The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Assessing the uptake and accumulation of heavy metals and particulate matter (PM_{10} and $PM_{2.5}$) from ambient air using tree leaves in Gorgan, Iran

Seyed Mahmoud Mehdinia[1] | Hadi Rahimzadeh[2] | Somaye Beirami[2] | Hosein Ali Nikbakht[1] | Hassan Reza Rokni[3] | Ebrahim Chavoshi[4] | Hossein Faraji[5]✉

1.Social Determinants of Health Research Center, Health Research Institute, Department of Environmental Health Engineering, Babol University of Medical Sciences, Babol, Iran.
2. Department of Environmental Health Engineering, Faculty of Health and Environmental Health Research Center, Golestan University of Medical Sciences, Gorgan, Iran.
3. Health Research Institute, Gonabad University of Medical Sciences, Gonabad, Iran.
4. Department of Environmental Health Engineering, Faculty of Health and Environmental Health Research Center, Hamadan University of Medical Sciences, Hamadan, Iran.
5. Tropical and Communicable Diseases Research Center, Iranshahr University of Medical Sciences, Iranshahr, Iran.

Article Info

Article type:
Research Article

Article history:
Received: 20January 2025
Revised: 17 May 2025
Accepted: 28 August 2025

Keywords:
Air pollution
Heavy metals
risk assessment
Suspended particles
Trees biomonitoring

ABSTRACT

Trees are effectively used as biological indicators of urban environmental pollution and can demonstrate the amount and intensity of pollutant accumulation. This cross-sectional-analytical study aimed to Assessing the uptake and accumulation of heavy metals and particulate matter (PM10 and PM2.5) from ambient air using tree leaves in Gorgan. Samples were collected from two types of trees in urban areas. Therefore, considering the number of trees (two types of elm and plane), 52 leaf samples (26 summer samples, 26 winter samples), 13 soil samples and 13 water samples were collected. Graphite Furnace Analyst 700 and ICP-MS7500cs atomic absorption spectrometers were used to measure metals. Carcinogenic and non-carcinogenic risks were assessed. Data analysis was performed using SPSS version 22 at a significance level of 5%. The highest concentration of Pb in dust in *Platanus* leaves was 60 mg/kg in the dry season. There was a statistically significant difference between the mean concentrations of Pb and Cr in dust accumulated on trees in the dry and wet seasons ($P < 0.05$). The highest average PM2.5 were related to the *Ulmus* tree species. The highest and lowest (TTHQ) were determined for the *Platanus* tree in the children group (3×10-4) and in the adult group (6.1×10-5), respectively. The highest and lowest (TLCR) values were found in the *Ulmus* tree in the adult group (2.1×10-9). Traffic sources play an important role in the production of heavy metals in dust, and dust particles can be used as an indicator of air pollution by heavy metals and suspended particles.

Cite this article: Mehdinia, S. M., Rahimzadeh, H., Beirami, S., Nikbakht, H.A., Rokni, H.R., Chavoshi, E., & Faraji, H. (2025). Assessing the uptake and accumulation of heavy metals and particulate matter (PM_{10} and $PM_{2.5}$) from ambient air using tree leaves in Gorgan, Iran. *Pollution*, 11(4), 1242-1259.
https://doi.org/10.22059/poll.2025.389118.2760

DOI: https://doi.org/10.22059/poll.2025.389118.2760

INTRODUCTION

As cities industrialize and air pollution with various heavy metals and other pollutants increases, plants, like other organisms, are affected by this pollution. Trees in urban green spaces and industrial areas, which are influenced by these pollutants in various ways, have different response mechanisms to the stress induced by heavy metals in the surrounding soil and air. Airborne dust particles primarily adhere to plant surfaces (Nachana'a Timothy, 2019). Leaves are the most sensitive part of a plant. In general, all plants can absorb heavy metals, but trees play a more effective role in absorbing metals present in urban environments, protecting

*Corresponding Author Email: *ho.farajiaghoz@irshums.ac.ir*

residential areas and human gathering centers from their adverse effects (Naderizadeh et al., 2016; Norouzi et al., 2015). Vehicles are generally the main sources of heavy metal (Roy et al., 2022) pollutants in cities, with these pollutants entering the environment as particles from exhaust or other vehicle components (Gupta, 2020; Roy et al., 2022). Pb is primarily released into urban environments as a result of the utilization of leaded gasoline (Ye et al., 2022). Cd is present in car tires and enters the urban environment through vehicle depreciation and traffic emissions (Negahban & Mokarram, 2021). Cr in the body causes bronchitis, respiratory congestion, and inflammation upon entry into the body (Rafeeq et al.; Shokoohi et al., 2020). Symptoms of Cr-related diseases in the respiratory system include sneezing, coughing, short and discontinuous breaths, and nasal itching (Gelardi et al., 2017; Shokoohi et al., 2020). Various parameters affect the emission of vehicular pollutants in the environment, encompassing street, traffic, and environmental conditions on a large scale (Wang et al., 2018). Suspended particles with a diameter of less than 10 microns (PM_{10}) are primary pollutants entering the air directly from sources (Jiang et al., 2019; Wang et al., 2018). Particles with sizes less than or equal to 2.5 microns, known as $PM_{2.5,}$ are atmospheric pollutants that pose serious concerns for public health because they easily penetrate the lungs and contain various other pollutants, exacerbating pollution due to global climate changes (Mukherjee & Agrawal, 2017). Some plants can tolerate relatively high levels of pollution, and sensitivity to air pollution varies among plants, depending on their biochemical characteristics such as leaf chlorophyll surface, leaf ascorbic acid content, leaf sap pH, and relative water content (Nadgórska–Socha et al., 2017; Pandey et al., 2015); exposure of ordinary citizens to urban soil or direct skin contact, ingestion, and inhalation of dust particles can pose serious risks to them (Naderizadeh et al., 2016; Norouzi et al., 2015). The city is located on the main axis of the Golestan-Mazandaran freeway and is the capital of Golestan province and is on the route to the pilgrimage city of Mashhad. Studies focusing on heavy metal absorption and accumulation in plants based on plant types and metal types in Gorgan have not been conducted thus far. Therefore, this study was conducted to biologically monitor the concentration of heavy metals in tree leaves, dust, soil, and water, and determine the absorption levels of $PM_{2.5}$ and PM_{10} particles in tree leaves in the city of Gorgan.

MATERIALS AND METHODS

Description of the study site

Gorgan, the capital of Golestan Province, is located geographically at longitude is 54, 12.9 to 54, 44.9 East and 36 30.46 to 36, 58.8 North latitude, with an elevation of 160 meters, situated 30 kilometers from the sea. In this comprehensive study, a statistical society consisting of leaves from various two species (*Ulmus* and *Platanus*) was collected from urban areas, representing the widest range of tree species with suitable dust absorption properties. Samples of dust (dry deposition) accumulated on tree leaves were also collected for analysis in urban areas. Samples of water and soil were collected from each urban area where leaf and dust samples were obtained. Fig.1. Location of the study area of Gorgan city.

