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Determination and Mapping of Regional Change of Pb and Cr Pollution in Ankara City Center

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Abstract As in the whole world, environmental problems have increased with the increase in residential areas in Turkey, and this situation has brought many problems, especially environmental pollution. Among the components of environmental pollution, heavy metals are the most dangerous and important in terms of human and environmental health. Especially Pb and Cr are among the most toxic and deadly heavy metals, and the concentrations of these heavy metals in the environment are constantly increasing. Soil is one of the elements most affected by the increase in pollution. Soils are both a nutrition and living environment for plants and one of the most important components of the environment. In addition, topsoil is one of the most important indicators of the level of air pollution. This study aimed to determine and map the Pb and Cr pollution in the city center of Ankara, the capital and the second-largest city of Turkey, with the help of topsoils. Within the scope of the study, Ankara city center was divided into sub-regions with different characteristics, and Pb and Cr analyzes were performed by taking topsoil samples from 50 points representing these regions. Then, the changes in Pb and Cr concentrations on a regional basis were statistically evaluated, the data were transferred to Geographic Information Systems (GIS) using ArcGIS

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10.7 software, then modeled with the kriging method, one of the interpolation methods, and pollution maps were created. As a result of the study, it has been determined that the Cr concentration is generally higher in the northwest-southeast axis of the study area, decreases as one goes to the northeast and southwest, and the region with the highest Pb concentration is located in the center of the study area, that is, in the west of the town of Sincan.

Keywords Ankara · Cr · Heavy metal · Pb · Soil

1 Introduction

Today, many of the most important problems in the world consist of problems that arise due to population growth. The total world population, which was only around 717 million in 1750, exceeded 7.8 billion in 2020 and is estimated to reach 8.5 billion by 2030 (Cetin, 2020; Cetin & Jawed, 2021, 2022; Cetin et al., 2018; Ozel, Varol, et al., 2021; Sevik, 2021; Sevik et al., 2020b, 2020c; Varol et al., 2022; Yucedag et al., 2021). In addition to the increasing world population, rural–urban migration also significantly increases the density in urban centers. While only 9% of the total population lived in urban areas throughout the world in the 1900s, this rate increased to 47% in 2000 and it is estimated that 90% of the world's population will live in urban areas by 2030 (Adiguzel et al., 2020, 2022; Bozdogan Sert et al., 2019, 2021; Kilicoglu et al., 2020). In our country, this rate is higher, and today, approximately 92.8% of the total population lives in urban areas (TUIK, 2020).

When the population growth is combined with the migration from rural to urban areas, the human population and density living in the unit area in urban areas have increased significantly and this situation has brought many problems with it (Adiguzel et al., 2020, 2022; Bozdogan Sert et al., 2019, 2021; Kilicoglu et al., 2021). The most important of the problems that arise in urban areas is undoubtedly environmental pollution (Cetin, 2020; Cetin & Jawed, 2021, 2022; Cetin et al., 2018; Cetin, Onac, et al., 2019; Koc, 2021; Sevik et al., 2020b, 2020c; Ucun Ozel et al., 2019; Varol et al., 2022; Yucedag et al., 2021). Studies show that environmental pollution in urban areas threatens the ecosystem and human life significantly. So much so that today, it is stated that around 7 million people worldwide lose their lives due to air pollution-related reasons every year (Jo et al., 2020). Air pollution is the biggest environmental health risk and is estimated to cause the death of approximately 1 in 8 people worldwide due to diseases such as heart diseases, stroke, respiratory diseases, and cancer. Air pollution manifests itself more in regions with high population density, and according to World Health Organization data, 92% of the world's population is reported to live in regions with low air quality in 2014 (Elsunousi et al., 2021).

