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ORIGINAL PAPER

Change of Cr concentration from past to present in areas with elevated air pollution

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Abstract
Chromium (Cr) is one of the most detrimental heavy metals, the concentration of which has increased significantly in nature in the last century. Cr pollution can cause toxic and harmful health effects by causing high accumulation levels in animal and human tissues, seriously affecting ecosystems and natural resources. Due to environmental and human health risks, it is critical to track the change of Cr pollution in the air and reduce it. This study aims to determine the suitable tree species that can be used for observing and reducing Cr pollution. For this purpose, samples (wood, inner bark and outer bark) taken from *Pinus pinaster*, *Cupressus arizonica*, *Picea orientalis*, *Cedrus atlantica*, and *Pseudotsuga menziesii* species grown in Düzce, Türkiye, which is among the 5 most polluted cities in Europe according to the World Air Pollution 2021 Report, were examined. The accumulation of Cr concentration was determined by species (40-year-old), organ, and direction, and changes in age range were evaluated. As a result of the study, while the highest concentration levels were determined in the outer bark in general, it was interpreted that the branching structure affected this situation. The study results reveal that, in general, Cr pollution is mainly caused by traffic. It has been determined that *C. arizonica* and *P. menziesii* are the suitable tree species that can be used for observing and reducing Cr pollution in the air.

Keywords Air pollution · Chromium · *Cupressus arizonica* · Heavy metal · *Pseudotsuga menziesii*

Introduction

In the last century, environmental pollution has become one of the most crucial problems worldwide (Çetin et al. 2020; Isinkaralar 2022). Increasing air pollution due to anthropogenic origin is one of the most critical agenda items due to its indirect effects such as global climate change, decrease in biodiversity, various diseases and deaths in living things, as well as directly threatening living creatures and ecosystems (Varol et al. 2021; Tekin et al. 2022; Sulhan et al. 2022). It is stated that more than 7 million deaths worldwide are caused by environmental pollution every year (Key et al. 2022).

Heavy metals are among the most damaging pollution factors on living things and ecosystems (Ghoma et al. 2022) because they can be harmful to living things even at low concentrations and remain in nature for a long time (Yayla et al. 2022). Among the heavy metals, chromium (Cr) is one of the most harmful ones, and Cr pollution seriously affects the ecosystem and natural resources, especially water and soil (Prasad et al. 2021).

Cr element is naturally found in rocky soils and volcanic dust. According to the International Agency for Research on Cancer, it is classified as a carcinogen (Sharma et al. 2020). Moreover, it is on the priority contaminant checklist of the Agency for Toxic Substances and Disease Registry. Cr is released from diverse anthropogenic and natural actions (Hossini et al. 2022). In the last few decades, its contamination in terrestrial and aquatic ecosystems has increased due to various anthropogenic activities. Cr contamination is a crucial environmental threat that seriously affects the natural and environment resources, primarily soil and water. Overexposure to Cr can direct to higher accumulation levels in

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animal and human tissues, resulting in poisonous and harmful health consequences. Many studies have shown that Cr is a toxic element that adversely simulates plant metabolic activities (Prasad et al. 2021).

Cr-contaminated water and soil eventually ruin the crop and enters the food chain, posing severe health hazards to humans (Singh et al. 2013). Trivalent (Cr^{3+}) and hexavalent (Cr^{6+}) Cr, the two most common oxidation forms, have entirely different toxicity and necessity in human health and soil. Cr^{6+} is often more poisonous than Cr^{3+} due to its specific solubility and high mobility (Shanker et al. 2005). Cr^{6+} has no known biological function and is a potent carcinogen (Monga et al. 2022). Bioaccumulation and chronic exposure to Cr as a harmful heavy metal cause toxicity and several pathophysiological flaws, such as burns, anemia, allergic reactions, and wounds, especially in the small intestine and stomach, and harm to the man reproductive system as well as sperm (Hossini et al. 2022). It also causes kidney, liver, lung cancer, and stomach damage, and sensitization and epidermal irritation (Kimbrough et al. 1999). Cr also has detrimental effects on plants, such as toxic effects on plant development, including changes in the germination cycle and the development of roots, leaves, and stems, which can simulate yield and total dry matter production (Shanker et al. 2005).

Due to these damages, monitoring and reducing Cr pollution is extremely important, which poses a significant threat to the ecosystem and living things. Observing and reducing the Cr element concentration change in the airborne is critical, which is extremely harmful, especially if inhaled into the human body (Yayla et al. 2022; Isinkaralar et al. 2022a). However, it is tough to track heavy metal pollution in the air due to the difficulty of straight observing methods, sampling, small concentrations of contaminants, and obtaining information about the change in the process (Koç 2021; Key and Kulaç 2022).

