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Monitoring the change of silicon pollution in air and usability of *Tilia tomentosa* in reducing pollution

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Abstract

In recent years, urbanization and environmental pollution have increased significantly, posing a risk to human health. The silicon (Si) concentration in the air is also increasing due to its intensive use in urban areas. Si is one of the heavy metals that pose a danger to human health, and it is known that heavy metals can be extremely harmful when inhaled from the air and taken into the human body. Therefore, monitoring and reducing the change of Si pollution in the air is important. This study tried to determine the usability of *Tilia tomentosa*, which is intensively grown in urban areas where heavy metal pollution can be at high levels, for monitoring and reducing the change of Si pollution in the air. Within the scope of the study, the changes of Si concentration in the stem parts of *Tilia tomentosa* grown in Düzce, among the five most polluted cities in Europe, depending on organ, direction, and age range in the last 60 years, were evaluated. As a result of the study, it was concluded that urban areas mostly cause Si pollution in the region. As a result of the study, it was determined that *Tilia tomentosa* is a suitable species that can be used to monitor the change in Si pollution and reduce pollution.

Keywords: Heavy metal; Silicon; Biomonitor; Phytoremediation; *Tilia tomentosa*

1. Introduction

The industrial revolution in the last century has caused permanent changes in almost every field worldwide. The most important of these changes are shown by many researchers as global climate change [1-5], urbanization [5-10], and environmental pollution [11-15]. Moreover, these problems are globally influential and interconnected. Namely, the industrial revolution in the field of industry in the last century has increased the need for raw materials, energy, and labor while enabling more production in a short time. Migration from rural to urban areas to meet the needed labor force has caused the population to gather in certain areas and created the problem of urbanization [16]. The use of fossil fuels to provide the energy needed has also significantly increased the CO_2 in the atmosphere and has become the main culprit of global climate change [17-18]. In addition, urbanization requires more people to live in a unit area and to meet this demand, the construction of high-rise buildings in limited space is mandatory. Water is used at a rate corresponding to approximately 18% of global annual industrial water use for producing concrete used in the construction of high-rise buildings. In addition, it is stated that approximately 10% of global carbon dioxide (CO_2) emission is caused by cement production, which is the primary material of the concrete output [19-28]. As a result, urbanization, global climate change, and environmental pollution, which have emerged due to industrial and technological developments, have become interconnected problems effective globally [16,18, 29-32].

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As a result of the extraction of various elements from underground mineral deposits to be used as raw materials in industrial activities and their release into nature, water [32-34], soil [33-37], and air [38-41] have been significantly polluted and started to threaten living life. The extent of air pollution is especially frightening. It is reported that approximately 90% of the world's population now breathes polluted air, 99% are exposed to poor air quality, and air pollution causes approximately 6 million premature births, approximately 3 million underweight babies, and approximately 7 million premature deaths worldwide every year [18,42].

Among the components of air pollution, heavy metals are the most dangerous and harmful. Some heavy metals can be toxic, carcinogenic, and fatal to humans, even at low concentrations. Therefore, Ag, Hg, As, Pb, Pd, Zn, Be, Al, Ba, Sb, Cd, Sr, Cr, U, Pu, Se, Tl, Cu, Th, and V are listed as priority pollutants by ATSDR [16]. It is even stated that heavy metals, which are essential for the survival of living organisms, can be harmful at high concentrations [42-45]. Moreover, if inhaled from the air, their effects are much more severe and harmful [14]. Therefore, it is important to monitor and reduce the change of heavy metal pollution in the air [46-48].

This study tried to determine the change in the concentration of Silicon (Si), one of the important and common elements, in the air and to determine the usability of *Tilia tomentosa* in reducing Si pollution. Silicon is a heavy metal that has increased in importance in recent years due to dust transportation and damages the cardiovascular and respiratory systems and the immune system [49]. This study investigated the accumulation levels of Si in the trunk parts of *Tilia tomentosa* trees growing in urban areas with high levels of heavy metal pollution.

