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ORIGINAL ARTICLE

# Variation of 40-year Pb deposition in some conifers grown in the air-polluted-urban area of Düzce, Türkiye

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## Abstract

Lead (Pb), one of the most lethal heavy metals (priority contaminant) in environmental and human health, spreads to the air as a metal or compound and has noxious properties. Therefore, tracking and diminishing Pb pollution are urgent and priority research topics. This study aims to contribute to the determination of suitable biomonitor species that can be used to observe Pb pollution shifts over a long period and hyperaccumulator species that can be used to lessen pollution. For this reason, it was selected to use species from Düzce, one of the five most unclean municipalities in Europe, including *Pinus pinaster*, *Pseudotsuga menziesii*, *Cupressus arizonica*, *Cedrus atlantica*, and *Picea orientalis*. The Pb concentration variations based on the species, organ, direction, and age range in the last 4 decades were assessed by examining the samples taken from tree species. The highest Pb concentrations were found in the outer bark and the east and north directions (high vehicle density) in almost all the species. These results showed that Pb pollution increases significantly due to vehicles. In conclusion, the displacement of Pb in wood was limited in these species; therefore, they could be used to track the Pb pollution change. *C. arizonica* and *P. menziesii* were determined to be suitable for reducing Pb pollution.

**Keywords** Biomonitor · *Cedrus Atlantica* · Lead · *Picea orientalis* · *Pinus pinaster*

## Introduction

One of the most critical problems is undoubtedly environmental pollution (Elsunousi et al. 2021), which is caused by anthropogenic activities in industrialization and urbanization (Tekin et al. 2022; Varol et al. 2022; Cetin et al. 2023). Environmental contamination has become such a big concern today that it is stated that nearly 2.5 million residential regions across Europe are polluted. Nearly 15% of these regions require immediate improvement planning, and 90% of the world's residents are now breathing polluted air (Cesur et al. 2022). Air contamination, which causes around 3.8–4.3 million premature births worldwide, causes the death of almost 7 million individuals annually (Ghoma et al. 2022). The most harmful and deadly component of air pollution, which is of great importance in causing human deaths, is considered heavy metals (HMs) (Aricak et al. 2020). Because HMs are not easily degraded in the environment and remain for a long time, they tend to accumulate biologically in alive bodies. Many of them are carcinogenic and poisonous, and their concentrations in airborne are continuously rising (Wani et al. 2018; Ucun Ozel et al. 2019; Erdem 2023; Isinkaralar 2022).

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Lead (Pb) is one of the most toxic HMs in the environment and human health. According to WHO (World Health Organization) and EPA (U.S. Environmental Protection Agency), the maximum recommended Pb concentration limit for all crops varies between 0.1 and 0.3 mg/kg (Ejaz et al. 2023). It causes developmental delays in children and neurological damage (Ejaz et al. 2023). The high accumulation of Pb in tree species causes chlorosis and necrosis and restricts plant growth, development, and yield (Malar et al. 2016). Pb is widely used in agricultural and industrial practices and, therefore, a widespread element; it is a HM that spreads to the air as an organic form (Tetraethyl and tetramethyl lead). Pb harms the ecological system the most with human actions (Bhat et al. 2019). Due to its potential harm, Pb is on the preeminence pollutant checklist of the ATSDR (Agency for Toxic Substances and Disease Registry) (Savas et al. 2021).

Monitoring and reducing Pb contamination is among the urgent and priority research issues due to its harm to various ecosystems and living things (Sulhan et al. 2022). However, tracking HM contamination in the air can be done directly or indirectly. The direct determination of the contamination is not chosen frequently because it is costly, the direct consequence of atmospheric contamination on the environment cannot be determined (Turkyilmaz et al. 2018; Isinkaralar et al. 2022a). Biomonitors are the most efficient approach for observing the indirect effect of HM contamination. Various studies have been carried out for a long time on using plants as biomonitors in monitoring changes in heavy metal pollution. Studies were first carried out in the 1970s on bryophytes, including lichens and mosses. The fact that bryophytes can accumulate much higher levels of heavy metals than they need and that the technology at that time was not capable of determining very low concentrations of heavy metals was effective in choosing bryophytes as biomonitors (Cowper 2024; Warczyk et al. 2024). However, since the age of bryophytes cannot be determined exactly, it is not known how long they have been exposed to heavy metal pollution. A similar situation occurs in evergreen plants (Key et al. 2023).

It can be determined how long deciduous plants have been exposed to heavy metal pollution. Moreover, in these plants, heavy metal concentrations in samples collected from areas without pollution can be compared with heavy metal concentrations in plants collected from areas with high levels of pollution. Many recent studies have used this method (Koc et al. 2024; Gültekin et al. 2025). However, the data obtained with this method only reflects the amount of pollution in one year, and information cannot be obtained about the change in pollution in previous years (Cesur et al. 2021). The needles of evergreen plants such as *Picea* or *Abies*, whose leaf age can be determined, provide the opportunity to compare. Thus, an idea can be obtained about the change in heavy metal pollution in the air in the recent past. However, this method can obtain data for at most 8–10 years (Sulhan et al. 2022).