Therefore, plants have been used in phytoremediation studies to observe the change in metal contamination in the atmosphere and reduce pollution for many years (Sevik et al. 2020; Isinkaralar et al. 2022b, 2023). In the 1960s, mosses and lichens were the first living organisms used as biomonitors to observe heavy metal air pollution. In the following years, many studies were conducted on using perennial plant organs (branches, leaves, and annual rings) as biomonitors (Cesur et al. 2021; Isinkaralar et al. 2022a). In addition, information is obtained about the accumulation of deciduous species in the last year (Cetin and Jawed 2021), and a max of 8–10 years of evidence can be obtained in studies on evergreen coniferous species (Cesur et al. 2022). However, studies on annual rings of woody species provide us with longer-term data. Primarily as a result of studies in the field of dendrochemistry and examining the chemical design of annual tree rings, essential information can be obtained on the contamination history and transport of chemical elements (Watmough 1997; Balouet et al. 2009), and this method has been extensively used in lately (Liu et al. 2018; Cesur et al. 2021).

However, studies have shown that different trees have distinct possibilities to accumulate some heavy metals in diverse organs and that heavy metal accumulation can be at different levels both in wood and other parts of trees grown in the same environment (Yayla et al. 2022; Karacocuk et al. 2022). Therefore, selecting the appropriate tree species in dendrochemistry and phytoremediation studies is very important. This study aims to determine the most suitable plant species that can be used to define the variation of Cr concentration in the air from the past to the present and to reduce pollution in Düzce, one of the cities with the highest air pollution in Europe. For this purpose, five species (*Pinus pinaster*, *Cupressus arizonica*, *Picea orientalis*, *Cedrus atlantica*, and *Pseudotsuga menziesii*) show optimum growth and development in regional conditions and which are most preferred in landscape studies, were preferred in the current study. These species are not natural for Düzce province, but they have been adapted to the region since they have been grown in this region for many years due to their high aesthetic value. In the observations, these species are often preferred because they are durable, have low maintenance costs, and are evergreen, shading, and screening. Due to these features, these species have been determined to be used intensively between roads and pavements and landscaping in parks.

Materials and methods

The study was conducted in only Düzce city, where air pollution is relatively high. Düzce, located in the Western Black Sea region of Türkiye (40°49′36.97″ N–31°10′31.40″ E) (Fig. 1), is among the 5 most polluted cities in Europe (PM2.5 averaged 44.4 µg/m^3) according to the 2021 World Air Pollution Report (IQAir 2021).

While a big part of Düzce consists of mountains, approximately 15% of the province is plain (140 m a.s.l.). Düzce plain, where Düzce city is located, is shaped like a concave or bowl because it is surrounded by mountain ranges from north to south and west to east (Özdede and Ak 2022). In Düzce, which is influenced by three climate types, summers are hot, winters are mild, and all seasons are rainy. According to the data between the years 1991–2021, the average annual temperature in Düzce is 12.6 °C and the monthly average precipitation amounts during the vegetation period (March-October) are respectively 46.9, 44.5, 51.0, 40.2, 14.8, 14.6, 17.9, 33.4 mm (MGM 2023). In Düzce, precipitation is more intense in autumn and winter.

Fig. 1 Sampling point, study area and its environment

Annual average wind frequency data of the Düzce Meteorology Provincial Directorate (2013) show that the prevailing wind direction is in the northeast-southwest (NE-SW) axis, and the average wind speed in the city is 0.7 m/s. However, the prevailing wind direction varies according to seasons and months (Özdede and Ak 2022). The fact that mountains surround Düzce province causes a decrease in wind speeds and causes fog and pollution to settle over the city and disperse late in the winter.

There are 5 large-scale industrial sites in Düzce and many small-scale industrial sectors. The sectors that have the highest number of facilities and employment in Düzce are; the textile industry, metal-machinery industry, food industry, forest industry, furniture industry, rubber-tire-plastic industry, mining industry, construction industry, automotive industry and chemical and pharmaceutical industry (Düzce Valiliği 2023). Düzce is shown as one of the 5 cities with the most polluted air in Europe. In the measurements made, it was determined that PM2.5 in the air increased up to 244.83 μg/m^3 and PM10.0 up to 386.31 μg/m^3 (Çevre, Şehircilik ve İklim Değişikliği Bakanlığı 2023).

Within the scope of the study, the main trunks of *Pinus pinaster* Aiton. (Pp), *Cupressus arizonica* Greene (Cpa), *Picea orientalis* L. (Po), *Cedrus atlantica* (Endl.) Manetti ex Carriere (Cda), and *Pseudotsuga menziesii* (Mirb.) Franco (Pm) species were cut by marking the north direction at the end of the vegetation season of 2022. Ten cm thick log samples were taken approximately 50 cm from the cut surface of the trunk. The log samples were brought to the laboratory and smoothed with a planer, and the annual rings were made visible. As a result of the annual ring count and examination, it was determined that the trees were about 40 years old. Considering the width of annual tree rings, they were clustered over five years, and specimens were taken from the inner bark (IB), outer bark (OB), and woods (WD) of all age groups using a steel drill. The study was carried out in three replications. The samples (in the form of sawdust) were placed in glass petri dishes and sat there for 2 weeks to become air-dry. Then the specimens were oven-dried at 45 ± 5 °C for one week. Dried samples (0.5 g) were taken, 6 ml of 65% HNO_3 and 2 ml of 30% H_2O_2 were added, and the samples were seated in the microwave oven developed for this analysis. Then samples were put into flasks and added up to 50 ml of ultrapure water. The prepared samples were analyzed with the ICP-OES (Inductively Coupled Plasma-Optic Emission Spectrometer, GBC Scientific Equipment Pty Ltd., Melbourne, Australia) device, and the Cr concentrations were computed by multiplying the acquired values with the dilution ratio. The laboratory where the analyses were made is accredited, and the detection limit for GBC Integra XL–SDS-270 ICP-OES device is 0.311 ppb for Cr. The method used in the study is frequently used in recent studies on this matter (Turkyilmaz et al. 2020; Çobanoğlu et al. 2022; Karacocuk et al. 2022).