Although air pollution draws the most attention among the environmental pollution components, studies show that soil pollution has increased dramatically, especially in the last 30 years (Khalid et al., 2017). Among soil pollutants, heavy metals have special importance due to their effects on humans and other living things, as well as on the ecosystem. This is primarily because some heavy metals such as Cd, Pb, As, and Hg are highly toxic to living organisms even at low concentrations. Moreover, some heavy metals such as Cd, Cr, Ni, As, Pb, and V are also carcinogenic. Studies show that almost all heavy metals can have a toxic effect after a certain concentration. (Bozdogan Sert et al., 2019, 2021; Cetin, 2020; Cetin & Jawed, 2021, 2022; Cetin et al., 2018; Savas et al., 2021; Sevik et al., 2020b, 2020c; Turkyilmaz et al., 2018a, 2018b; Ucun Ozel et al., 2020; Varol et al., 2022; Yucedag et al., 2021).

One of the properties of heavy metals that make them dangerous is that they do not easily deteriorate and disappear in nature. In addition, they tend to bioaccumulate in living organisms, and many of them can be quite harmful to humans since there is no effective tolerance or excretion mechanism from living structures (Aricak et al., 2020; Bozdogan Sert et al., 2019; Cetin & Jawed, 2021, 2022; Sevik, Cetin, et al., 2019; Sevik, Ozel, et al., 2019). Therefore, monitoring heavy metal pollution is of great importance.

Topsoil in urban areas is mostly shaped by the accumulation of airborne particulate matter on the soil surface, and topsoil gives very accurate results in determining heavy metal pollution. Therefore, many studies have been conducted on monitoring heavy metal pollution using topsoil (Ahmed et al., 2016; Jafari et al., 2018; Wang et al., 2018). This study, it is aimed to determine and map the Pb and Cr pollution in the city center of Ankara, the capital and the second-largest city of Turkey, with the help of topsoils. Within the scope of the study, the sampling points were determined on the maps; then, samples were taken from the topsoil and heavy metal analyzes were made. The obtained data were evaluated both statistically and interpreted by transferring them to maps with the help of GIS.

2 Materials and Methods

Within the scope of the study, first of all, the city center of Ankara was divided into sub-regions with different characteristics and the points to be taken as examples were determined to represent these regions. Ankara is located in 39°55′48″N, 32°51′00″E. Preliminary studies conducted within the scope of the study revealed that samples should be taken from 50 points. The soil material used in the study was taken from the topsoil (0–5 cm depth) at the determined points and then labeled and brought to the laboratory. In the laboratory, the soils were sieved, placed in Petri dishes, and dried at 45 °C for 15 days.

Since it is difficult to homogenize the soil sample to be used in the study and its elemental content is highly variable, 6 replications were studied.

After the samples to be collected were dried, they were analyzed with the help of the ICP-OES device and their Pb and Cr concentrations were determined. The data to be obtained were first evaluated with the help of variance analysis and Duncan test using the SPSS package program. Then, the Pb and Cr values of the soil samples taken from different locations were transferred to the Geographic Information Systems (GIS) using ArcGIS 10.7 software, and the coordinates and projections of the data were defined first. Then, it was modeled with the kriging method, one of the interpolation methods, and pollution maps were created. The area and percentages of each map made were also calculated in the excel program.

3 Results

The changes of the elements evaluated within the scope of the study on a regional basis in areas with different traffic densities and the changes depending on the traffic density in different regions were evaluated separately.

3.1 Change of Cr Element

Cr, which is the subject of the study, is one of the most toxic and poisonous elements. The variation of Cr concentration by region in areas with different traffic densities is given in Table 1.

As can be seen in the table, the variation of Cr element in all traffic densities based on region and the basis of traffic density in all regions is statistically significant at the 99.9% confidence level ($p<0.001$). In areas without traffic, the lowest Cr concentrations are calculated as 18.63 ppm (zone 3), 32.08 ppm (zone 10), and 37.81 ppm (zone 5), while the highest Cr concentrations are 65.91 ppm (zone 2)), 65.48 ppm (zone