2. Material and methods

The study was carried out on linden (*Tilia tomentosa*), a species frequently used in landscape studies throughout Europe. The tree subject to the study was obtained from Düzce province. Düzce is one of Europe's five most polluted cities, according to the World Air Pollution Report 2021 [50,51]. Samples were taken 2022 outside the vegetation season by determining the north direction. The log sample, which was brought to the laboratory and its surface leveled, was determined to be 60 years old, and samples were taken from the wood part, inner bark, and outer bark, which were grouped as five years each, with the help of a steel drill. The samples were then dried in an oven at 45 °C and pre-burned in a microwave oven specially designed for this process. The pre-burning samples were analyzed by ICP-OES and Si concentrations were determined. This method has been widely used in previous studies in this field [50-53].

The data obtained were analyzed using the SPSS 22.0 package program, and variance analysis was applied to the data. In addition, the Duncan test was applied for the factors showing statistically significant differences at a minimum 95% confidence level ($p < 0.05$). The data were tabulated, analyzed, and interpreted after considering the Duncan test results.

3. Findings

Mean values and statistical analysis results for the variation of Si concentration in linden by organ and direction are given in Table 1.

Table 1 Variation of Si concentration in linden by organ and direction

Organ	North	East	South	West	F Value	Average
OB	409,7 cB	463,7 cC	123,4 cA	476,4 cC	367,8***	368,3 c
IB	141,7 bC	384,7 bD	64,2 bA	73,8 bB	3315,9***	166,1 b
Wood	87,0 aB	288,5 aC	28,6 aA	67,5 aB	120,3***	121,9 a
F Value	379,4***	22,7***	95,0***	418,6***		21,8***
Average	114,0 b	307,8 c	38,2 a	105,2 b	61,7***	

When the values in the table are examined, it is seen that the change in Si concentration in linden is statistically significant in all organs on the basis of direction and on the basis of organs in all directions. In all directions and according to the average values, the highest values were obtained in the outer bark, while the lowest values were obtained in the wood. Regarding direction, the highest values were obtained in the east, and the lowest values were obtained in the south direction. The variation of Si concentration in linden by period and direction is given in Table 2.

Table 2 Variation of Si concentration in linden by period and direction

Period	North	East	South	West	F Value
2018-2022	114,0 fC	375,0 jD	49,7 eB	18,3 abA	4893,2***
2013-2017	121,9 gC	366,4 iD	49,0 eB	27,6 cdA	2614,3***
2008-2012	112,0 fC	335,9 hD	38,3 dB	23,4 A	3598,2***
2003-2007	97,0 eB	306,1 gC	18,3 abA	15,5 aA	16767,0***
1998-2002	88,4 cdB	292,5 dC	33,4 cA	UL	9323,0***
1993-1997	86,0 cB	302,5 gC	23,1 bA	20,2 abcA	3560,8***
1988-1992	92,6 deB	277,3 eC	15,2 aA	UL	4326,0***
1983-1987	71,3 bB	263,9 dC	18,6 abA	UL	3520,5***
1978-1982	68,6 bC	253,1 cD	16,5 aA	24,4bcd B	3317,5***
1973-1977	62,5 aB	250,4 cC	35,2 cdA	35,9 eA	2862,3***
1968-1972	69,3 bC	223,8 bD	20,0 abA	28,8 dB	7768,6***
1963-1967	60,7 aB	214,7 aC	22,6 bA	413,4 fD	3326,3***
F Value	132,7***	343,0***	66,5***	3099,4***	

The variance analysis determined that the change in Si concentration in linden was statistically significant in all periods based on direction and in all directions based on period. Si concentration in linden in the west direction remained below the determinable limits in 1998-2022 and 1988-1987. A very high value (413.4 ppm) was obtained only in the period 1963-1967 in the western direction. The values obtained in the west and east directions are generally the lowest in the study. The highest values were usually obtained in the east direction.

4. Result and Discussion

Three significant results were obtained from the study. First, the Si concentration determined in the outer bark of the tree subject to the study is very high. The Si concentration determined in the inner bark is higher than in the wood but much lower than in the outer bark. This indicates that the Si concentration in the outer bark is due to particulate matter. Many studies have reported that heavy metals contaminate particulate matter in the air after leaving their source, and particulate matter contaminated with heavy metals adheres to the organs of plants [41,42,48]. Thus, the adhesion of particulate matter contaminated with heavy metals to the surface of rough organs such as bark increases the concentration of heavy metals in these organs [2,10].

Contamination of the bark by heavy metals generally increases the concentration of heavy metals in the inner bark. This is because heavy metals can enter the plant directly from the soil through the roots, the air through the stomata in the leaves, or the stem parts [2]. It is usual for some of the heavy metals in the outer bark to be transported to the inner bark, which increases the concentration of heavy metals in the inner bark.