Annual tree rings especially provide critical details on this subject. Temperate zone woody plants renew their cambium activity yearly, creating a new annual ring. With the help of these annual rings, the different amounts of heavy metal accumulation in different species and the effect of genetic differences on heavy metal accumulation can be compared over a long period. Although various investigations on annual rings as biomonitors have been performed recently, the amount of knowledge on the accretion of HMs in the tree cell and their transfer between tree organs is minimal (Isinkaralar et al. 2022b; Kuzmina et al. 2023). By examining the annual rings of suitable species, important information can be obtained about the change in heavy metal pollution in a region. Since the obtained data reflect the change in heavy metals over a very long period, interpretations are made based on the amount of change in heavy metal concentration. Thus, the differences arising from each tree species taking in different amounts of heavy metals depending on its anatomical structure are also eliminated. In addition, since the need to compare the obtained data with other individuals has been eliminated, the necessity of taking samples from areas without pollution has also been eliminated. This method is the most widely used and accepted method in studies conducted on the subject in recent years (Yasar Ismail et al. 2024; Koç et al. 2025; Ozturk Pulatoglu et al. 2025). This method, which was used in the studies mentioned and whose effectiveness has been proven by the scientific community, was used in this study.

This current research tried to determine that the change in Pb concentration harms human and environmental health and is often associated with vehicle density based on species, year interval, organ, and direction. Within the scope of the study, 5 exotic species (*Cedrus atlantica*, *Pinus pinaster*, *Cupressus arizonica*, *Pseudotsuga menziesii*, and *Picea orientalis*) were preferred. These species were determined to show low maintenance, optimum development in regional conditions, high aesthetic importance due to durability, and use in landscape practices in the urban area of Düzce.

Düzce air is ranked fifth most polluted in European cities (IQAir 2021) due to various industrial activities, such as cement, plastic, paint, parquet, quarries, and glass factories. Previous studies claimed that air HM pollution had been elevated recently (Isinkaralar 2022; Sevik et al. 2023) that the highest PM10.0 and PM2.5 values were measured at 386.31 and 244.83 μg/m$^3$ in the city air (Çevre, Şehircilik ve İklim Değişikliği Bakanlığı 2023). Therefore, the study is aimed to determine the proper species within five species in terms of biomonitoring and increasing Pb concentration in the air last 4 decades in Düzce, Türkiye.

In the studies carried out so far, numerous studies have been performed on the usability of different species in observing HM change. Studies on the usability of annual rings are becoming increasingly important, especially in determining the HM change in the long term. However, many factors effectively mitigate HM pollution; the most important is the plant species. Unlike other studies, this study evaluated the change in different plant species grown in the same environment comparatively based on species, organ, direction, and time interval. As is known, heavy metals can enter the plant body directly from the roots of the soil, the leaves in the air, or the stem parts (Cobanoglu et al. 2023). The two pathways of heavy metals entering the plant body (from the air and the stem parts) reflect the heavy metal pollution in the air. The amount of heavy metals entering the roots varies according to their presence in the soil. The soil structure is similar since the plants in question grew in the same area. Therefore, the difference in Pb concentration obtained in the study was evaluated as a reflection of the Pb concentration in the air. A similar method has been used in many studies to determine the change in the concentration of many heavy metals in the air, such as Pb (Turkyilmaz et al. 2018; Isinkaralar 2024) and Cr (Ozturk Pulatoglu et al. 2025), Pd (Sevik et al. 2024), As (Yasar Ismail et al. 2024), Sb (Canturk et al. 2024) over time. The study objectives are to determine (a) the Pb accumulation potentials of these species, (b) how the concentrations of Pb in the air differ in the accretion in the organs (wood, outer bark, and inner bark) of the plants trunk, (c) at what level Pb passes between plant organs after it is taken into the cell, and (d) how Pb concentrations in annual tree rings change periodically. Thus, it is aimed to achieve information on the contaminants that are the origins of Pb and the most proper trees that can be used for tracking and diminishing this pollution.

## Materials and methods

The current study was performed in Düzce city, Nortwest region of Türkiye, where atmospheric pollution is moderately high. Düzce is listed among the five most polluted cities in Europe reported by the 2021 World Air Pollution (IQAir 2021). The study area, a park, is located on the eastern edge of the city (40°49’36.97” N −31°10’31.40” E) (Fig. 1) and approximately 675 m far away from the D-100 highway (running from a west-to-east state road in Türkiye). Although the prevailing wind orientation alters based on months and seasons, the prevailing wind direction in the city is in the NE-SW (northeast-southwest) axis (Düzce Meteorology Provincial Directorate 2013). In this study, the main stems of *Cedrus atlantica* (Endl.) Maanetti ex Carriere, *Cupressus arizonica* Greene, *Pinus pinaster* Aiton., *Pseudotsuga menziesii* (Mirb.) Franco, and *Picea orientalis* L. species were cut right above the ground by marking the north direction end of the 2022. The structure of the outer bark of trees, in particular, is one of the factors that most affect the retention of heavy metals in the bark and, therefore, the concentration of heavy metals in the bark and, subsequently, in the wood. The bark structures of the trees in question are different from each other. The bark of *P. menziesii* is dark gray-brown or blackish green, smooth, and has resin bubbles on it. As it ages, it becomes rough and scaly in the form of deep longitudinal cracks. In *C. arizonica*, the bark is thin and papery and peels off quickly, and a characteristic bark pattern appears as scattered brown-red large and small spots on a grayish-green background. The trunk bark of *P. orientalis* is initially smooth and has scaly cracks as it ages (Kandemir et al. 2014). The bark of *C. atlantica* has a boxy pattern of rectangle shapes as the tree ages, horizontally lenticellied and gray-brown (Yılmaz 2017). *P. pinaster*’s bark becomes thick, deeply cracked, and reddish brown in advanced ages (Kurtça 2018).