Sample Volume and Calculation Method

In this study, the statistical population included leaves of various tree species (*Ulmus* and *Platanus*) in the city, which is the most widespread tree species with suitable dust absorption properties. Dust (dry sediment) accumulated on the leaves of the studied trees in the city was also sampled. Water and soil samples were also collected from urban areas, and leaf and dust samples were taken. To determine heavy metals and suspended particles, samples were taken from two tree species in urban areas. Considering two types of tree leaves (*Ulmus* and *Platanus*), 30 leaf samples were collected from urban areas (15 samples in the dry season, 15 samples in the wet season). Also, 15 soil samples and 15 water samples were collected from urban areas.

Fig. 1. Location of the study area of Gorgan city

The sampling method of water, soil, and tree leaves in urban areas was random. In this study, an attempt was made to sample areas with high and low traffic. It should be noted that to calculate sampling error, each type of experiment was performed with 3 repetitions.

Sampling of Leaves and Soil

Leaf samples for heavy metal analysis were transported to the laboratory in plastic bags, washed immediately upon arrival, the washed samples were then dried in the oven, pulverized by the mill, and passed through a 2 mm sieve. For investigation of suspended particles, the solution obtained from washing leaf samples was passed through a filter using a vacuum pump and the collected particles were weighed (Zeng et al., 2018).Soil samples were collected by a gardener's spade from the surface soil (depth of 5-20 cm). A sample was taken from the intersection point and four additional samples were taken from four points at a 50-meter radius from the central sampling point. The subsamples were mixed together to obtain a composite soil sample. Soil samples were stored in polyethylene bags and transferred to the laboratory for further analysis. The soil samples were passed through a 2 mm polyethylene sieve to prepare for digestion. A portion of each soil sample was ground and sieved through a 100-mesh sieve. The samples were then passed through a 2 mm sieve in the laboratory, and glass containers were used for water samples collected from the city area and transferred to the laboratory for analysis(Hadayat et al., 2018; Zeng et al., 2018).

Preparation, Digestion, and Elemental Content Determination in Plant Samples

First, the samples were cleaned of soil and dust using a plastic brush and distilled water twice. Then, they were dried in the open air on wide clean paper for one day. After complete air drying, the leaf samples were placed in an oven at 60 to 100°C for 24 hours in the laboratory. Subsequently, the samples were powdered using a blender and passed through a 2 mm sieve. 0.5 g of each leaf sample was precisely weighed using a laboratory balance and transferred to sterile glass containers. Then, 4 ml of concentrated nitric acid, was added to each sample, and the containers were sealed. In a Ben Mary bath, the samples were heated in two stages at 65°C and 100°C for 60 and 90 minutes. After cooling, to digest organic materials, 0.2 mL of 37% hydrogen peroxide was added to the samples and left in this condition for 30 min. The samples were then filtered using Whatman filter paper 0.42 and brought to a 25 mL volumetric flask by distillation twice with distilled water (Yadav et al., 2017).

Preparation and reading of elements content in dust samples accumulated on leaves

First, the filter containing the dust was placed in the oven at 80°C for three hours to dry, and then the samples were poured into the beaker and 5 cc of concentrated nitric acid was added to it to be digested and placed on a hot plate at 80°C for 30 minutes. data, after cooling, add 5 ml of HCLO4 to the samples and heat again until a semi-dry and transparent solution is obtained. After that, the samples were filtered with filter paper 42 and made up to a volume of 25 ml with double distilled water (Meddich et al., 2020).

Preparation, digestion, and determination of element content in soil samples

First, 0.5 grams of the sample is weighed with an accuracy of 0.001 grams, and then 5 cc of concentrated nitric acid is added to it in a Teflon container and placed at a temperature of 80 to 90 degrees Celsius for 0.5 hours. Then 6 cc of a mixture of concentrated HF and HClO4 is added to it in a volume ratio of 3:1. Heating is continued until the sample is completely dissolved. Then5 cc of hydrochloride was added and heating was continued until the volume of the solution reached 3 cc. Finally, the sample volume reaches 50 cc with distilled water (Gopal et al., 2021).

Analysis of heavy metals in leaves, soil and suspended sediment and water samples

In order to measure the concentration of Pb, Cd, and Cr in the sediments on the leaves, soil and inside the leaves and water, it was read graphite furnace atomic absorption device (Analyst 700) and inductively coupled plasma mass spectrometry (ICP-MS7500cs). The LOD and LOQ of Pb and Cr in the samples were 0.141, 0.032 and 1.325, 0.141 μg/L, respectively, using a Perkin Elmer Analyst 700 graphite furnace atomic absorption spectrometer. The calibration curve of each of these elements was drawn from a 1000 mg/L stock solution at concentrations of 10, 40, 60, 80, 100 and 300 μg/L.

Evaluation of the amount of suspended particles accumulated on the leaves of trees

In order to determine the size and content of particles accumulated on the leaves of the trees, first the leaf samples were completely washed in distilled water. To separate suspended particles with a diameter of 10 and 2.5 microns, the obtained solution was first passed through Whatman 91 paper filters (to retain PM10 suspended particles) and then through a 42 μm filter (to retain PM2.5 suspended particles) and then filtered. Then the filters were dried in an oven at 80 degrees Celsius for three hours and then placed in a dryer and weighed. Washed suspended particles include the particles on the upper and lower surface of the leaf, so it was stated for the surface of the leaf when calculating and determining the amount of suspended particles (Santunione et al., 2024).

Preparation of spatial distribution maps of elements

To prepare maps that classify the concentration of heavy metals in the study area using the weighted interpolation method, version 9.3 of ArcGIS software was used. Data were collected using ArcGIS software to create a database of results related to the concentration of elements, and spatial distribution maps for each element were drawn based on the weighted interpolation method (IDW).

Data analysis

Statistical data, including mean, standard deviation (SD), and coefficient of variation for heavy metals in dust, leaves, soil, and water samples from different areas, were presented. Normality of the data was evaluated using the Shapiro-Wilk test, and a significant level of P-value >0.05 was considered as the criterion. All figures and tables were plotted using Office 2016 and Excel 2016 software.

Risk assessment of heavy metals

The health risk assessment of any potentially toxic metal is usually determined based on the level of risk and on the basis of its carcinogenic and non-carcinogenic risk to human health(Plunkett, 2011). To estimate the risk factor, first the average daily dose (ADD) (mgkg-1day-1) of heavy metals through inhalation is calculated using Eq. 1. (Faraji & Shahryari, 2023).

$$ADD = \frac{C \times IR \times EF \times ED}{PEF \times BW \times AT} \quad (1)$$

In this Eq.1. C is the average concentration of heavy metals in dust (mg/kg), IR is the inhalation rate (m^3/day), EF is the collision frequency, ED is the duration of exposure (years), and PEF is the emission of particles. factor (m^3/kg), BW is the average body weight (kg), AT is the average time of exposure to non-carcinogenic effects (Wang et al., 2021).