The obtained data were analyzed by using SPSS 22.0 package program. The Duncan test was applied for the factors with significant differences of at least a 95% confidence interval ($P < 0.05$) by using variance analysis (ANOVA) to the data. Thus, the variation of Cr element concentration based on tree species, direction, organ, and year range was determined and evaluated separately.

Results and discussion

The variation of Cr concentration by species type and direction is illustrated in Fig. 2. The variation in Cr element concentration is noteworthy ($P \leq 0.05$) in all species based on direction and in all directions based on species. It is noticed that there is a notable alteration between the Cr concentrations obtained in different directions in all species. Notably, the lowest concentrations are found on the south side for Pp, Cda, and Pm, while on the west side for Cpa and Po. In addition, it is noticed that the highest Cr values are found on the east side for all species except Cda. The highest average Cr values on the north and east side in Cpa and the values on the north and west side in Pm are close to each other.

The variation of Cr concentration based on age range in the wood and direction is illustrated in Fig. 3. The highest Cr values are seen on the east side, and the lowest rates in the south and west side. The Cr values on the east and west sides increased from 1985 to 2000 and then decreased. On the other hand, the Cr values in the south side decreased until 2000, then increased. The Cr values on the north side almost showed the same trend throughout the time period.

The variation of Cr concentration by plant part and direction is given in Fig. 4. The variation in Cr element concentration in the organs was significant ($P \leq 0.05$) only in the north and south directions. The highest values in directions were obtained in the IB, while the minimum concentrations were in the north and west in the OB organ and the east and south in the wood. Generally, the lowest values in IB and WD were found on the south side and the maximum in the east and north.

The variation of Cr element concentration by organ and species is illustrated in Fig. 5. It is clear that the highest Cr

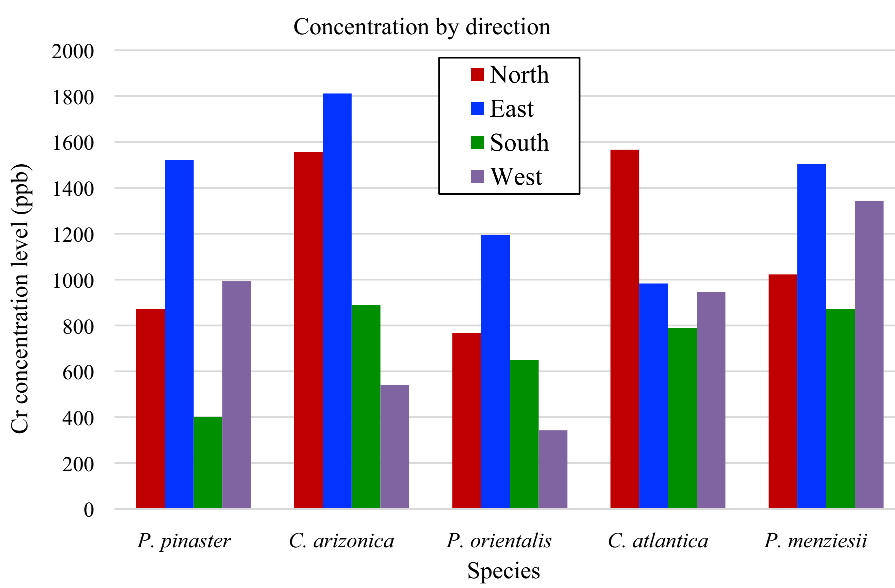
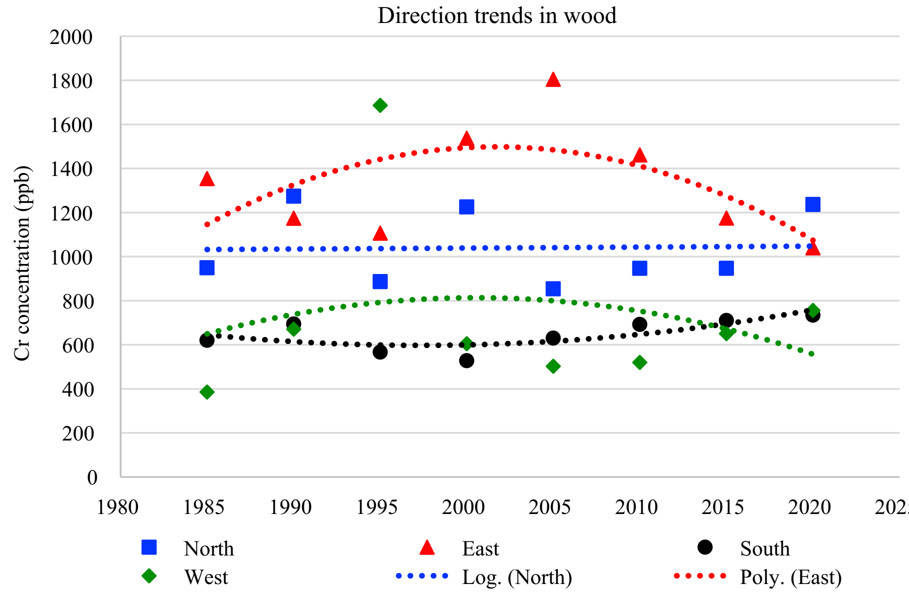