The trees were about 15 m tall and 40 years old. In the area where the trees are located, the trees are planted in rows, and there is a distance of approximately 20 m between them. Therefore, the roots and branches of the trees will not affect each other or prevent air circulation between them. The area where the study is carried out is flat and can be considered homogeneous regarding climate and soil conditions. The trees were cut down in late 2022, and then, approximately 10 cm thick log samples were obtained about 50 cm from the cut surface of the main stem and taken into the laboratory.

The log samples were smoothed by a planer in the laboratory, and the annual tree rings were much more observable. The examination of annual tree rings revealed that these tree species are 40 years old. Since the annual tree ring widths, 5-year annual growth is grouped as single, and samples as sawdust form were taken from the OB (outer bark), IB (inner bark), and WD (wood) using a portable steel drill. Samples from each tree species’ organs (IB, OB, and WD) and wood samples from each age category of each tree species were triplicated. In the study, 5 tree species × 5 log samples x 4 directions × 10 (8 age group + inner bark + outer bark) × 3 replications = a total of 3000 samples were used to analyze.

The sawdust samples were put in glass petri dishes for two weeks to become air-dry in the laboratory. Afterward, the samples were oven-dried (45 °C) for about seven days. 0.5 g dried sawdusts were transferred into glass petri dishes, 65% $HNO_3$ (6 ml)and 30% $H_2O_2$ (2 ml) were added, then placed in the microwave oven (200 °C) for 15 min. Then, the solution was transferred into flasks and filled up to 50 ml of


UKRAINE
ROMANIA
BULGARIA
SERBIA
GREECE
ALBANIA
TURKEY
GEORGIA
ARMENIA
AZERBAIJAN
SYRIA
IRAQ
ISRAEL
JORDAN
MOLDOVA
Black Sea
Azov Sea
Caspian Sea
Mediterranean Sea
Sea of Crete
Istanbul
Bursa
Ankara
Izmir
Konya
Antalya
Adana
Gaziantep
Aleppo
Mosul
Nicosia
Beirut
Damascus
Jerusalem
Amman
Baghdad
Alexandria
Cairo
Benghazi
Athens
Thessaloniki
Tirana
Skopje
Sofia
Pristina
Belgrade
Bucharest
Budapest
Kishinev
Odesa
Dnipro
Donetsk
Rostov-on-Don
Volgograd
Tbilisi
Yerevan
Baku
Tabriz
Karaj
0 155 310 620 930 1 240
Km
0 0.10.2 0.4 0.6 0.8
Km
N
S
E
W
Legend
Sampling point
Highway
Residential area
Agricultural area

**Fig. 1** Study location and its environment

ultrapure water. The solutions were transferred to the ICP-OES (Inductively Coupled Plasma-Optic Emission Spectrometer, GBC Scientific Equipment Pty Ltd Melbourne, Australia) appliance for element analysis. This procedure has been frequently used in various studies (Çobanoğlu et al. 2022; Isinkaralar et al. 2022b; Koç et al. 2022).

The normality and equality of variances were assessed using suitable Kolmogorov-Smirnow and Levene tests, respectively. The obtained actual values were then subjected to the analysis of variance (ANOVA), and the Duncan test was used for the factors with noteworthy differences of at least a 95% confidence interval ($p<0.05$). Consequently, the difference of Pb element concentration based on tree species, organ, direction, and year span was specified and assessed individually. Results were presented in tables and graphs, while species names are abbreviated, such as *P. pinaster* as Pp, *C. arizonica* as Cpa, *C. atlantica* as Cda, *P. menziesii* as Pm, and *P. orientalis* as Po.

## Results

The concentration of Pb varied based on species, organ, and direction (Table 1).

The variation of average Pb concentration by species and direction was significant (Table 1) and is illustrated in Fig. 2. The maximum Pb levels were found in the east direction in Cpa, Pp, and Po, while in the east direction in Cda and west in Pm. Regarding direction, the highest Pb values were generally obtained for all species except Pm in the north and east directions.

The alteration of Pb concentration levels by tree species and organ was significant (Table 1) and is presented in Fig. 3. The highest Pb concentration in the OB, IB, and WD was observed by Pm, Pp (followed by Cda), and Pm (followed by Cpa), respectively. The lowest Pb concentration levels were found in Po in the IB and OB, while in the WD, it was obtained in Po, followed by Pp.

The alteration of Pb concentration in wood based on year range and direction was significant (Table 1) and is demonstrated in Fig. 4. The most elevated values were usually found in the east and sometimes in the north based on year. Pb concentration in the east direction increased until 2000 and then decreased until 2020. Almost the opposite trend was observed in the south direction. Pb concentration decreases in the northern and western directions from 1985 to 2020.