Table 1 Change of Cr element by region

Area	Density of traffic					*F* value
	No traffic	Less intense	Middle	Dense	Too dense	
1	54.89 Ed	41.14 bB	63.03 hE	53.04 cC	38.14 bA	827.6***
2	65.91 iC	37.82 aA	51.75 dB	75.62 iD	52.27 dB	3465.9***
3	18.63 aA	53.66 dC	52.00 dB	72.81 hD	53.89 eC	12,658.9***
4	58.15 fE	42.77 bC	33.98 aB	46.13 bD	29.35 aA	6051.2***
5	37.81 cB	36.36 aA	36.82 bAB	45.82 bC	69.65 hD	1889.6***
6	53.54 dC	46.76 cB	59.60 gE	58.66 dD	44.45 cA	1795.6***
7	58.76 fC	54.50 dB	49.81 cA	63.23 fD	88.88 iE	440.8***
8	62.78 gC	62.14 eB	58.33 fA	65.07 gD	66.91 gE	2133.5***
9	65.48 hD	60.95 eB	55.45 eA	62.17 eC	62.18 fC	409.2***
10	32.08 bA	72.49 fE	65.35 iD	42.73 aB	62.42 fC	2060.5***
F value	5219.7***	459.2***	842.3***	3217.2***	21,039.7***	

***: p<0.001

Letters: Shows the group they are in as a result of the Duncan test. Lowercase letters are vertical values; capital letters are horizontal values; (Duncan test shows the group it is in as a result)

9), and 62.78 ppm (zone 8.). In low-traffic areas, the lowest Cr concentrations were calculated as 36.36 ppm (zone 5), 37.82 ppm (zone 2), 41.14 ppm (zone 1), and 42.77 ppm (zone 4). The highest Cr concentrations were calculated as 72.49 ppm (zone 10), 62.14 ppm (zone 8), and 60.95 ppm (zone 9). Cr concentrations vary between 33.98 ppm (4th region) and 65.35 ppm (10th region) in areas with medium traffic density, and the lowest values are in the 5th region (36.82 ppm) and 7th region after the 4th region. (49.81 ppm); the highest values are observed in the 1st region (63.03 ppm) and the 6th region (59.60 ppm) after the 9th region.

It is observed that the Cr concentration values increase even more in the areas where the traffic is very heavy. The lowest values in these areas are 42.73 ppm (zone 10), 45.82 ppm (zone 5), and 46.13 ppm (zone 4), while the highest values are 75.62 ppm (zone 2), 72 81 ppm (zone 3), and 65.07 ppm (zone 8). In areas with heavy traffic, the highest value was 88.88 ppm (7th district) and the next highest values were calculated as 69.65 ppm (5th district) and 66.91 ppm (8th district). The lowest Cr concentrations in these areas were calculated as 29.35 ppm (zone 4), 38.14 ppm (zone 1), and 44.45 ppm (zone 6.).

When the variation of Cr concentration on a regional basis depending on the traffic density is examined, it is seen that the values obtained in the 2nd region, 3rd region, 5th region, and 9th regions are gathered in four homogeneous groups according to the Duncan test results and the other regions are collected in five homogeneous groups. Looking at the table values, the lowest value among all values was obtained in the 3rd region with 18.63 ppm in areas where there is no traffic. It is noteworthy that no region is included in the first homogeneous group in areas with heavy traffic. While 2 of the lowest values were obtained in areas with no traffic, low density, and high density, 3 were obtained in areas with moderate traffic. The variation of Cr concentration in the study area is given in Fig. 1.

When the map showing the change of Cr concentration in the area evaluated within the scope of the study is examined, it is seen that the Cr concentration is below 46 ppm in an area covering approximately 13.65%

