World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

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Availability of *Cedrus atlantica* annual rings in monitoring the change in airborne sulfur pollution

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World Journal of Advanced Research and Reviews, 2023, 18(01), 227–234

Publication history: Received on 25 February 2023; revised on 05 April 2023; accepted on 08 April 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.18.1.0583

Abstract

Heavy metals are one of the components that threaten human health and the ecosystem the most among the components of air pollution, which has become a global problem. Sulfur, an important air pollutant, is not only a serious threat to human health at high concentrations, but also extremely dangerous for the ecosystem and constitutes a significant part of the pollutant load in many cities. Therefore, monitoring the change of sulfur pollution in the air is very important.

In this study, the usability of *Cedrus atlantica* annual rings was investigated in observing the change in sulfur pollution in the air. Within the scope of the study, samples taken from a *Cedrus atlantica* tree grown in Düzce, one of Europe's 5 most polluted cities, were analyzed, and the change of sulfur concentration from the past to the present was investigated. As a result of the study, the highest concentrations were obtained in the outer bark and north direction. In addition, it has been found that there has been a substantial increase in sulfur pollution in recent years.

Keywords: Heavy metal; Biomonitor; *Cedrus atlantica*; Annual ring; Sulfur

1. Introduction

In recent years, air pollution has been one of the most critical threats to humans, other living things, and ecosystems worldwide [1]. Especially some air pollution factors, such as heavy metals, are hazardous to human health and the ecosystem, even at low concentrations [2-4]. Sulfur (S), one of these pollutants, is one of the most critical air pollution components. In fact, for all animal species, sulfur is an essential component of vitamins, proteins, amino acids, enzymes, and other biomolecules. Recently, however, the increasing prevalence of oil refining and smelting of sulfur compounds of metallic minerals into free metals has significantly impacted the sulfur balance in the environment. Sulfur dioxide (SO_2), an important air pollutant, can adversely affect human and animal health by causing bronchoconstriction, bronchitis, and increased pulmonary resistance [5].

Sulfur dioxide is a colorless gas released from the combustion of diesel fuel and coal. SO_2 and particulates constitute a significant part of the pollutant load in several cities. It may cause irritation, reduced vision, and some respiratory diseases. High S exposure is dangerous to life. Sulfur dioxide reacts with moisture in the nose, throat and nasal cavity, harming human health and thus destroying the nerves in the respiratory system. Higher concentrations affect those who have asthma, bronchitis, and lung and heart conditions. SO_2 can be hazardous to the respiratory system and lung functions and cause eye irritation. It causes respiratory tract inflammation, coughing, mucus secretion, chronic bronchitis, and asthma aggravation, making people more prone to respiratory infections. On days when SO_2

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concentration is high, hospital admissions due to cardiac problems and mortality increase. SO_2 combines with water to form sulfuric acid; it is the core component of acid rain and causes deforestation [6].

In recent years, environmental pollution, and especially the concentrations of some pollutants in the air, have increased significantly due to factors such as industrial activities, an increase in the number of vehicles, and mining activities [11-14]. This increase threatens human and environmental health significantly [15-18] and is the main cause of global climate change due to changes in the composition of the air [19-22].

The direct effects of air pollution on human health are severe. It is claimed that roughly 7 million people die every year due to air pollution [23-24]. Therefore, monitoring and reducing air pollution, especially the concentrations of pollutants important for human health and the ecosystem, are among the priority research topics [25-27]. In this study, the usability of *Cedrus atlantica* in monitoring the change of sulfur concentration in the air and reducing sulfur pollution was investigated.

2. Material and methods

The study was carried out on log samples of a *Cedrus atlantica* tree growing in Düzce. According to the 2021 World Air Pollution report, Düzce is one of the 5 most polluted cities in Europe [28]. Within the scope of the study, the main trunk of the *Cedrus atlantica* tree was cut by marking the north direction at the end of the vegetation season of 2022, and a log sample was taken from the ground at the height of about 50 cm. The sample taken was brought to the laboratory, the annual rings were grouped as five years, and samples were taken from the outer bark, inner bark, and woods in each direction using a steel drill. S in these organs were analyzed with the help of the ICP-OES device in the samples that were dried in an oven at 45 °C for two weeks. This method has been used frequently in heavy metal studies in recent years [29-32]. The obtained data were evaluated with the help of the SPSS package program, and variance analysis and the Duncan test were applied to the data.

3. Results

The directional changes of S concentrations in the bark and wood of *Cedrus atlantica* and the statistical analysis results are given in Table 1. As seen in Table 1, the change in S concentrations in samples taken from different directions in all organs and the change in S concentrations in samples taken from different organs in all directions is statistically significant, at least at the 95% confidence level. When the values were examined, the highest S concentrations were generally obtained in the northern direction and the outer bark.

Table 1 S concentrations in *Cedrus atlantica* organs

ORGAN	South	West	North	East	F value	Mean
Wood	74.3 Ba	107.1 Ba	83.0 Ba	21.3 Aa	4.8 **	74.1 a
Inner Bark	79.6 Aa	86.8 Ba	227.7 Db	121.8 Cb	1619.8***	128.9 a
Outer Bark	591.8 Bb	606.0 Cb	790.4 Dc	254.3 Ac	3416.3***	560.6 b
F value	65.8***	219.6***	220.3***	676.9***		133.7***
Mean	132.4	175.5	204.7	76.9	1.6 ns	

Different letters following each other represent the statistical difference at $p \leq 0.05$. Uppercase letters represent left to right and lowercase letters from top to bottom. *** ≤ 0.001. ** ≤ 0.01. ns=not significant.