The difference of average Pb concentration by tree organ and direction was significant (Table 1) and is given in Fig. 5. The variation of Pb concentration in the north and south directions were ordered as OB > IB > WD. In the east, it was ordered as OB > WD > IB, while in the west direction, it was ordered as IB > OB > WD. Notably, the values obtained from the north and east directions, especially in the OB, are much higher than the other directions.

The variation of average Pb concentration levels by species and period was significant (Table 1) and is illustrated in Fig. 6. When the graph is examined, the Pb concentration in Cda wood decreased from 1985 to 2020. Pb concentrations in Pp and Po species increased approximately until 2000–2005 and then decreased. On the contrary, Pb concentrations in Pm species decreased until 2010 and increased after that. Pb concentrations in Cpa species decreased until 2000 and increased after this year.

The variation of Pb concentration in 5 selected species by organ and direction is given in Table 2. The Pb concentration in Pp is relatively elevated, especially in the east direction, and the Pb concentration level in the east side increase to 8.17 mg/kg in OB and 5.94 mg/kg in WD. The average values of the east direction are 5 times higher than those of the west direction.

Pb levels remained below the detectable thresholds in OB and IB in the east direction of Cpa. The Pb concentration is relatively high, especially on the east side, and the Pb level in the WD reaches up to 6.27 mg/kg. Except for the east, the average Pb values obtained in the north are also relatively elevated. The Pb values in WD obtained in these directions are 3 to 6 times higher than in the west.

In the east, the Pb concentration in Po stayed below the detectable thresholds in OB. The highest Pb concentration in WD was observed on the east side (5.49 mg/kg), while the lowest Pb concentrations in each organ were also found on the west side. The Pb concentration in WD in the east direction is around 2 to 5 times higher than in other directions.

The Pb concentration in each organ of Cda was relatively high, especially on the north side. The Pb concentration variation for all directions in each organ was not significant ($P>0.05$) except on the west side ($P\leq0.05$). The peak Pb concentration in the west direction was observed in IB, while the lowest one was in WD. The Pb concentration in WD in the north direction is around 2 times higher than in the other directions.

The Pb concentration in Pm stayed below the detectable thresholds in the IB in the east direction. In the eastern direction, the variation based on tree organs is not noteworthy ($P>0.05$). The highest Pb concentration in OB, IB, and WD of Pm were found in the north (9.67 mg/kg), west (5.62 mg/kg), and west (5.56 mg/kg) directions, respectively. The Pb

**Table 1** Summary of analysis of variance for Pb

| Source of variation | df | *P*-value |
|---|---|---|
| Species (S) | 4 | 0.001 |
| Tissue (T) | 2 | 0.001 |
| Direction (D) | 3 | 0.001 |
| S x T | 8 | 0.001 |
| S x D | 12 | 0.001 |
| T x D | 6 | 0.001 |
| S x T x D | 24 | 0.001 |

concentration in OB in the north direction is around 2 to 4 times higher than in other directions.

## Discussion

According to this analysis, the east and north sides have the most enormous quantities of Pb elements. Given that Pb is one of the HMs most closely linked to vehicle density (Sevik et al. 2020; Turkyilmaz et al. 2020), the highway's presence in the northeast of the study region is assumed to be the source of this circumstance. Some studies are in line with our results. For instance, in a study, the Pb ratio in the wood was 2.16 mg/kg on the roadside, whereas the average Pb concentration was 0.98 mg/kg on the other side (Sevik et al. 2020). The Pb element concentration in *Ailanthus altissima* leaves, which was 0.32 mg/kg in areas without traffic, increased to 8.18 mg/kg in areas with heavy traffic (Sevik et al. 2019). Similarly, it has been revealed in many

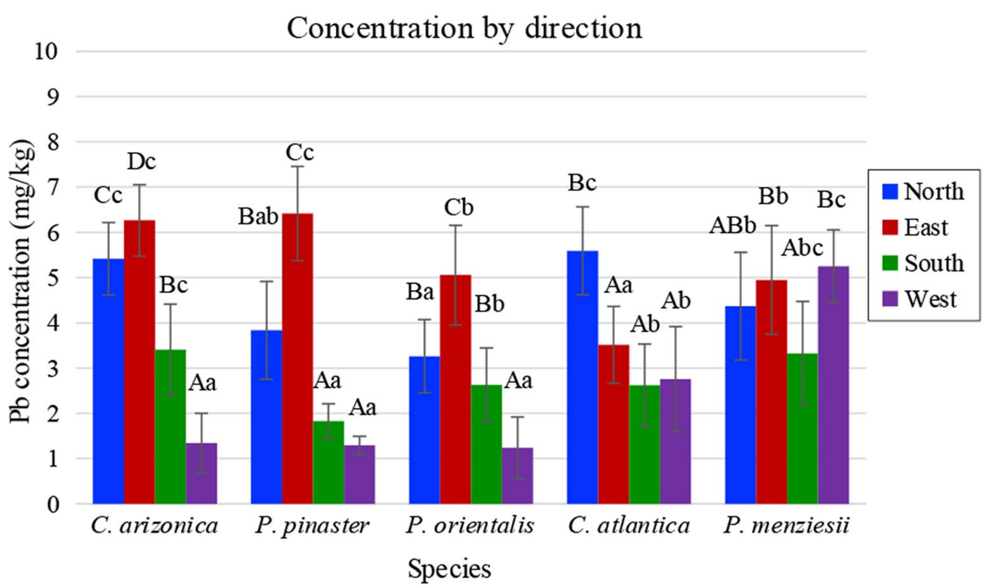


**Fig. 2** Variation of Pb concentration (mg/kg) by tree species and direction. [Note: Capital letters indicate statistical differences between the Pb means of a species in different directions, while lowercase letters indicate differences between the Pb means of different species in a direction ($p<0.05$).]