The second significant result of the study is that the highest concentrations were obtained in the north and east directions, and the lowest concentrations were obtained in the south and west directions. There are highways and residential areas to the north and east of the area where the samples were taken and agricultural areas to the south and west. Previous studies show that heavy metals are released mainly into nature as a result of mining [54], industry [50,51], traffic [36,37], urban areas [9,10], and agricultural activities [55]. The study results can also be interpreted as releasing Si from traffic and urban areas. Granite and some other rocks are complex silicates used extensively in the construction industry. Concrete and cement are prepared with sand and clay, which contain the element silicon. Sand is also the main raw material for glass. In its silicate form, silicon is used in pottery, enameled kitchenware, and heat-resistant ceramics [56]. Therefore, it is normal for Si to be released into nature from urban areas.

The third significant result obtained in the study is that there is a substantial difference between the Si concentrations determined in neighboring wood tissues. For example, in 2003-2007, the Si concentration obtained in the northern direction was 97.0 ppm, while 306.1 ppm in the eastern direction and 18.3 ppm in the southern direction. This difference between neighboring wood tissues indicates that the transfer of Si in the wood is limited. This result shows that the species subject to the study is suitable for monitoring the change of Si concentration in the air. As it is known, the limited transport of heavy metals in wood tissue is a desirable feature in tree species that can be used to monitor the change of heavy metal concentrations in the air. The studies so far show that each tree species can be suitable as a biomonitor for different heavy metals. For example, *Cedrus deodora* for Cu, *Picea orientalis* for Tl, *Cedrus atlantica* for Ni, Cr, and Mn, *Cupressus arizonica* for Cd, Ni, Cr, Tl, Fe, and Zn, *Corylus colurna* for Cd, Ni, Zn, Co, Pb, Cr, Mn and Zn and *Pseudotsuga menziesii* for Cr. This is because the displacement of these elements in the wood of these species is limited. However, *Cedrus deodora* for Pb and Zn, *Pinus nigra* for As, Sr, Pd, V, Ag, Se, Sb and Tl, *Cedrus atlantica* for Co, and *Cupressus arizonica* for Bi, Li, and Cr are not suitable biomonitors for monitoring changes in their concentrations [55,57]. Heavy metal accumulation can vary significantly between species and organs within the same species [36,37]. This is due to the simultaneous involvement of many factors in the uptake and accumulation of heavy metals in plants. The uptake and movement of heavy metals into plants are influenced by several factors, including plant species, organ structure, surface area, interactions between heavy metals and plants, and weather conditions [48]. Furthermore, plant habitus and development also significantly influence heavy metal uptake and accumulation [44,47]. Thus, all factors affecting plant habitus also affect the uptake and accumulation of heavy metals in these plants. Plant habitus is influenced by many factors, including genetic structure [58-61], edaphic [62-54] and climatic [65-74] environmental factors, as well as stress factors [75, 76], maintenance, pruning and hormone applications [77-81]. Therefore, many of these factors directly and indirectly affect each other, and thus, the potential of plants to accumulate heavy metals and knowledge of this complex mechanism is still limited [54, 82-84].

As a result of the study, it was determined that Si can accumulate at high levels in linden wood. Plants are tools that can be used effectively to reduce heavy metal pollution. Especially the wood part is the organ in plants where heavy metals generally accumulate the least. However, in phytoremediation studies, plants that can accumulate heavy metals in the wood part are also important because the wood part is the largest organ of the plant in terms of mass [10, 16]. The study results show that Si concentrations are pretty high in linden wood, which indicates that this species is suitable for phytoremediation studies to reduce the pollution of these elements.

5. Conclusion

The study tried to determine the usability of linden trees in monitoring and reducing the change of Si pollution in urban areas with high levels of heavy metal pollution. The study results show that linden is a highly suitable species for monitoring and mitigating Si pollution. The study results show that urban areas largely cause Si pollution in the air. This can be interpreted as a serious threat to human health. Therefore, necessary precautions should be taken in residential areas. For this, it is essential to identify the areas with high pollution levels first and then take measures to reduce the pollution. Plants, especially trees, can be used effectively in this regard.

Compliance with ethical standards

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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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