Fig. 2 Variation of Cr concentration levels by species and direction

Fig. 3 Variation of Cr concentrations based on age range and direction



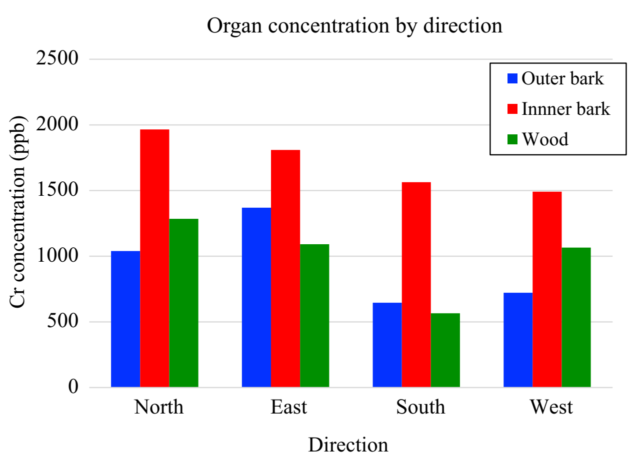


Fig. 4 Variation of Cr concentrations based on plant part and direction

concentrations are obtained in IB in Pp, followed by Cpa and Pp species. In WD, the highest Cr values are seen in Po, while the lowest is in Cpa. There is no significant variation in OB for all species.

The variation of Cr element concentration by period and species is illustrated in Fig. 6. It is seen that the Cr concentration was increased throughout 1985–2020 in Cpa and Po while the Cr values were highest in Cpa. The Cr concentration in Cda and Pm decreased until 2010, then stayed almost the same. However, the Cr concentration in Pp increased until 2005, then decreased until 2020.

Within the scope of the study, the difference in Cr concentration based on direction, organ, and age range was analyzed separately for each species, and the change of Cr concentration in Pp is given in Table 1. It is found that the variation in the Cr element rate in all directions based on age category and direction in all age ranges is at a statistically significant level ($P \leq 0.05$). Cr element concentration remained below the detectable limits in the south direction in 2003–2012 and east in 1988–1992. When the values are tested, the values obtained, especially in the east direction, are pretty high. In contrast, the values obtained in the south are generally the lowest. On the east side, where the highest values are found, the values obtained in 2003–2012 are quite high. Based on organs, the peak rates were acquired in OB in general. Again, in all organs, the maximum values are acquired in the east and the smallest in the south direction.

The variation of Cr concentration at Cpa is given in Table 2. According to the results of the ANOVA, the change of Cr concentration in Cpa in all directions based on age range and direction in all age ranges is at a momentous level ($P < 0.05$). When the results are reviewed, it is noted that the uppermost ratios are usually found in the east and the lowest ratios in the south and west sides. In the east aspect, where the highest ratios are acquired, the values obtained in 2003–207 are quite high. While there was no statistically substantial difference ($P > 0.05$) between the organs on the north and east sides, the highest concentration rates in the south and west sides were obtained in the OB.

The Cr element concentration variation in Po is given in Table 3. It is noted that the Cr element concentration in Po is statistically significant in all directions based on age range and direction in all age ranges. In the east direction, Cr concentration remained below the detectable limits in 2013–2022. When the values are tested, it is notable that the concentrations obtained, especially in the east direction, are quite high. In contrast, the values obtained in the west are generally the lowest. On the east side, where the