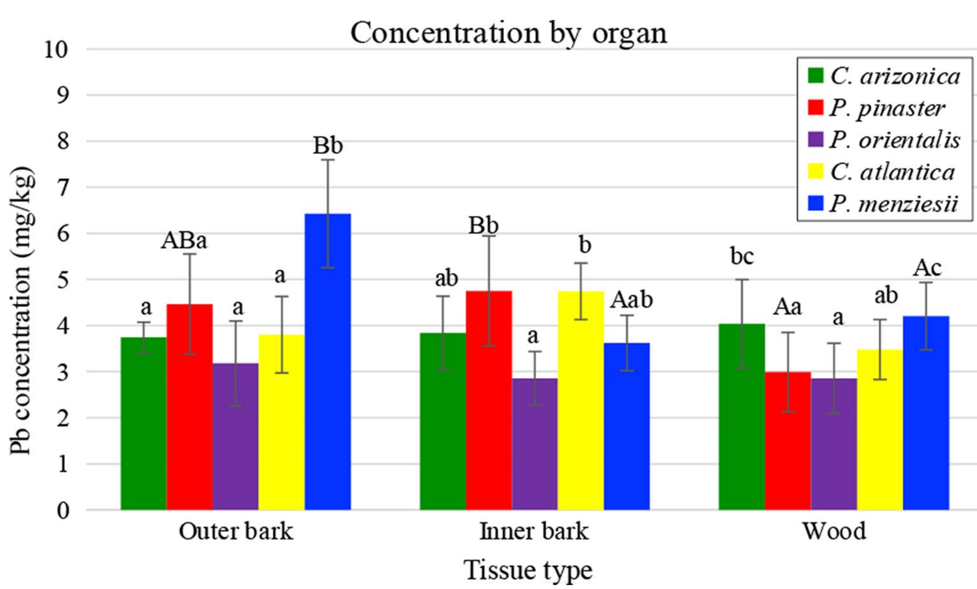


**Fig. 3** Variation of Pb concentration (mg/kg) by organ and species. [Note: Lowercase letters indicate statistical differences between Pb averages in the same organs of species, while capital letters indicate differences between Pb averages in different organs of a species ($p<0.05$).]

