, tissue, surface structure, etc.), interaction with HM and plants and organ, duration of HM exposure, atmospheric conditions (humidity, precipitation, wind, etc.), but there is ono study providing sufficient information about the levels of these factors' effects (Shahid et al., 2017; Karacocuk et al., 2022). In addition, HM accumulation in plants is formed under the mutual interaction of genetic structure and environmental factors (Savas et al., 2021). Therefore, genetic differences in different plants may affect HM accumulation even in the same species. Therefore, evaluating HM concentration levels in plant organs formed in different years in the same plant will provide more accurate results as it will eliminate genetic structure-related errors (Cesur et al., 2022; Sevik et al., 2020a).

There is only limited information about the speciation and transfer (between organs) of HMs after their intake into the plant (Savas et al., 2021). For instance, Zhang (2019) reported that Zn and Pb elements were transferred within the woods of *Cedrus deodora* to a certain degree, but the Cu element remained almost immobile. Koç (2021c) reported that Ni had a very limited transfer in the wood of *Cedrus atlantica*, but the same did not apply to Co. Cesur et al. (2021) determined a limited transfer of Cd and Ni in *Cupressus arizonica* woods. Hence, there is only limited information about the factors affecting the intake of HMs into plant bodies and their behavior after intake (Binda et al., 2021).

6 Conclusions and Suggestions

Given the results achieved, Cd concentration ranged within a narrow band in both organs and annual rings of Turkish hazelnut. It suggests that Cd was transferred within the woods of this tree species. Hence, annual rings of Turkish hazelnut cannot be used in tracking the variation in Cd concentrations. However, it was concluded that there were notable differences in Fe and Al concentrations in woods that have formed in consequent periods and the same period. These results suggest that Fe and Al concentrations are transferred within the wood in a limited manner. Hence, annual rings of Turkish hazelnut trees can be used in tracking the variation in Fe and Al concentration levels in the air from the past to date.

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Declarations

Conflict of interest The authors declare that they have no known competing interests in this paper.

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