The variation of S concentrations in *Cedrus atlantica* woods is given in Table 2. As can be seen from the table, S concentrations in *Cedrus atlantica* woods remained below the determinable limits until 1988 in the south direction, 1998 in the west direction, 1993 in the north direction, and until 2003 in the east direction, and also in the 2003-2007 period in the north direction. While the S concentrations were below the determinable limits in the past years, they have increased over the years and reached very high concentrations in recent years. The increase in S, especially after 2013, draws attention.

Table 2 S concentrations in *Cedrus atlantica* woods by years

Age	South	West	North	East	F value
1983-1987	UL	UL	UL	UL	-
1988-1992	3.4 a	UL	UL	UL	-
1993-1997	2.4 a	UL	111.0 c	UL	10258.3***
1998-2002	5.8 Ab	69.6 Ca	8.4 Ba	UL	4251.4***
2003-2007	65.7 Bc	80.7 Cc	UL	9.8 Aa	3054.0***
2008-2012	92.8 Cd	73.4 Bb	17.8 Ab	18.8 Ab	13750.2***
2013-2017	113.8 Be	135.4 Dd	128.8 Cd	19.5 Ab	18179.0***
2018-2022	236.7 Df	176.6 Ce	148.9 Be	37.1 Ac	5692.5***
F value	13182.9***	5033.3***	7499.4***	720.6***	

Different letters following each other represent the statistical difference at $p \leq 0.05$. Uppercase letters represent left to right and lowercase letters from top to bottom. UL=Under Limit. *** ≤ 0.001.

4. Discussion

The most important results of the study are that the S concentrations in *Cedrus atlantica* organs are generally above the detectable limits, the highest concentrations in the organ are obtained in the outer bark, the direction in the north, and there has been a significant increase in S concentrations in recent years.

First, it was determined that S concentrations in *Cedrus atlantica* organs were above the detectable limits, and there were significant differences between adjacent wood samples in terms of direction and period. This situation shows that *Cedrus atlantica* is a suitable biomonitor for monitoring S pollution. As is known, biomonitors are generally used to monitor heavy metal pollution in the air [33-36].

Annual rings of trees are the most preferred biomonitors for observing the changes in heavy metal concentrations in the air during the process. To date, studies have been accomplished on the usability of annual tree rings in the monitoring of Al, Ca, Cu, Zn, Co, Fe, B, Cd, Mn, Cr, Na, Ba, Mg, P, As, Bi, Cd, Ni, Li elements [37-42]. However, the essential need for more information on this subject is the transfer of elements after they enter the tree [43]. Studies have shown that *Cedrus* annual rings are suitable biomonitors for the monitoring of Cr, Mn [44], Pb, Co, Fe [45], Cd, Ni, Zn [46], and Ca [47] elements. However, there are limited studies on the availability of annual rings in monitoring the variation of S concentration [48-50].

The study obtained the highest S concentrations in the outer bark and the north direction. There is a busy main road and residential area in the north direction. Sulfur dioxide is a colorless gas released from the combustion of diesel fuel and coal [6]. Therefore, it is natural for the S concentration to be high in the north direction. High concentrations of S in the outer bark may be associated with the concentration of particulate matter in the air. In the studies, it was determined that heavy metals in the air adhere to the particulate matter, that the particulate matter is contaminated with heavy metals, and that these particulate substances adhere to the bark of the trees and the heavy metal concentrations in the outer bark increase [51-53]. The high concentration of S in the outer bark indicates a high level of S pollution in the atmosphere.

As a result of the study, it has been found that there has been a substantial increase in S concentrations in recent years. This situation is thought to be predominantly related to the number of vehicles. Many other heavy metals, such as S, are also emitted into the atmosphere mainly by traffic, and the growth in the number of vehicles in recent years is the main cause of heavy metal pollution in the air [45-46].

As a result of the study, it was found that *Cedrus atlantica* is a suitable biomonitor that can be used to observe the change of heavy metal pollution in the air. The entry and accumulation of heavy metals into the plant body are shaped as a result of a very complex mechanism, and many factors such as plant species, weather conditions, organ structure, plant habitus, and heavy metal type are determinative in this process [37, 52-53]. In addition, this process is closely related to plant metabolism [54]. Plant metabolism is also shaped by the interaction of genetic structure [55-58] and

environmental settings [59-70]. In addition, stress factors such as drought [71-75], UV-B [76], radiation [77], and fertilization [78] also significantly affect plant growth. Therefore, these factors affecting plant metabolism also significantly affect heavy metal absorption and accumulation in plants [79-80].

5. Conclusion

Heavy metals, which have special importance among the components of air pollution, are pollutants whose concentration in the atmosphere has increased in recent years and are highly harmful to human and environmental health. Therefore, observing and reducing heavy metal pollution is of great importance. Studies show that biomonitors are the most suitable tools to be used for this purpose. This study evaluated the usability of *Cedrus atlantica*, which is frequently used in landscape studies in monitoring and reducing S pollution in the air. As a result of the study, it was determined that *Cedrus atlantica* is a suitable biomonitor that can be used for this purpose. In addition, the results of the study show that there has been a significant increase in S pollution in recent years. S is a pollutant that significantly affects the ecosystem as well as human health. It is recommended that urgent measures be taken to reduce S pollution. For this purpose, suitable species that can be used for phytoremediation applications should be determined and planted in areas with high pollution levels.

Compliance with ethical standards

Acknowledgments

We thanks to Bartin University, Faculty of Forestry and Kastamonu University, Faculty of Architecture and Engineering.

Disclosure of conflict of interest

The authors declare that they no conflict of interest. The none of the authors have any competing interests in the manuscript.

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