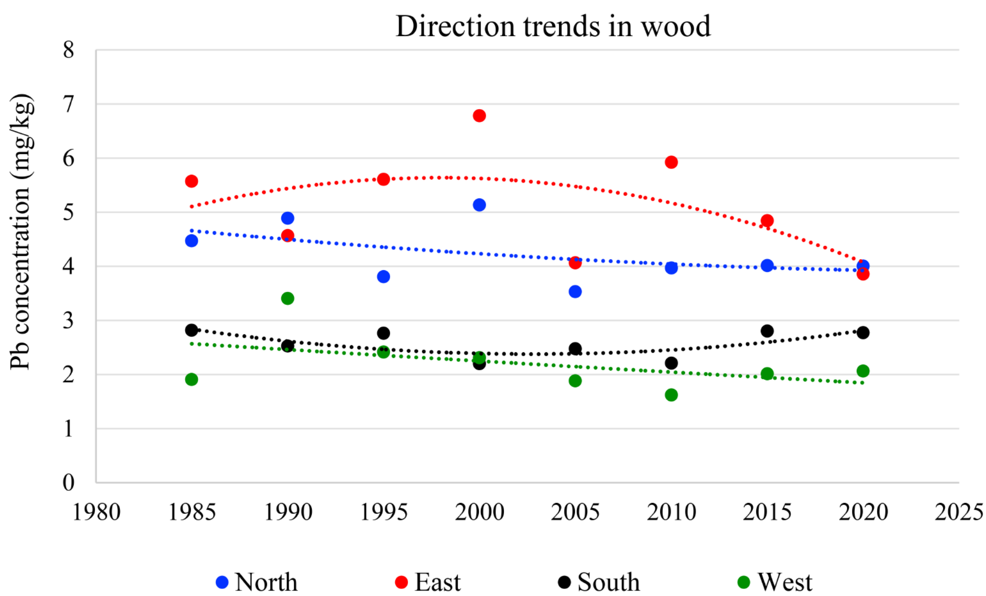


**Fig. 4** Variation of Pb concentration (mg/kg) in wood by year range and direction

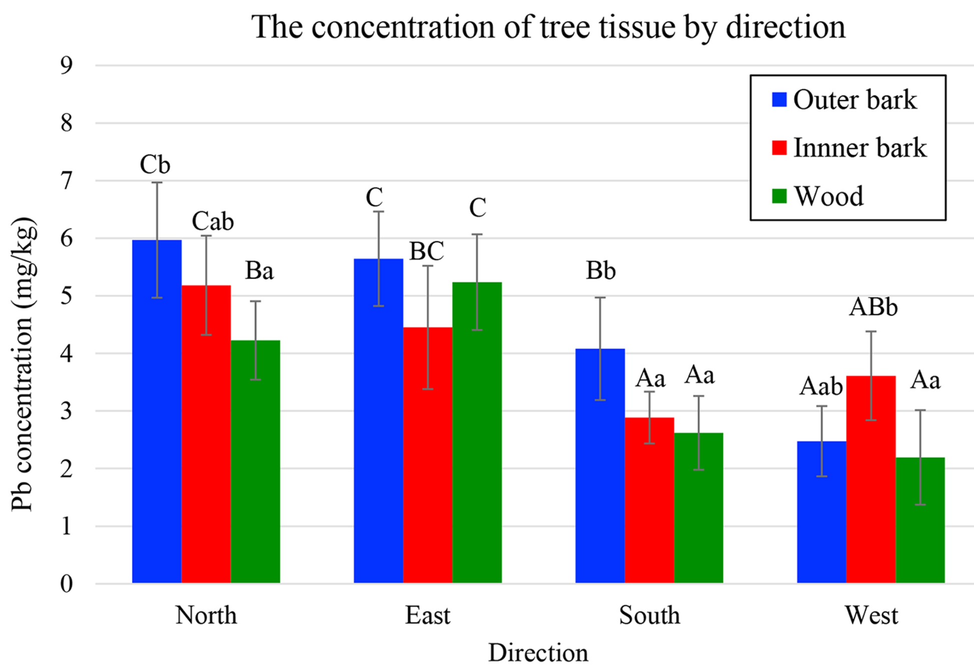


**Fig. 5** Variation of Pb concentration (mg/kg) by organ and direction. [Note: Lowercase letters indicate statistical differences between the Pb averages of different organs in the same direction, while capital letters indicate differences between the Pb averages of an organ in different directions ($p < 0.05$).]

investigations that the Pb concentration in plants increases due to traffic (Turkyilmaz et al. 2020; Cetin et al. 2022; Key and Kulaç 2022).

Besides vehicle density, tree organs, and organ structures are critical in element accumulation. It was revealed that the alteration of Pb concentration levels on an organ basis was also significant, and the maximum concentrations were commonly found in the OB, especially on the side with heavy traffic. The elevated Pb levels in the OB, especially on the heavy traffic side, are related to the bark structure and particulate matter (PM). Studies have determined that HMs in the airborne stick to PM and contaminate it with HMs; HM concentrations in these tree organs (bark, leaf, brach) boost as these particulate substances settle on tree organs (Turkyilmaz et al. 2019). The irregular surface texture of the OB promotes the adhesion of PMs here. The elevated concentration of metal elements in the bark, especially in the heavy traffic route, is elucidated by the contagion of PMs in this way with metal elements induced by traffic (Kuklová et al. 2022).

However, some results from the current study contradict the generalization mentioned before. For example, Pb concentrations in the OB and IB in the direction of heavy traffic at Cpa and in the OB at Po stayed below the detectable thresholds. However, in these species, the maximum Pb concentrations in WD were found on the eastern side,