Fig. 5 Variation of Cr concentrations by organs and species

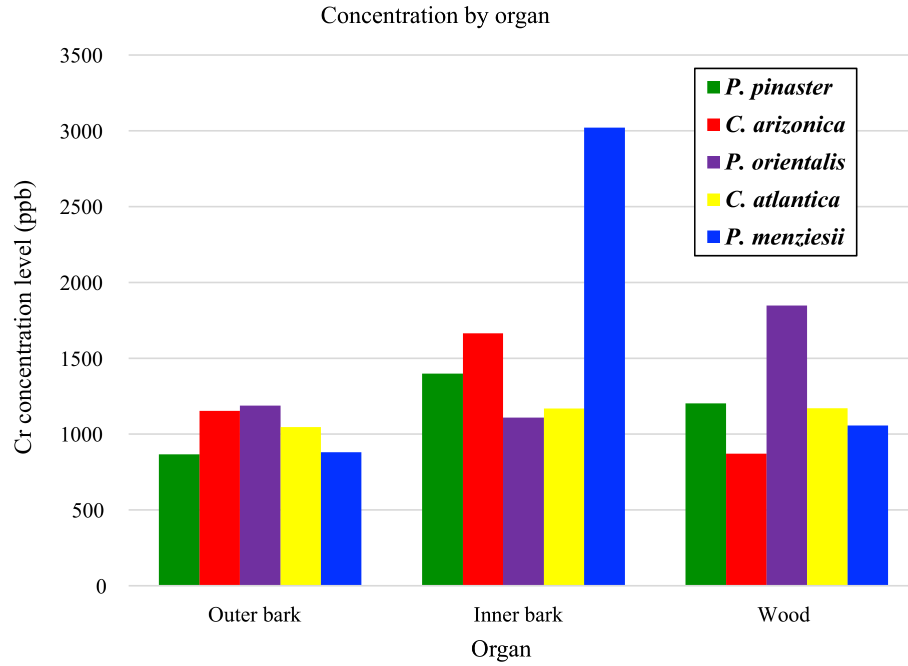
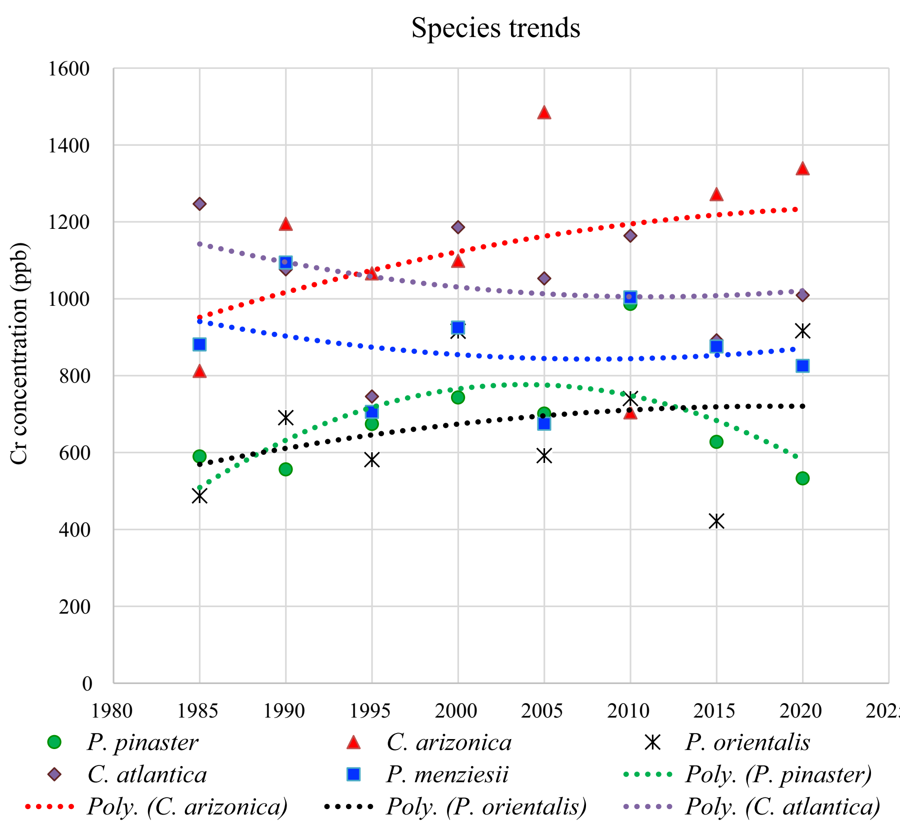


Fig. 6 Variation of Cr concentrations by period and species



highest values are found, the values obtained in 1988–1992 are quite high. Again, in all organs, it is seen that the highest values are found in the east, and the lowest rates are obtained in the west side.

The Cr element concentration variation in Cda is given in Table 4. As a result of ANOVA, it was found that the Cr concentration in Cda was statistically significant in all directions in terms of age range and direction in all age

Table 1 Variation of Cr element concentrations (ppb) in *P. pinaster* species

Age range	North	East	South	West	*F*-Value
2018–2022	725.3 Cd	705.2 Ca	416.0 Bd	284.8 Aabc	326.9***
2013–2017	531.0 Bc	1313.0 Cc	345.4 Ac	321.7 Ade	2963.5***
2008–2012	475.3 b	2190.3 e	UL	294.1 bcd	4017.8***
2003–2007	216.0 a	1561.8 d	UL	325.9 e	13,914.9***
1998–2002	1050.9 Bg	1343.0 Cc	295.7 Ab	282.8 Aabc	3884.5***
1993–1997	877.6 Be	1231.3 Cb	282.5 Aab	305.6 Acde	2067.0***
1988–1992	949.2 f	UL	457.2 e	261.9 a	2755.2***
1983–1987	482.5 Bb	1339.2 Cc	266.4 Aa	270.5 Aab	795.5***
F-value	361.3***	1198.7***	88.4***	6.8**	