Evaluation of non-carcinogenic risk by THQ risk index

According to Eq. 2, the non-carcinogenic risk of heavy metals with THQ is calculated:

$$THQ = \frac{ADD}{RFD} \quad (2)$$

In this Eq, ADD is the average daily inhalation and RfD is the inhalation reference dose in mg/kg/day. If THQ > 1, there is a risk of non-carcinogenic effects, but if THQ < 1, there is no apparent risk to the population at risk. The cumulative risk value of different metals in a species is calculated through Eq. 3. (Wu et al., 2023). A description of the parameters used in the risk assessment is given in Table 1.

$$\mathrm{HI} = \sum\nolimits_{k=0}^{n} \mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD1}} + \frac{\mathrm{EDI}}{\mathrm{RfD2}} + \ldots + \mathrm{EDI} / \mathrm{RfDi} \quad (3)$$

Assessment of carcinogenic risk by LCR index

The probability of cancer occurrence shows the degree of carcinogenicity of an agent, which is calculated by the Eq. 4.

$$\mathrm{LCR} = \mathrm{ADD} \times \mathrm{CSF} \quad (4)$$

where CSF is the carcinogenic slope factor in mg/kg/day. If the value is 1×10^{-6} < LCR < 1×10^{-4}, it indicates acceptable or tolerable risk and human health, but if LCR > 1×10^{-4}, the possibility of high risk and development of cancer in is human (Li et al., 2023).Table 2 lists the values of the parameters used in the risk assessment equations. Table 2. lists the values of the parameters used in the risk assessment equations.

Table 1. Description of parameters used in risk assessment (Qiang et al., 2025)

input parameter	unite	children	adults
IR	m^3/day	10	20
ED	Years	6	24
EF	Day	350	350
BW	Kg	15	70
PEF	m^3/day	1.36×10^9	1.36×10^9
AT (non-carcinogenic)	Day	ED×365	ED×365
AT (carcinogenic)	Day	70×365	70×365

RESULTS AND DISCUSSION

The results of examining the concentration of heavy metals in the dust accumulated on tree leaves, of the studied urban area in two seasons, dry and wet, are described in Table 3. The highest concentration of lead in dust in *Platanus* leaves was 60 mg/kg in the dry season. There was a statistically significant difference between the mean concentrations of Pb and Cr in dust accumulated on trees in the dry and wet seasons ($P < 0.05$).

The mean Cd concentration in dust accumulated on trees in the dry and wet seasons was not statistically significantly different ($P = 0.287$).

The concentration of heavy metals in dust collected from tree leaves

Fig. 2. shows the distribution map of Cd (A1, and A2) in the leaves of *Ulmus*, and *Platanus* in wet season. The highest concentration of Cd in the dust accumulated on the leaves of the *Platanus* tree was reported in the wet season with a concentration of 0.52 mg/kg corresponding to the *Ulmus* tree and the lowest concentration in the wet season with a concentration of 0.31 mg/kg corresponding to the *Platanus* tree. The highest and lowest average concentration of Cd in the wet season was related to the *Platanus* tree with a concentration of 0.48 mg/kg and the *Ulmus* tree with a concentration of 0.45 mg/kg. Fig.2. (A3 and A4) shows the concentration of Cd in the leaves of *Ulmus* and *Platanus* in dry. The highest concentration of Cd of the *Platanus* tree was reported in the wet season with a concentration of 0.86 mg/kg corresponding to the *Ulmus* tree and the lowest concentration corresponds to *Ulmus* mg/kg 0.3. The highest and

Table 2. The recommended standard for the assessment of dust assessment (Victor et al., 2018)

parameter	Pb(mg/kg)	Cd(mg/kg)	Cr(mg/kg)
RFD_{inh}	0.035	0.0001	0.001
CSF_{inh}	0.042	0.041	6.3

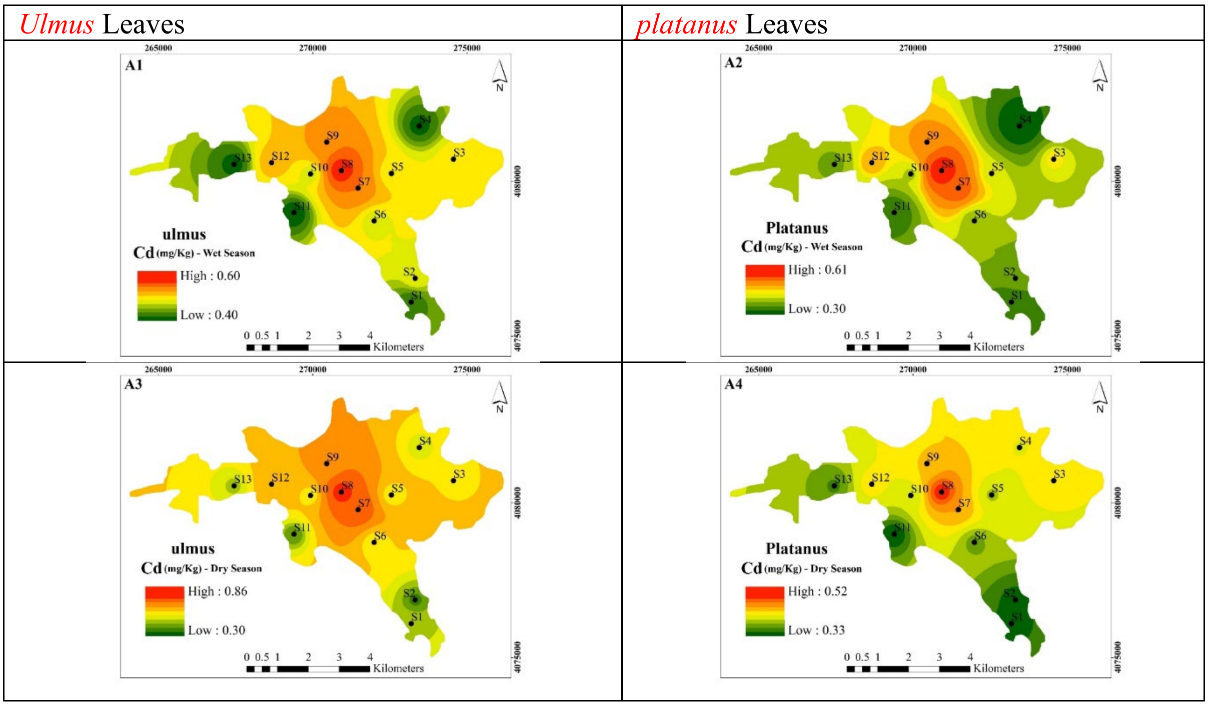

Fig. 2. Spatial Distribution of Cd concentrations in dust on tree leaves (wet and dry seasons)