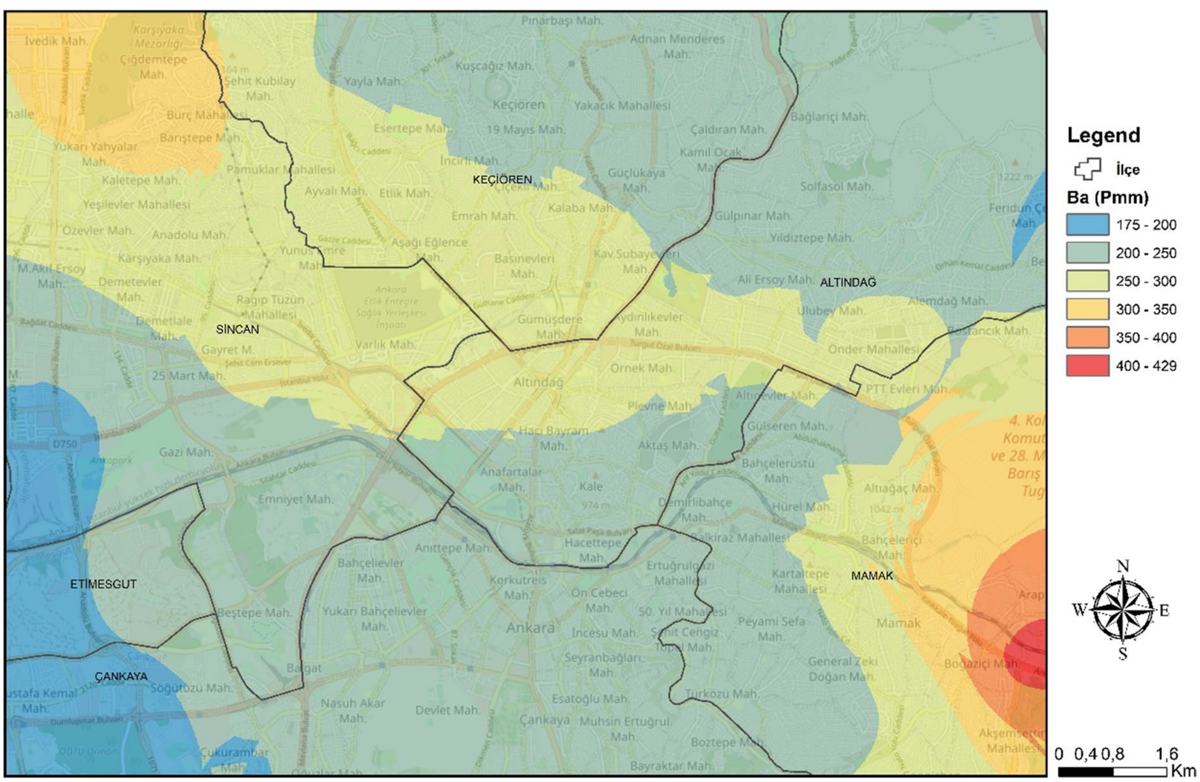

Fig. 1 Change of Cr concentration

of the study area and above 62 ppm in an area covering 6.10%. As a result of the calculations made, the Cr concentration is approximately 46–50 ppm in 13.22% of the study area, 50–54 ppm in 22.96%, 54–58 ppm in 22.51%, and 21.56%. It was determined to be in the range of 58–62 ppm. As can be seen in the map showing the change in Cr concentration, the region with the highest Cr concentration is in the southwest of the study area, within the borders of Mamak district. In general, it can be said that the Cr concentration is higher in the northwest-southeast axis of the study area, and the Cr concentration decreases as one goes to the northeast and southwest.

3.2 Change of Pb Element

The variation of Pb concentration, which is one of the elements most associated with traffic density, in areas with different traffic densities on a regional basis is given in Table 2.

Pb is one of the first elements that come to mind in heavy metal studies in terms of its effect on human health and ecosystem, and its relationship with traffic density. The results of the study show that the variation of Pb element in all traffic densities based on region and the basis of traffic density in all regions is statistically significant at the 99.9% confidence level ($p < 0.001$).

In areas without traffic, the highest Pb concentrations were obtained in the 8th region (82.50 ppm), 9th region (34.95 ppm), and 4th region (26.83 ppm). The lowest values in these areas were obtained in the 10th region (11.07 ppm), the 5th region (16.24 ppm), and the 2nd region (17.42 ppm). In areas with low traffic, the highest values are obtained in the 10th region (43.55 ppm), 7th region (31.16 ppm), and 1st region (25.98 ppm), while the lowest values are obtained in the 5th region (13.97 ppm).), region 2 (17.27 ppm), region 9 (19.44 ppm), and region 3 (19.65 ppm). When the table values are examined, it is seen that the Pb concentration decreases to 6.82 ppm in the areas with a medium density of traffic, and this value is obtained in the 5th region. The next lowest values were obtained in the 8th region (13.48 ppm), the 4th region (13.67 ppm), and the 7th region (16.63 ppm). The highest values in these areas were obtained in the 10th region (38.21 ppm), the 6th region (30.05 ppm), and the 1st region (28.16 ppm), respectively.