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

UL Under limit, *ns* not significant

$^{**}P \leq 0.01$

$^{***}P \leq 0.001$

Table 2 Variation of Cr concentrations (ppb) in *C. arizonica* species

Age range	North	East	South	West	*F*-Value
2018–2022	3089.4 Dg	1464.8 Ca	484.5 Bb	319.4 Af	38,804.4***
2013–2017	1655.8 Dd	1236.4 Ba	1325.3 Cg	871.6 Ag	1504.0***
2008–2012	947.7 Ca	1171.7 Da	431.2 Ba	266.8 Ad	10,583.3***
2003–2007	987.1 Ab	4166.3 Bb	608.3 Ad	179.7 Abc	14.0**
1998–2002	1743.4 De	1709.0 Ca	642.9 Be	299.2 Ae	17,929.8***
1993–1997	1188.7 Bc	1577.0 Da	1299.2 Cf	198.7 Ac	1685.6***
1988–1992	2193.0 Df	1852.7 Ca	569.9 Bc	163.9 Ab	18,027.5***
1983–1987	996.6 Cb	1492.6 Da	651.1 Be	109.0 Aa	6696.1***
F-value	5348.1***	9.1***	7256.6***	1421.0***	

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

UL Under limit, *ns* not significant

$^{**}P \leq 0.01$

$^{***}P \leq 0.001$

ranges. It is seen that the Cr concentrations obtained, especially in the years 2003–2012 in the north direction, are quite high. Apart from that, the lowest rates were generally found on the south side.

The variation of Cr concentration in Pm is illustrated in Table 5. It is noted that the alteration of Cr element concentration in Pm in all directions based on age range and direction in all age ranges is statistically significant. However, Cr concentration was below the detectable limits in 1983–1987, 1993–1997, and 2013–2022 in the east direction, where relatively high values were obtained in other species. It is noted that the highest ratios are generally found in the west and east directions.

Variation of Cr concentration based on tree species, organ, and period

This study determined that the metal element subject to the study accumulated within the determinable limits in almost all samples. This indicates that the studied species have a high potential to accumulate heavy metals. It was determined that the Cr concentration increased up to 3021.5 ppb in bark and 4166.3 ppb in woods in this study. In the studies carried out on different species to date, it was determined that the Cr concentration in the barks increased up to 1588.4 ppb in *Cedrus atlantica* (Savas et al. 2021), 2691.3 ppb in *Cupressus arizonica* (Cesur et al. 2022), 4176.1 ppb in *Platanus*

Table 3 Variation of Cr concentrations (ppb) in *P. orientalis* species

Age range	North	East	South	West	*F*-Value
2018–2022	809.6 Bf	UL	1232.7 Cf	707.4 Af	667.7***
2013–2017	532.9 Bc	UL	547.1 Bd	185.4 Ac	2193.9***
2008–2012	502.5 Bb	1341.0 Dc	952.4 Ce	166.0 Abc	5844.2***
2003–2007	609.2 Ad	1029.8 Ba	570.8 Ad	157.8 Cb	240,037.6***
1998–2002	1263.6 Cg	1309.9 Dc	498.4 Ac	590.7 Be	3629.8***
1993–1997	671.3 Ce	1079.4 Db	332.4 Ba	242.4 Ad	2533.1***
1988–1992	515.4 Cbc	1754.2 Dd	315.1 Ba	177.9 Abc	2933.8***
1983–1987	345.6 Ba	1112.8 Db	388.4 Cb	103.4 Aa	1199.0***
F-value	881.2***	555.9***	7557.6***	987.0***	

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

UL Under limit

$^{***}P \leq 0.001$

Table 4 Variation of Cr concentrations (ppb) in *C. atlantica* species

Age range	North	East	South	West	*F*-Value
2018–2022	935.7 Aa	949.3 Ad	1141.4 Ce	1011.2 Cd	44.0***
2013–2017	955.7 BCa	974.4 Ce	688.8 Ac	948.5 Bd	382.3***
2008–2012	1981.8 Df	975.6 Ce	903.1 Bd	794.6 Ac	2062.0***
2003–2007	1958.8 Df	735.3 Bc	852.7 Cd	664.9 Ab	2061.3***
1998–2002	1611.2 Cc	1776.2 Dg	684.4 Bc	672.2 Ab	26,678.6***
1993–1997	1238.5 Db	538.4 Ba	409.6 Aa	796.0 Cc	115.4***
1988–1992	1683.8 Cd	587.9 Ab	516.1 Ab	1518.3 Be	349.3***
1983–1987	1736.8 De	1471.6 Cf	1312.8 Bf	465.6A a	2933.8***
F-value	2409.6***	3948.8***	153.8***	136.3***	

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

$^{***}P \leq 0.001$

orientalis, and 3937.6 ppb (Yayla et al. 2022) in *Ailanthus altissima*. In woods, it reached up to 1804.6 ppb in *Cedrus atlantica* (Savas et al. 2021), 150.6 ppb in *Acer negundo*, 187.1 ppb in *Ulmus minor*, 147.9 ppb in *Nerium oleander* (Karacocuk et al. 2022), 1024.9 ppb in *Thuja occidentalis* (Isinkaralar et al. 2022a, b), 1488.8 ppb in *Photinia serrulata*, 1609.3 ppb in *Cupressus arizonica* (Cesur et al. 2022), 3702.4 ppb in *Elaeagnus angustifolia*, and 1566.4 ppb in *Ailanthus altissima* (Yayla et al. 2022).