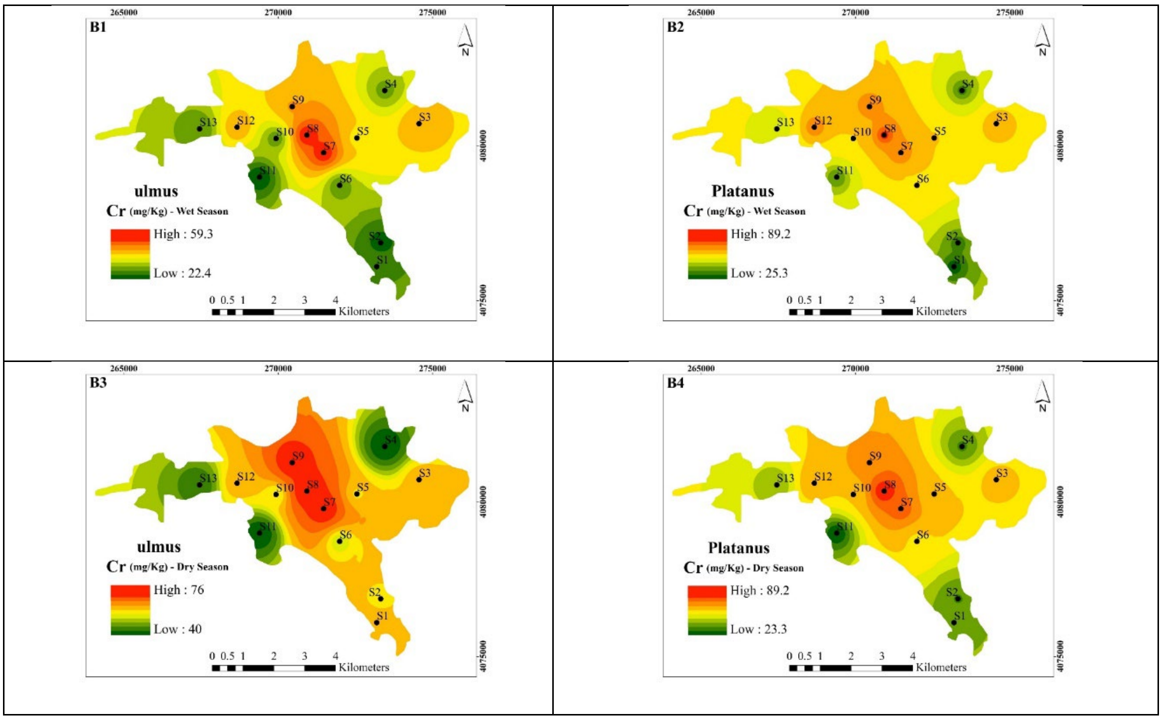

Fig. 3. Spatial Distribution of Cr concentrations in dust on tree leaves (wet and dry seasons)

lowest average concentration of Cd in the wet season was related to the *Ulmus* tree with a concentration of 0.45 mg/kg. The lowest concentration of Cd was related to the *Ulmus* tree for both dry and wet. The mean Cd concentration in dust accumulated on trees in the dry and wet seasons was not statistically significantly different (P = 0.287).

According to Fig 2, the concentration of Cd in suspended particles accumulated on the leaves of trees in the hot and cold season, the highest concentration of Cd was observed during the dry season with a concentration of 0.86 mg/kg. The average concentration of Cd suspended particles on the Ulmus tree was higher for both seasons. the average Cd for the *Ulmus* tree has been higher compared to the *Platanus* tree for both seasons. The publication of metals from dust covers tire wear, brake abrasion, and suspended dust (Yuan et al., 2020). The study of Isinkaralar et al showed that the high concentration of Cd metal on the side of the roads and urban areas is caused by motor vehicles, which confirms the issue of the present research (Isinkaralar et al., 2022).

Fig.3. shows the distribution map of Cr (B1, and B2) in the dust accumulated on the leaves of *Ulmus*, and *Platanus* in wet season. The highest concentration of Cr of the *Platanus* tree was reported in the wet season with a concentration of 89.3 mg/kg corresponding to the *Platanus* tree and the lowest concentration of 22.4 mg/kg corresponding to the *Ulmus* tree. The highest and lowest average concentration of Cr in the wet season was related to the *Ulmus* tree with a concentration of 61.3 mg/kg and the *Platanus* tree with a concentration of 38.4 mg/kg.Fig.3. (B3 and B4) shows the concentration of Cr in the leaves of *Ulmus* and *Platanus* in dry. The highest concentration of Cr of the *Platanus* tree was reported in the wet season with a concentration of 87.5 mg/kg corresponding to the *Platanus* tree and the lowest concentration corresponds to *Platanus* mg/kg 23.3. The highest and lowest average concentration of Cr in the wet season was related to the *Platanus* tree with a concentration of 61.45 mg/kg. The lowest Cr concentration was related to the *Ulmus* tree in the dry season. There was a statistically significant difference between the mean concentrations of Cr in dust accumulated on trees in the dry and wet seasons ($P < 0.05$).

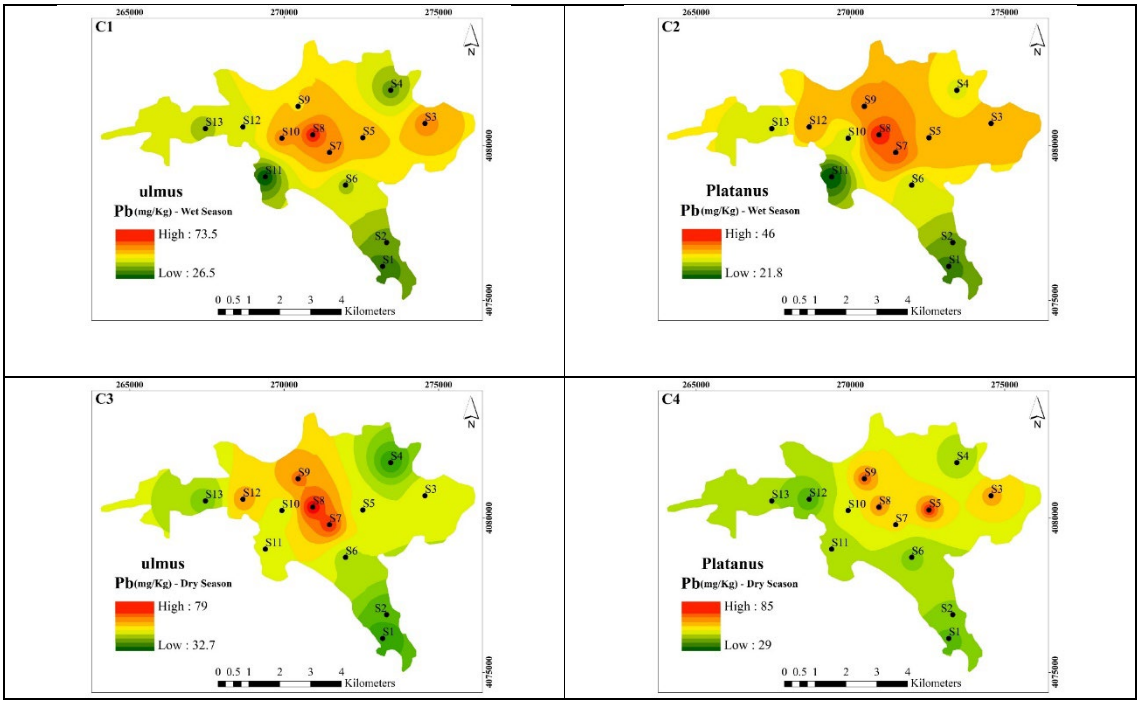

Fig. 4. Spatial Distribution of Pb concentrations in dust on tree leaves (wet and dry seasons)

According to the zoning Fig. 3, the highest amount of Cr is related to the *Platanus* tree. The highest average Cr is in the winter season and related to the *Platanus* tree. The nature of Cr is part of ore, especially chromite and cryolite (Li et al., 2021). Cr is an element that is necessary for the transport of insulin molecules insulin molecule to transport glucose into the cells to carry out glycolysis (Cesur et al., 2021). Liu et al emphasized the role of human activities in the release of Cr metal in the urban environment, and the present study shows this (Liu et al., 2019).