In areas with heavy traffic, the highest values are in the 3rd region (37.28 ppm), the 2nd region (29.31 ppm), and the 7th region (24.86 ppm), and the lowest values are in the 10th region (13.98 ppm). The mean values were obtained in zone 1 (18.00 ppm) and zone 8 (18.80 ppm). In areas with heavy traffic, the Pb concentration reached its highest value at 38.00 ppm in the 5th region, and the next highest values were obtained in the 6th region (28.60 ppm) and the 3rd region (26.98 ppm). The lowest values in this area were obtained in the 2nd region with 13.82 ppm and in the first region with 15.97 ppm.

When evaluated in general, it is seen that the variation range of Pb concentration is mostly in a narrow range (between about 15 ppm and 30 ppm), but it decreases to 6.82 ppm and can reach up to 82.50 ppm.

Table 2 Change of Pb element by region

	Density of traffic					
Area	No traffic	Less intense	Middle	Dense	Too dense	*F* value
1	23.52 dC	25.98 gD	28.16 gE	18.00 bB	15.97 bA	1199.6***
2	17.42 cB	17.27 bB	17.13 dB	29.31 gC	13.82 aA	3382.6***
3	15.96 bA	19.65 cB	25.97 fC	37.28 hE	26.98 fD	2454.2***
4	26.83 fE	25.01 fD	13.67 bA	18.93 cB	23.54 eC	729.0***
5	16.24 bC	13.97 aB	6.82 aA	19.50 dD	38.00 hE	2909.5***
6	24.71 eC	22.68 eB	30.05 hE	19.74 dA	28.60 gD	2208.0***
7	17.31 cB	31.16 hE	16.63 cA	24.86 fC	27.00 fD	936.3***
8	82.50 hE	20.94 dC	13.48 bA	18.80 cB	27.20 fD	98.853.1***
9	34.95 gD	19.44 cA	22.95 eC	20.77 eB	20.80 cB	8396.7***
10	11.07 aA	43.55 iE	38.21 iD	13.98 aB	21.43 dC	21.005.3***
F value	22.164.7***	1712.9***	10.322.7***	2677.6***	2040.9***	

***: p<0.001

Letters: Shows the group they are in as a result of the Duncan test. Lowercase letters are vertical values; capital letters are horizontal values; (Duncan test shows the group it is in as a result)

Looking at the table values, it is seen that three of the values obtained in areas with no traffic; two of the values obtained in areas with low, medium, and heavy traffic; and one of the values obtained in areas with high traffic are the highest values. It is noteworthy that the highest value in the 3rd region is in the areas with heavy traffic, and the highest value in the 9th region is in the areas where there is no traffic. The variation of Pb concentration in the study area is given in Fig. 2.

When the map showing the change of Pb concentration in the study area is examined, it is seen that the region with the highest Pb concentration is located in the center of the study area, that is, in the west of Sincan county. When the values are examined, it is seen that the Pb concentration is above 29 ppm in approximately 9.19% of the study area. The Pb concentration is in the range of 21–23 ppm in approximately 28.92% of the study area, in the range of 23–25 ppm in 27.36%, in the range of 25–27 ppm in 7.72%, and in the range of 27–23 ppm in 14.57%. It is calculated to be in the range of 29 ppm. Pb concentration is below 21 ppm in approximately 12.24% of the area subject to the study.

4 Results and Discussions

The results of the study show that the variation of both Cr and Pb concentrations in all traffic densities based on region and the basis of traffic density in all regions is statistically significant at the 99.9% confidence level ($p < 0.001$). The subject of the study, Cr and Pb, are among the elements most commonly associated with traffic density, and in many studies, it is stated that the concentrations of both elements in the environment increase due to traffic (Alaqouri, Genc, et al., 2020; Alaqouri, Ozer Genc, et al., 2020; Cesur et al., 2021).