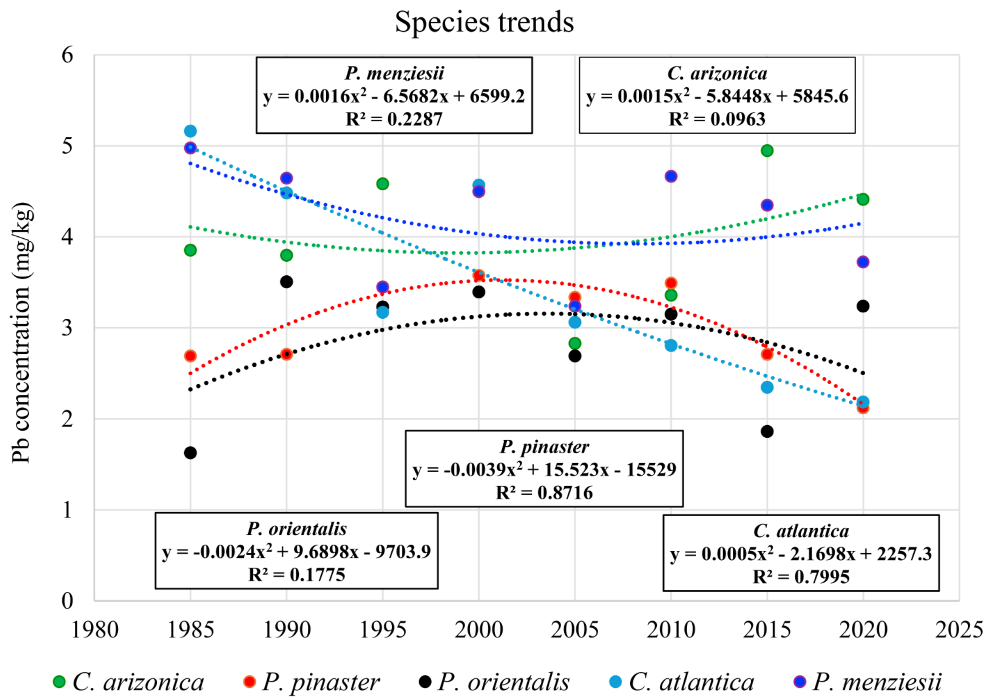


**Fig. 6** Alteration of Pb concentration (mg/kg) by tree species and period

**Table 2** Pb concentration (mg/kg) of wood and bark tissue of five conifers from Düzce, Türkiye, sampled by direction

| Pinus pinaster (Pp) | | | | |
|---|---|---|---|---|
| Plant organ | North | East | South | West |
| Outer Bark | 5.60 Cb | 8.17 Da | 2.63 Bb | 1.46 Ab |
| Inner Bark | 7.15 Cb | 8.00 Da | 2.18 Bab | 1.67 Ac |
| Wood | 3.20 Ba | 5.94 Ca | 1.63 Aa | 1.23 Aa |
| *Cupresus arizonica* (Cpa) | | | | |
| Outer Bark | 4.18 Ca | UL | 3.64 Ba | 3.42 Ac |
| Inner Bark | 5.42 Ca | UL | 3.75 Ba | 2.33 Ab |
| Wood | 5.57 Ca | 6.27 C | 3.34 Ba | 9.58 Aa |
| *Picea orientalis* (Po) | | | | |
| Outer Bark | 4.91 Cb | UL | 3.27 B | 1.36 A |
| Inner Bark | 4.13 Cab | 2.45 B | 2.50 B | 2.34 A |
| Wood | 2.95 Ba | 5.49 C | 2.56 B | 1.08 A |
| *Cedrus atlantica* (Cda) | | | | |
| Outer Bark | 5.48 D | 3.47 B | 2.55 A | 3.71 Cab |
| Inner Bark | 6.60 D | 2.90 A | 3.37 B | 6.09 Cb |
| Wood | 5.48 C | 3.60 B | 2.54 A | 2.15 Aa |
| *Pseudotsuga menziesii* (Pm) | | | | |
| Outer Bark | 9.67 Db | 5.28 B | 8.31 Cb | 2.44 Aa |
| Inner Bark | 2.61 a | UL | 2.63 a | 5.62 b |
| Wood | 3.93 Ba | 4.86 BC | 2.79 Aa | 5.56 Cb |

According to Duncan's analysis, digits followed by the different letters (a, b, c, or A, B, C) are statistically distinctive at $P \leq 0.05$. UL: Undetectable limit. Uppercase letters indicate horizontal directions, while lowercase letters illustrate vertical directions.

where traffic was heavy. Studies showed that HMs could store in the tree tissue either by being captivated by the root or entering from the air through the tree leaves or directly into the trunk (Chen et al. 2021; Erdem et al. 2023). Plants' broad roots take up free-$Pb^{2+}$ ions and mineral nutrients from Pb-contaminated soils (Engwa et al. 2019). They reach apoplastic routes after being absorbed and passively stored by the roots, at which point the vascular flow system translocates them. Nevertheless, apoplastic and symplastic pathways—transpiration-driven pathways—are used by transporters to deliver a small amount of Pb to the leaves (Wang et al. 2021). Although a portion of the absorbed lead is transferred to the plant's aerial sections, most of the lead is kept in the plant's roots (Kumar et al. 2017). Plants also take up Pb ions by capillary action or cellular respiration from the surrounding air (Colin et al. 2022). Through stomatal and cuticular routes, plant leaves permit the absorption of Pb-ions polluted by the air, which causes leaf chlorosis. Upon reaching the endodermis region of plant species, these ions adhere firmly to the plasma membrane and cell wall (Engwa et al. 2019).

Also, as explained above, high concentrations of HMs in the OB are usually due to particulate matter that adheres to the bark and is polluted with HMs. However, in this study, the Pb concentration in the OB is significantly low in Cpa and Po. This situation is likely due to the lack of natural branch pruning since the tree species are densely branched and grow freely in the environment in which they are grown. Dense branching prevents particulate matter from contaminating the OB of the stem. However, the Pb concentration in the WD is very high in this direction, indicating that Pb is taken from the leaves to the plant, transferred, and accumulated into the wood.

The amount of knowledge about the speciation of metal elements in the tree and their transfer between plant parts is restricted since their entry into the tree tissue (Yayla et al. 2022). Due to distinct entry pathways, heavy metal accumulation occurs at different levels in each plant organ (Erdem et al. 2023). However, in biomonitoring and phytoremediation studies, the wood part of the tree is vital. Unlike other organs, the wood part of the tree constitutes the most prominent part in terms of volume and keeps heavy metals away from nature for many years. Therefore, the importance of the wood part in phytoremediation studies is high (Şevik et al. 2024). Some studies on this subject show that the relocation of some metal elements in tree wood may differ from species to species. For instance, Zhang (2019) stated that Zn and Pb elements are partially replaced in *Cedrus deodora* woods, but the Cu element is rarely replaced. However, the relocation of Zn, Cr, and Pb in the WD is minimal in *Corylus colurna* (Key and Kulaç 2022). Ni element transfer in wood in *Cedrus atlantica* is quite limited, but this is not the case for Co (Koç 2021). Cesur et al. (2021) reported that the exchange of Cd and Ni elements is limited, while Bi concentration transfers are higher in *Cupressus arizonica* woods. It is stated that the relocation of Cd, Zn, and Ni elements between organs is limited in *Cedrus* (Cobanoglu et al. 2023), and Cd is transferred in wood, while the transfer of Fe and Al is quite restricted in *Corylus colurna* (Key et al. 2022).