Fig.4. shows the distribution map of Pb (C1, and C2) in the dust accumulated on the leaves of *Ulmus*, and *Platanus* in wet. The highest concentration of Pb of the *Platanus* tree was reported in the wet season with a concentration of 83.2 mg/kg corresponding to the *Ulmus* tree and the lowest concentration of 21.4 mg/kg corresponding to the Platanus tree. The highest and lowest average concentration of Pb in the wet season was related to the *Ulmus* tree with a concentration of 51.3 mg/kg and the *Platanus* tree with a concentration of 33.7 mg/kg.Fig.4. (C3 and C4) shows the concentration of Pb in the leaves of *Ulmus* and *Platanus* in dry. The highest concentration of Pb of the *Platanus* tree was with a concentration of 83.5 mg/kg corresponding to the *Platanus* tree and the lowest concentration corresponds to *Platanus* mg/kg 33.2. The highest and lowest average concentration of Pb in the wet season was related to the *Platanus* tree with a concentration of 60.5 mg/kg. The lowest Pb concentration was related to the *Ulmus* tree in the wet season. There was a statistically significant difference between the mean concentrations of Pb in dust accumulated on trees in the dry and wet seasons ($P < 0.05$).

The highest average concentration of Pb is related to the *Platanus* tree in the dry season. The presence of Pb can be attributed to human activities and traffic (Li et al., 2021). The distance from the pollutant source can also affect the amount of element absorption by plants (Jahantab, 2021). The leaves of trees are suitable accumulators of heavy elements, especially in industrial and polluted areas (Rafati et al., 2020).

The concentration of heavy metals(Cd, Cr and Pb) absorbed by leaves

In order to analyze the concentration of metals absorbed in the leaves of the trees, samples

Table 3. The average concentration of heavy metals in dust accumulated on tree leaves

Metal	Dry				Wet			
	Leaves mg/kg		Max.	Min.	Leaves mg/kg		Max.	Min.
	Ulmus	*Platanus*			*Ulmus*	*Platanus*		
Cd	0.44±0.17	0.39±0.05	86	0.3	0.46±0.05	0.47±0.08	0.61	0.3
Cr	59±12.1	59±19.9	89.2	23.3	38±12.9	61±26.1	89.6	22.4
Pb	55±15.6	60±20.6	85.1	29.2	50±15.9	33±6.9	73.5	21.8

Table 4. Average concentration of Cd, Cr and Pb in leaves based on trees, seasons

Metal	Dry seeson (mg/kg)		Wet season(mg/kg)	
	Ulmus	*platanus*	*Ulmus*	*platanus*
Cd	0.0025±0.0	0.0025±0.0	0.0025±0.009	0.0025±0.0
Cr	0.0022±0.01	0.002±0.01	0.01±0.002	0.0024±0.0093
Pb	0.011±0.0012	0.003±0.0087	0.0028±0.009	0.0015±0.0093

of the leaves of the trees were taken from 13 specified stations. Table 4 shows the average concentration of Cd, Cr and Pb in the leaves of trees based on seasons. Regarding the absorption of Cd metal by tree leaves, considering that the amount of Cd absorption by tree leaves was below the detection limit and less than 0.005 (mg/kg), the concentration of Cd metal was considered as 0. 0025.The highest and lowest average concentration of Cr absorbed by *Ulmus* leaves was measured in the wet season with a concentration of 0.01 and in the dry season with a concentration of 0.002 mg/kg. Also, the highest and lowest average absorbed Pb was reported in *Ulmus* leaves in the dry season with a concentration of 0.011 and in the wet season in the leaves of *platanus* with a concentration of 0.0015 mg/kg. There was a statistically significant difference between the mean concentration of Pb absorbed by leaves in the dry and wet seasons ($P < 0.05$).

According to Table 4, the *Ulmus* tree absorbed the most Cr in wet season and the *platanus* had the least absorption, so the absorption of Pb by the *Ulmus* was more and the *Platanus* had the least Pb absorption. Leaves of trees important for metal pollutants are used specifically for monitoring metal reservoirs (Ahmed, 2023). Therefore, leaves are more sensitive than other plant organs. The results showed that among the investigated metals, the amount of Pb accumulation in the leaves of two species is higher than other metals (Rafati et al., 2020).

The results indicate that the ability of different tree species to absorb particles depends on the morphological, physiological and ecological characteristics of the leaf *Ulmus*, due to its ovate leaves and serrated teeth, large leaf length and width, morphological characteristics such as cuticle and high density of hairs on the leaf surface, and coarsely toothed leaf margins, can absorb and trap suspended particles in large quantities. On the other hand, evidence indicates that smooth and soft leaves such as those of the sparrow tongue have a lower ability to accumulate suspended particles (Nwaogu).

The concentration of heavy metals in in agricultural soil, irrigation water

In order to analyze the concentration of metals in water and soil, water sampling was done from the soil of 13 stations marked on the map and also from 13 stations. Fig 5 Distribution of Cd, Cr and Pb concentrations in soil (D1, D2 and D3) and water (E1, E2 and E3). The highest concentrations of Cr and Pb in soil were observed in regions 3 and 4, respectively, while the lowest amounts were found in points 2 and 4. The average concentrations of Cr and Pb were

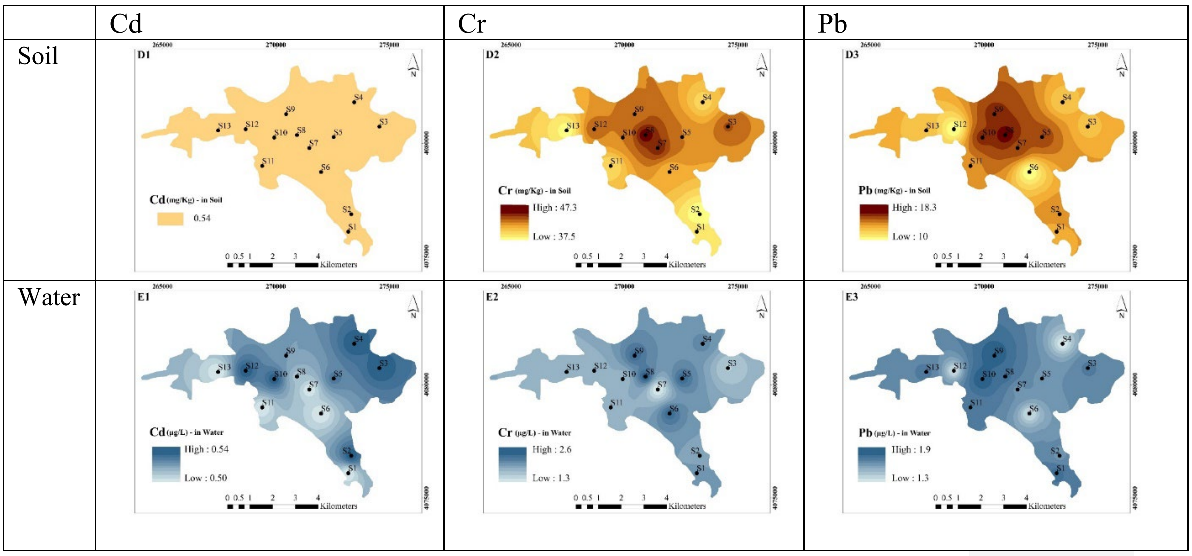

Fig. 5. Spatial distribution of heavy metal concentrations (Cd, Cr and Pb) in agricultural soil (D) and irrigation water (E)

42.5 and 13.6 mg/kg of dry weight, respectively. The highest concentrations of Cr and Pb in water samples were found in station 1 and 3, while the lowest amounts were observed in station 2 and 4. Due to the Cd concentration in water samples being below the detection limit in the study areas. the concentration of Cd metal was considered as 0.0025. As shown in Fig 5, the average concentrations of Cr and Pb in water were 2 and 1.6 µg/l, respectively.