Numerous studies have been conducted on the variation of Pb and Cr concentrations in soil in urban areas. Zhao et al. determined that it is closely related to fertilizer application. Jia et al. (2019) stated in their

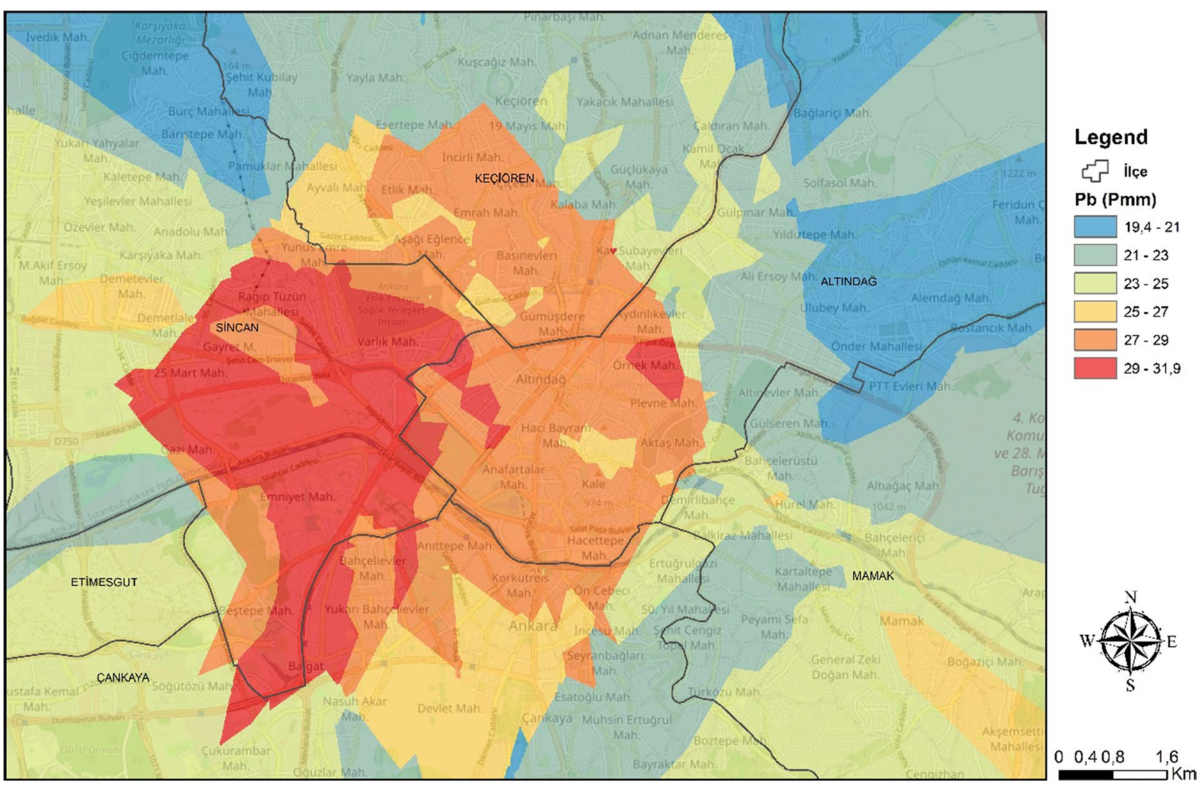

Fig. 2 Variation of Pb concentration

study that Cr contaminant rates in the textile industry, metal processing industry, and chemical industry are 94%, 55%, and 40%, respectively, and Pb contaminant rates are 2%, 15%, and 20%, respectively.

Quiao et al. (2019) stated that mineral activity and pH value are primary factors for total and water-soluble heavy metals. Liu et al. (2019) determined that the Cr concentration in different land types is turf areas > farmland > artificial garden > forest area > forest-grass area. Jin et al. (2019) stated that Cr increased mainly due to natural resources in children's playgrounds, while the increase in Pb was due to traffic activities. Ye et al. (2019) determined that the main identifiable anthropogenic sources of heavy metals are traffic exhaust, sources associated with organic matter output (for example, sewage). Jiang et al. (2020) determined that four sources contribute to heavy metal accumulation in soils in Jiedong District: agricultural practices (23.08%), industrial activities (29.10%), natural resources (22.87%), and traffic emissions (24.95%).