The most important feature desired in the species that can be used in the determination of metal contamination is the capability of the species to accumulate Cr elements that are the subject of the study. Studies show that each species has a different potential to accumulate different heavy metals (Karacocuk et al. 2022). Species that can accumulate heavy metals in the wood part, which constitutes an enormous mass of trees, provide a significant advantage in reducing heavy metal pollution (Cesur et al. 2022). In this study, it was found that there was no substantial distinction between the species. This result shows that all of the species in this study can be used to reduce Cr concentration in the air.

Another significant result of the study is that there was a large difference between the heavy metal levels in the plant parts in diverse sides formed in the identical period. This situation can be interpreted as a limited transfer of heavy metals between plant parts. Although studies on using annual rings of trees as biomonitors have been accomplished in the last decades, the knowledge on the speciation of heavy metals in trees and their shift between plant parts are pretty narrow (Koç 2021; Cobanoglu et al. 2023). For example, Zhang (2019) stated that in the annual tree rings of *Cedrus deodora*, zinc (Zn) and lead (Pb) concentrations shifted to a particular period, while the copper (Cu) concentration did not alter at all. It is stated that the allocation of nickel (Ni) in wood is restricted in *Cedrus atlantica*, and therefore, *Cedrus atlantica* annual tree rings are a convenient biomonitor for

Table 5 Variation of Cr concentrations (ppb) in *P. menziesii* species

Age range	North	East	South	West	*F*-Value
2018–2022	623.6 Bc	UL	396.8 Aa	1455.2 Cf	664.9***
2013–2017	1057.8 Cf	UL	643.5 Ae	926.1 Ba	347.1***
2008–2012	825.9 Bd	1628.8 Dd	483.3 Ab	1075.4 Cc	1414.3***
2003–2007	498.5 Ab	529.6 Bb	488.1 Abc	1183.2 Cde	4303.4***
1998–2002	456.7 Aa	1548.9 Dc	516.4 Bd	1177.5 Cde	5289.7***
1993–1997	456.4 Aa	UL	508.3 Bcd	1152.3 Cd	1278.7***
1988–1992	1030.0 Be	501.5 Aa	1613.7 Df	1231.1 Ce	5875.0***
1983–1987	1183.6 Cg	UL	481.6 Ab	978.1 Bb	998.6***
F-values	1238.5***	5550.3***	3036.4***	89.3***	

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

UL Under limit

***$P \leq 0.001$

tracking the alteration in Ni element concentration in the process, but this is not the case for cobalt (Co) (Koç 2021). *Cupressus arizonica* annual tree rings are claimed to be suitable for tracking the variation of Ni and Cd levels but not for bismuth (Bi) elements (Cesur et al. 2021). On the other hand, the results of this study can be interpreted as a limited level of Cr transition in wood in all species subject to the study.

The highest Cr rates are found in the east and north directions. The Ankara-İstanbul highway, which passes near the study area and is one of the busiest highways in Türkiye, passes through the northeast of the study area. According to these results, Cr concentrations increase significantly depending on traffic density. In studies on heavy metals, Cr is most linked with traffic density (Cetin et al. 2022; Savas et al. 2021).

Cr accumulation and transfer in plants

Plants can take up both Cr^{3+} and Cr^{6+}, but the mechanism of Cr absorbed by plant species stays undefined. Because Cr does not have a fundamental function in the metabolism of tree species, a distinct mechanism for plant Cr uptake has yet to be determined. The uptake of Cr^{3+} into the plant takes place in a passive process by diffusion in the cation exchange region of the cell wall (Singh et al. 2013); that is, no energy expenditure by the plant is required. Transporters consider Cr^{6+} uptake an active mechanism to uptake essential elements such as sulfate (Oliveira 2012). Mainly, plants take up Cr through transporters distinct for absorbing ions necessary for plant metabolism. It is claimed that plant species' ability to absorb Cr depends on the type of Cr and the plant type (Shahid et al. 2017a, b; Sharma et al. 2020).

Translocation of both states of Cr from plant roots to shoots is quite restricted. In addition, it was determined that the Cr accumulation in the roots was 100 times higher than the shoots, independent of the shoots (Zayed et al. 1998). Crwas found to be the least mobilized in roots among various heavy metals (Singh et al. 2013). They also stated that this situation is due to the weak translocation of Cr due to the structure of insoluble compounds and that Cr^{3+} forms a complex like Cr ethylenediaminetetraacetate enantiomers (Cr-EDTA) in the vacuoles where it is in soluble structure and is then transported to the above-ground tissues of the trees.

Kabata-Pendias (2000) stated that while Cr transfer from tree belowground parts to aerial tissues is restricted, the translocation relies on its chemical structure in the plant tissue. He also stated that the smaller translocation of Cr to airborne plant organs might be due to the modification of Cr^{6+} to Cr^{3+} in plants and the tendency of Cr^{3+} to adhere to plant cell walls (Kabata-Pendias and Szteke 2015).