The concentrations and descriptive statistics of Cd, Pb, and Cd in irrigation water and soil are presented in Table 3. The permissible limits for metal concentrations in water, according to FAO/WHO, are Pb (5000 µg/L), Cd (10 µg/L) and Cr (50 µg/L). For agricultural soil, the permissible limits are Pb (100 mg/kg body weight), Cd (3 mg/kg body weight) and Cr (100 µg/L) (Baghaie & Aghili, 2019; Jaafarzadeh et al., 2022).

Based on the one-sample t-test, the mean concentration of the studied elements in water samples was significantly different from the permissible limit ($P < 0.05$) (Fig.5). In soil samples, the mean concentration of the studied elements was significantly different from the permissible limit ($P < 0.05$). Spearman's correlation coefficient showed that there is a direct and positive relationship between the heavy metals Cd, Pb and Cd in water and the amount of heavy metals in tree leaves, which was obtained as r=0.55, 0.73 and 0.63, respectively. The results also showed that there is a significant and direct relationship between the heavy metals in soil and the amount of heavy metals Cd, Pb and Cd, which was obtained as r=0.1, 0.77 and 0.63, respectively.

The concentration of PM_{10} and $PM_{2.5}$ particles in dust deposited on leaves

The concentration of PM_{10} and $PM_{2.5}$ particles in dust deposited on leaves of *Ulmus*, and *Platanus* trees are shown in Fig. 6 and 7. According to the map (F1 to F4) shows The highest absorption of PM_{10} particles on *Ulmus* trees in the dry season was reported to be 147 µg/cm^2, while the lowest absorption was observed on plantain tree trees in the wet season with a concentration of 38.1 µg/cm^2. The average concentration of PM_{10} particles deposited on leaves was approximately 168 µg/cm^2 in the dry and 113 µg/cm^2 in the wet season. Similarly, the highest absorption of $PM_{2.5}$ particles on *Ulmus* trees in the dry season was 3.26 µg/cm^2, and the lowest absorption on *Ulmus* trees in the wet season was 0.445 µg/cm^2. According to the map (H1 and H4) shows the average concentration of $PM_{2.5}$ particles deposited on *Ulmus* trees was higher compared to plantain tree trees. The average concentration was around 3.26 µg/cm^2 in

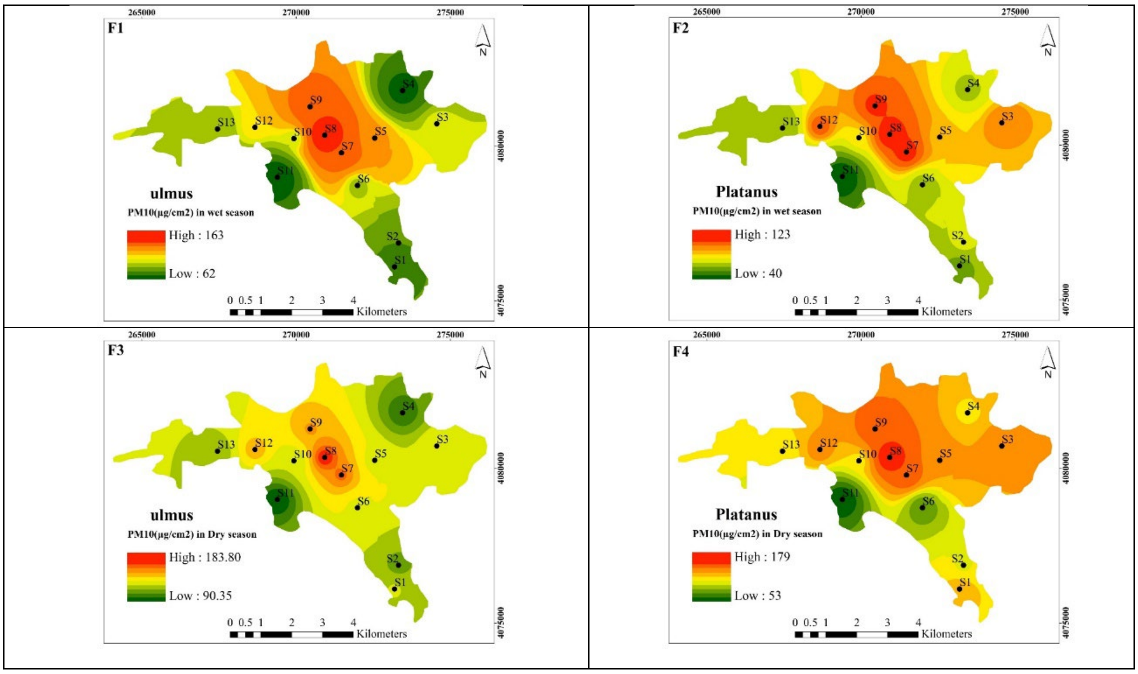

Fig. 6. Spatial Distribution of the concentration of suspended particles (PM10) on tree leaves

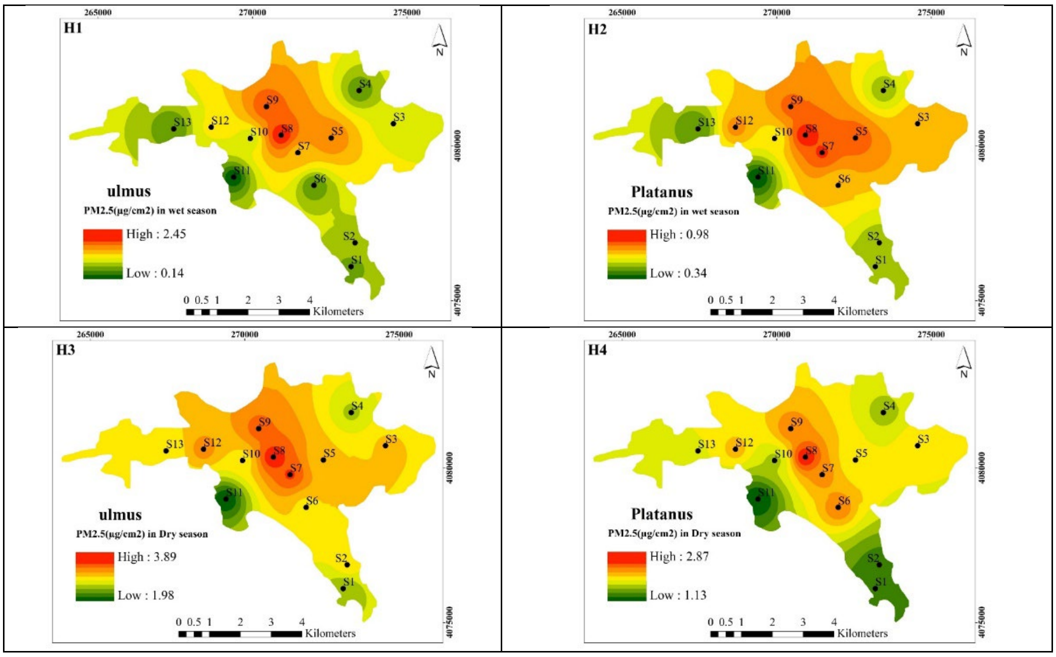

Fig. 7. Spatial Distribution of suspended particles (PM 2.5) on tree leaves

the dry and 0.980 µg/cm^2 in the wet seasons, with 0.576 µg/cm^2 and 0.698 µg/cm^2 in low and high precipitation seasons, respectively. There was a statistically significant difference between the mean concentrations of PM10 and PM2.5 particles in dust deposited on leaves in the dry and wet seasons ($P < 0.05$).