Heavy metals in the soil can pose a potential threat to the local ecosystem and human health (Zhao et al., 2020). Mao et al. (2019) examined the variation of Pb and Cr elements in soil and rice plants and found that the heavy metal levels in the soil decreased with increasing soil pH, while rice sprouts accumulated heavy metals more easily under low soil pH conditions. Soil is an environmental factor that affects plant growth along with climatic factors (Varol, Ozel, et al., 2021; Canturk & Kulaç, 2021; Koc et al., 2021; Varol, Canturk, et al., 2021). Heavy metals can also be a stress factor for plants, and like other stress factors (Koc & Nzokou, 2018; Ozel, Abo Aisha, et al., 2021; Ozel, Cetin, et al., 2021; Yildiz et al., 2014), they can disrupt plant growth (Cetin, Sevik, et al., 2019; Turkyilmaz et al., 2020). In addition, heavy metal concentrations are at high levels in plant organs grown in soils contaminated with heavy metals (Aricak et al., 2019; Cetin et al., 2020). Therefore, the consumption of plants grown in soils polluted with heavy metals as food can be extremely harmful to human health (Sevik et al., 2020a, 2020b, 2020c).

The results of the study show that Cr and Pb concentrations are quite high in some regions in Ankara city center. These regions are also regions where the number of people living in a unit area is quite high, and therefore, the number of people affected by this pollution will be at a very high level. European Environment Agency states that approximately 2.5 million living areas across Europe are contaminated and approximately 14% of these areas need urgent improvement planning (Cesur et al., 2021; Karacocuk et al., 2021). According to the World Health Organization (WHO), 90% of the world's population now breathes polluted air, and air pollution is the cause of death of approximately 7 million people each year (Jo et al., 2020). It is thought that the share of heavy metals in these deaths is quite high.

Heavy metals accumulating in the air can both descend to the earth with the effect of rain, snow, or gravity, pollute soil and water resources, and directly harm people through the respiratory tract. Between 5 and 9 December 1952 in London, approximately 4000 people lost their lives due to air pollution-related reasons; the total number of deaths, including those who lost their lives in the following months, reached 12,000. It has been shown that it is contaminated with very small particles at the level (Ateya, 2020; Shahid et al., 2017). Therefore, it is of great importance to monitor the change of heavy metal concentrations in the air. Since the heavy metal concentrations in the topsoil generally reflect the heavy metal pollution in the air, it can be considered as an extremely useful method in determining the regional variation of the heavy metal pollution level.

5 Conclusions

Heavy metal pollution is one of the most important environmental pollution factors that threaten human health, and therefore, it is extremely important to monitor heavy metal pollution, especially in regions with high human density. In this study, the change in the concentration of Pb and Cr, which are the most harmful and toxic elements in terms of human and environmental health, in the city center of Ankara was determined and pollution maps were created. Within the scope of the study, necessary measures should be taken to reduce the pollution level in regions where Pb and Cr pollution is intense. The most important measures that can be taken in this context are primarily to reduce the traffic density, which is an important source of Pb and Cr pollution. It is recommended to reduce the use of individual vehicles in regions with high pollution levels, to use public transport and to use less polluting vehicles.

Pb and Cr concentrations will naturally be higher in the organs of plants grown in areas with high pollution levels. Therefore, it is recommended not to grow plants that can be used for food in these regions, and instead of these plants, plants that contain more heavy metals in their body are recommended to reduce soil and air pollution with the help of these plants.

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Author Contribution MC, AMOA, OBMA, FA, HS, and IZC designed the study and performed the experiments; AMOA, OBMA, FA, HS, IZC, and MC performed the experiments, analyzed the data, and wrote the manuscript.

Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code Availability Not applicable.

Declarations

Ethics Approval and Consent to Participate Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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