General evaluation

As a result, while the highest Cr levels were found in the OB in Po, Pm, and Pp species, there was generally no difference between the organs in Cda and Cpa. On the other hand, all species generally obtained the most elevated concentrations in wood in the east or north side. High concentrations of metals in the OB in heavily metal-polluted areas are related to the structure and contamination of the bark. In areas close to the source of pollution, heavy metals in the airborne adhere to particulate matter, contaminating particulate matter with them. These particulate substances settle on plant organs and increase heavy metal concentration ratios in these plant parts (Turkyilmaz et al. 2019; Cesur et al. 2021). Due to the rough surface design of the OB, particulate matter can easily adhere here. Thus, heavy metal concentration ratios are elevated, especially in the barks on the side of heavy traffic (Sevik et al. 2019; Cobanoglu et al. 2023). However, in the study, this situation is not observed in Cda and Cpa, especially in heavy traffic. This situation is due to the branching structure of these two species. Both species branch heavily from the lower part of the tree, and their dense branches and needles prevent particulate matter from contaminating the trunk bark. On the other hand, the elevated ratio of Cr in the wood in the side of heavy traffic in all of the species can be interpreted as that Cr is transported to the stem after being taken from the leaves in these species.

Heavy metal entry and accumulation in the plant tissue are shaped under the influence of many elements. Among these factors, especially air humidity, the wind that provides the transport of pollution factors, heavy metal, and plant interaction are the most critical factors (Turkyilmaz et al. 2020). In addition to these, plant habitat is also highly effective (Cobanoglu et al. 2023). In addition, genetic structure and environmental conditions that affect plant phenotypic characters also influence heavy metal entry and accumulation in the plant (Key et al. 2022). Therefore, environmental conditions and genetic structure should be equalized as much as possible in biomonitors to observe the change in metal pollution. In this study, the area where the trees grow is an area that has a flat, homogeneous soil structure, and the climatic conditions are equal to each other because the trees are close to each other. Therefore, environmental conditions are almost the same. Genetic differences were also eliminated since the study was carried out on samples taken from the organs and different sides of the same tree. Previous studies emphasized that sampling should be done by paying attention to these issues (Cesur et al. 2022; Yayla et al. 2022). Thus, the study results are highly reliable.

The study aims to observe the change of Cr element concentration in the air from past to present and to determine the most suitable species that can be used to reduce pollution. As a result, the highest Cr concentrations in woods were obtained in Cpa and Pm species. These species are also the species with the most remarkable difference in Cr concentrations in woods formed in the same year on different sides or successive years in the same direction. These results show that Cpa and Pm are the suitable species that can be used both for changing Cr concentration in the air during the process and reducing Cr pollution. The results also show that the Cr accumulation potentials of the species subject to the study are at different levels in different organs. This result is generally in parallel with the results obtained in the studies carried out to date. In many studies on the subject, it has been revealed that different plant species have dissimilar potentials to collect different elements (Sevik et al. 2020; Karacocuk et al. 2022; Koç et al. 2022; Yayla et al. 2022).

Conclusion

This study aimed to determine the species that can be used in monitoring the change and reducing the Cr concentration in the air in the province of Düzce. In conclusion, it was determined that all of the tree species subject to the research were suitable for this purpose. Some features are sought in species that can be used as biomonitors in monitoring heavy metal pollution. Some of these features are that plant species can accumulate heavy metals in their bodies. However, they do not die with this effect; they can be found in their environment, and there is a correlation between heavy metal pollution and heavy metal concentration in plant organs. However, another feature sought in the species to be used in monitoring the change of heavy metal concentration in the air, especially by using annual rings, is the restricted transfer of the metal in the wood. All of the species subject to the study provide this feature for Cr. Therefore, all species subject to the study are suitable biomonitors to monitor the change in Cr concentration. However, among these species, Cpa and Pm have a higher Cr concentration difference in adjacent parts of the wood than other species and better reflect the pollution variability. Consequently, it is suggested to prefer these two species in monitoring the change of Cr concentration. However, all species subject to the study are suitable biomonitors for observing the alteration in Cr element concentration.

However, it was determined that the Cr accumulation potential was higher among these species, especially in the woods of Cpa and Pm. The wood part is the enormous organ of the tree by mass. Therefore, species that can accumulate a lot of Cr in the wood part can be used effectively to reduce Cr pollution in the air. According to the study results, Cpa and Pm are the most suitable species that can be used to reduce Cr pollution in the air. When these species are grown in the open field, they frequently branch from the bottom and act as an effective living barrier, especially in polluted areas. The fact that they have lived a healthy life for more than 200 years makes it possible for them to act as effective air pollution preventers during this time.

In conclusion, Cr concentration was very high in all of the samples used in the study. This situation shows that the Cr pollution in the region where the study was conducted is at dangerous levels. The element Cr is one of the most menacing in terms of environmental and human health. Therefore, it is necessary to reduce Cr pollution in the region, shift living spaces to cleaner areas, and warn the public against pollution risks.

It was concluded that Cr pollution is mainly caused by traffic. Necessary measures should be taken around the roads, which are the primary source of Cr pollution, to prevent the pollution from reaching living and agricultural areas. For this purpose, it is recommended to create live fences that act as barriers by using species such as Cpa and Pm between the highway and the living and agricultural areas.

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Declarations

Conflict of interest The authors declare no competing interests. The authors have no competing interests to declare that are relevant to the content of this article. We confirm that the work is original and has not been published elsewhere, or currently under consideration for elsewhere publication.

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