According to Fig.5 The permissible limits of Cr, Pb and Cd in soil samples are determined by WHO and IEQS 150,100 and 2 mg/kg respectively (Chávez-García & González-Méndez, 2021). The average concentration of Cd, Cr and Pb was lower than the WHO standard. Using chromium-based paints, adding Cr to lubricants and oils, and using gasoline containing Pb can

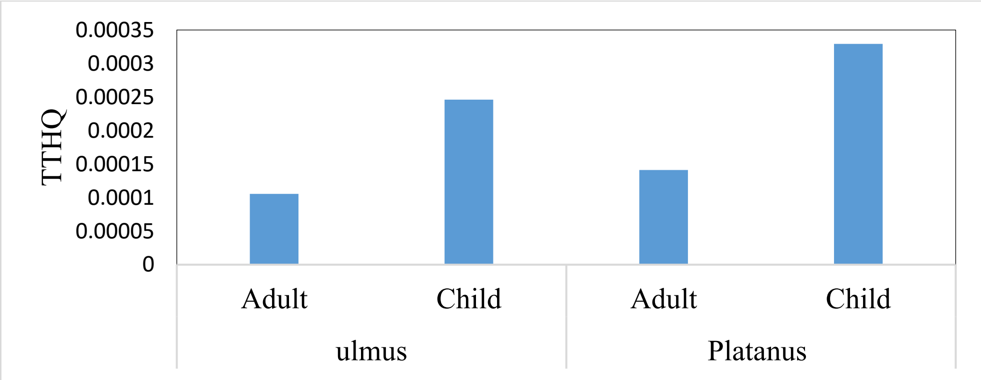

Fig. 8. Cumulative Hazard Index (TTHQ) of heavy metals in dust adsorbed on tree leaves

increase the concentration of heavy metals in the soil. According to Fig. 5, the amount of Pb, Cr and Cd was less than the permissible limit. The permissible limits of Cd, Pb and Cr in water are determined by national standard (1053) and WHO 5,10 and 50 μ g/kg respectively (Maleki & Jari, 2021; Organization, 2009, 2022). From the potential physiological effects of metals, after entering the general bloodstream, they are distributed in most body tissues, and are replaced in the tissues of the liver, kidney and bone marrow. The distribution of metals in brain tissue depends on their solubility in adipose tissue. The higher the solubility in adipose tissue, the faster the passage through the blood-brain barrier. Mercury compounds enter the brain more quickly compared to inorganic compounds of this metal.

Traffic sources play an important role in the production of heavy metals in dust, and air pollution with heavy metals is caused by urban traffic and transportation. It has been proven that pollution caused by transportation and traffic includes toxic and harmful substances such as Pb, and Cd (Farahi et al., 2025).

Urban development, increased traffic, improper use, increased energy consumption, and the lack of regulations and standards to limit industrial areas and comply with environmental regulations have caused public health in cities to be jeopardized due to a significant decrease in air quality (Zhou et al., 2018).

By examining the land accumulation index, heavy traffic, tire wear, and erosion of metal parts of paint and motor components of vehicles were identified as the main factors in causing lead pollution (Valaei et al., 2019).

A study conducted in Beijing found that the origin of Cd and Pb metals in the urban environment can be attributed to transportation and urban traffic activities, which is consistent with the current study (Chen et al., 2010).

The results related to the assessment of non-carcinogenic risk of heavy metals in dust

The results regarding the average daily dose of heavy metals in two groups of adults and children are shown in the table. The highest and lowest level of ADD Cd dose was observed in *Platanus* trees with a value of 2.1 $\times 10^{-10}$ mg/kg/d in the children's, and in *Ulmus* with a value of 8×10^{11} in the adult, respectively. The highest and lowest ADD of Pb in the *Platanus* tree in the children was on average 2 $\times 10^{-7}$ mg/kg per day and 1.2 $\times 10^{-8}$ in *Ulmus* tree in adults, respectively The highest and lowest Cr ADD in children and adults were observed in *Platanus* and *Ulmus* tree with values of 3 $\times 10^{-8}$ and 1 $\times 10^{-8}$ mg/kg/d. In general, the ADD in the children's group is higher than in adults.

The THQ values for heavy metals studied in children and adults are shown in the table. The highest average THQ for Cd, Cr, and Pb in children was in *Platanus* tree trees ($2.4\times^{10-7}$), (3×10^{-4}), and (8.1×10^{-7}), respectively. The lowest THQ value for Cr was in *Ulmus* trees (8×10^{-8}), and for

Cr and Pb, it was in *Ulmus* trees (3.1×10^{-6}) and (1.2×10^{-12}) in adults. The Risk Characterization Ratio (TTHQ) values are shown in Fig 8. The highest and lowest TTHQ values were observed in *Platanus* tree trees in children (0.00032923) and *Ulmus* trees in adults (0.000105497).

The results showed that according to Fig. 6 and 7 , the overall average concentration of PM_{10} and $PM_{2.5}$ particles accumulated on tree leaves respectively, the highest and lowest accumulation was related to *Ulmus* and *Platanus* trees *Ulmus* leaves can absorb and trap suspended particles due to having egg-shaped leaves and jagged teeth, large length and width of the leaf, morphological features such as cuticle and high density of hairs on the surface of the leaf (Ozdemir, 2019). And with the increase in roughness, the tree's ability to accumulate and trap suspended particles increases (Zhang et al., 2017).Also, with the increase in the density of hairs and the ratio of the leaf surface and the number of grooves in the leaf, the accumulation of suspended particles increases (Chen et al., 2017).The morphology, physiology and ecology of plant foliage, such as the density of stomata, texture, amount and density of the wax coating, roughness and moisture of the leaf surface, are the main factors affecting the accumulation and ability to retain various suspended particles (Shao et al., 2019). According to Table 5 The mean ADD for non-carcinogenic effects was higher in children than in adults. The highest average THQ of in children's group was found in *Platanus* tree and the lowest amount of Cd was found in *Ulmus* in adults. Therefore, the THQ values were less than one for all, and the THQ risk index was higher in Cr than in the other two metals. According to fig 8 The TTHQ index was less than one in two groups of children and adults. The non-carcinogenic risks for the children group were slightly higher than the adults. Because children are more exposed to heavy metal pollution. The study of Khazei et al., Hassan et al., and Gholizadeh et al, who worked on leaf dust, confirms this present study. According to the results of the assessment of the carcinogenic risk of heavy metals in dust, the ADD in the adult group is higher than in the children group.