In the current research, the Pb concentration level was relatively high in the woods shaped in different years, especially in the eastern direction during the 1990–2015 period. This situation is thought to be related to the number of vehicles and gasoline quality. It is stated that 90% of the Pb in the airborne has been formed due to the use of leaded gasoline in automobiles since 1925. Although leaded gasoline was banned in the 2000s, the number of vehicles increased significantly (Isinkaralar 2024).

As an outcome, the maximum Pb concentrations in wood were found in Pm and Cpa. In the investigations on the accumulation of HMs in dissimilar tree species, it has been thought that the tree species is the most critical factor affecting HM accumulation. Many studies have revealed that HM concentrations in plants developed in similar conditions differ significantly (Karacocuk et al. 2022). HM accumulation potential in plants results from metabolic activities and growth performance occurring in this process. The mutual interaction of genetic codes and environmental situations impacts tree growth and development (Yigit et al. 2021; Özel et al. 2022).

The study results reveal that Pb concentration varies significantly depending on the tree species, organ, direction, and time interval evaluated in the study. Studies show that many factors that affect each other work simultaneously on the entry and accumulation of heavy metals into the plant body. Some of these factors can be listed as physical and chemical properties of metals, forms, morphology of organs, surface area, plant habitus, surface texture, duration of exposure to metals, and environmental conditions (Sevik et al. 2019). Since many other features are related to the plant species, perhaps the most important of these factors is the plant species (Karacocuk et al. 2022). Therefore, it has been determined that heavy metal concentrations in plants growing in the same environment are at different levels in numerous studies (Sevik et al. 2024; Koç et al. 2025; Ozturk Pulatoglu et al. 2025). All phenotypic characteristics of living things are shaped by the interaction of genetic structure and environmental conditions (Hrivnák et al. 2024 ; Özdikmenli et al. 2024). Plant species are also the most critical factor that shapes the genetic structure and the interaction of the plant with the environment. In addition, characters such as organ structure, surface area, and texture are also shaped depending on the plant species. Therefore, it is natural that the most important factor affecting heavy metal accumulation is the plant species. However, the fact that heavy metal concentrations are at different levels in different parts of the organ in the same plant species, even in the same tree and in the same organ (for example, in wood as in this study), is shaped depending on environmental conditions and especially the amount of heavy metal in the air and the interaction of the metal with the plant (Şevik et al. 2024). The differences between the data obtained as a result of the study can be explained in this context.

## Conclusion and suggestions

In conclusion, it was noted how the Pb concentrations altered in diverse directions, and the maximum concentration levels were obtained in almost all species on the north and east routes. Considering that the main roads with high vehicle density are in the east and north directions and the prevailing wind direction is northeast and southwest, it can be concluded that Pb accumulation in the trees may originate from traffic. It has been determined that the HM concentration levels in the annual rings have changed significantly based on the year range, and this change has been an increasing trend for Cpa and Pm, especially in recent years.

Moreover, it was concluded that Pb concentration levels in annual rings differed considerably in different directions in the same year range and in consecutive year intervals in all species. The concentration variation in annual rings showed that these species' Pb allocation in wood is restricted. According to this result, the tree species and method used in this research can effectively observe the variation in Pb concentrations.

In conclusion, the peak Pb concentrations in WDs were obtained in Pm and Cpa tree species. In studies aimed at reducing HM contamination in the atmosphere, the element concentration in wood is more important in other organs. Because the wood part is the largest part of the tree in mass and unlike many other organs, it does not separate from the tree and mix with the ecosystem again. Thus, HMs introduced into the woods are stored here and eliminated from the environment. Consequently, plants with a high potential for HM accumulation in the WD portion can effectively reduce HM contamination in the airborne. According to the results, the recommended species to reduce Pb pollution in the airborne are Pm and Cpa.

The most critical problem limiting the study is the lack of data on the level of Pb pollution in the air. As is known, direct measurement of heavy metal pollution in the air is quite difficult and expensive. This is the main reason why biomonitors are needed. However, in the studies conducted to date, there is no study in which both the pollution in the air and the accumulation in biomonitors are measured and compared simultaneously. This situation makes it very difficult to establish a relationship between the heavy metal concentrations determined in plant organs and the level of pollution in the air. It is recommended that future studies focus on this issue.

Another issue limiting the study is the lack of information on the movement of heavy metals after they enter the plant body and their speciation. Although there are numerous studies on agricultural plants on this subject, there are very few studies on perennial woody species. This situation makes it difficult to interpret the obtained data. It is recommended that this issue be evaluated in future studies.

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## Declarations

**Ethics approval and consent to participate** Not applicable.

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