The results related to the evaluation of carcinogenic risk of heavy metals in dust

The Lifetime Cancer Risk Ratio (LCR) values for heavy metals studied in adults and children

Table 5. The average daily absorption of heavy metals and estimates the Target Hazard Quotient (THQ) for adults and children (mg/kg. Day)

Leaves		Cd		Pb		Cr	
		ADD	HQ	ADD	HQ	ADD	HQ
Ulmus	Adult	8E-11	8E-08	1.2E-08	1E-04	1E-08	3E-06
	Child	9E-11	9E-08	1E-08	1E-04	1E-08	3E-06
Platanus	Adult	2E-10	2E-07	2E-08	2E-04	2E-08	7E-06
	Child	2.1E-10	2E-07	3E-08	3E-04	3E-08	8E-06

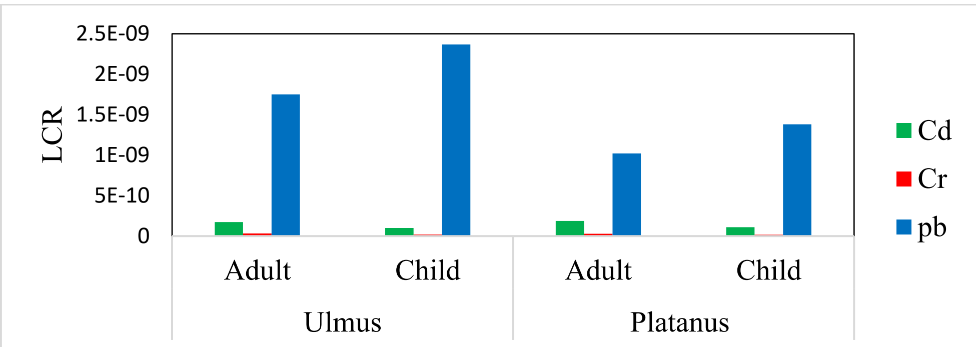

Fig. 9. Risk ratio (LCR) of heavy metals in dust adsorbed on tree leaves

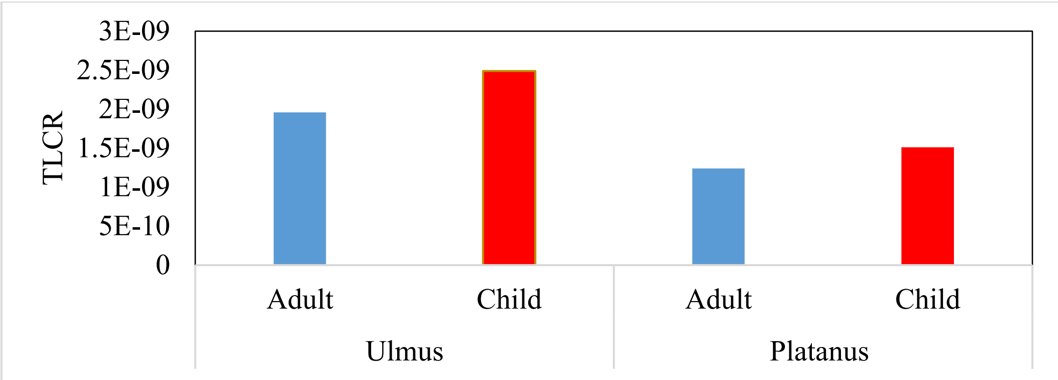

Fig. 10. Cumulative risk index (TLCR) of heavy metals in dust adsorbed on tree leaves

are shown in Fig 9. The highest average LCR for Cd, Cr, and Pb in adults was in *Ulmus* trees (3.1×10^{-10}) and *Platanus* tree trees (1.8×10^{-9}), and the lowest Cd value was in *Ulmus* trees (1×10^{-10}), while Cr and Pb values were in *Platanus* tree trees (5×10^{-10}) and (5.3×10^{-11}) in children. The Total LCR (TLCR) values are shown in Fig 10. The highest and lowest TLCR values were observed in *Platanus* tree trees in adults (2.1×10^{-9}) and *Ulmus* trees in the region (7.3×10^{-10}) in children.

In Fig 9 and 8, The highest average LCR of Cd, Cr and Pb in the adult group is in sycamore, and the lowest amount of Cd was estimated in the *Ulmus* of the adult group. According to the obtained values, the LCR index for all metals was within the permissible range (1×10^{-6} < LCR < 1×10^{-4}), and the values of the risk index (TLCR) in all studied groups were within the permissible range. And there is no risk to health. But the TLCR is slightly higher for adults than for children. Also, TLCR were slightly higher for children than for adults. Because children are more exposed to heavy metal pollution, they inadvertently inhale significant amounts of dust through their mouths, and because they have weaker immune systems, they are more susceptible to heavy metal poisoning (Boroujerdnia et al., 2020).

In a study conducted by Qanavati et al. in 2018 in Abadan, the TLCR of all heavy metals in street dust was higher for children than for adults, which is consistent with the present study (Sadeghdoust et al., 2020).

CONCLUSIONS

The study results also showed that the highest average suspended particle concentrations were related to *Ulmus* trees. The ability of different tree species to absorb particles depends on their morphological, physiological, and ecological leaf characteristics. *Ulmus* trees, with their large egg-shaped leaves, serrated edges, large leaf size, and morphological features like cuticles and dense surface hair density, can effectively absorb and trap suspended particles. The results of this study showed that the highest concentrations of the heavy metals studied, except for Cd, were in urban and high-traffic areas. This can be attributed to the increase in population and the number of vehicles used, which exacerbates pollution. The results of the risk assessment of heavy metals showed that the risk index due to the absorption of Cr, Cd, and Pb in dust is less than one, and the non-carcinogenic risk of these metals for children and adults is at a safe level, as well as the average and maximum values of the TLCR of these metals in dust for children and adults are in the safe range. In connection with the risk assessment of heavy metals, the hazard index is less than one, and the average values of the carcinogenic risk of these metals in dust are within the safe range for children and adults. The study shows that the carcinogenic and non-carcinogenic risk of these metals for children and adults was within safe limits. The information obtained from this research can be used to control and prevent air pollution with dust and heavy metals and to plant suitable trees in the city for responsible organizations. Urban planners should prioritize tree species with higher particulate retention capacity. Further studies should assess long-term heavy metal accumulation trends in urban trees. The urban plan of Gorgan is to explain the air quality situation in terms of heavy metals and suspended particles, the trend of changes in heavy metals in dust, leaves, soil, water, and factors related to these factors, and to assess the health risks arising from them in order to reduce heavy metals and suspended particles in dust. The study is conducted at the city level. Urban planners should prioritize tree species with higher particulate retention capacity. Further studies should assess long-term heavy metal accumulation trends in urban trees.

ACKNOWLEDGEMENTS

This research was supported by the Vice-Chancellor of Research and Technology of Babol University of Medical Sciences with project code: IRMUBABOL.REC.1401.004. The authors are grateful to Golestan University of Medical Sciences, Faculty of Health, for conducting the experiments in this research.

GRANT SUPPORT DETAILS

This work was supported by Babol University of Medical Sciences, Iran.

CONFLICT OF INTEREST

The authors declare that there are no financial or non-financial interests to disclose.

LIFE SCIENCE REPORTING

This study does not contain any studies with human participants or animals performed by any of the authors.

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