ORIGINAL PAPER

Heavy metal concentrations in the outdoor and indoor air of high-traffic areas in Tehran, Iran

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ABSTRACT

Tehran is a polluted metropolitan and the capital of Iran, where heavy traffic and excessive energy consumption (especially gasoline) are the major sources of heavy metal emissions. This study aimed to investigate the variations in heavy metal concentrations on the aerosols of the outdoor and indoor environments in the high-traffic regions of Tehran. This was a descriptive, applied research in terms of methodology. Six internal-external stations were specified in three high-traffic regions. Sampling was performed in six replications for each station during fall 2018 (n=36). After the extraction of the heavy metals from the fiberglass filters using acidic digestion based on the ASTM method, their concentrations were measured via ICP-OES. Data analysis was performed in SPSS using MANOVA. According to the results, regions 2, 3, and 15 had the highest traffic in Tehran during the study, with the traffic rate estimated at 25-27% h/day on average. A significant difference was observed between the outdoor and indoor regions in terms of heavy metal concentrations (P<0.05). The order of the mean concentrations of heavy metals in the open spaces was as follows: Al > Fe > Pb > Mn > Cu > Zn > Cr > As > Ni > Cd. Aluminum and cadmium had the highest and lowest concentrations, respectively. In addition, the high concentration of lead and heavy traffic was alarming in Afsariyeh Street (region 15). Considering the adverse effects of pollution on the health of citizens, serious measures should be taken to control traffic in Tehran.

Keywords: Heavy metals, Traffic volume, Tehran metropolitan, Indoor and outdoor environment

Introduction

According to the World Bank report in December 2016, air pollution has become the deadliest form of pollution and the fourth leading risk factor for premature deaths worldwide.[1] Air pollution is a major environmental concern in metropolises. The International Agency for Research on Cancer (IARC), which is affiliated to the World Health Organization (WHO), has classified suspended particulates into group one of carcinogens regardless of their size or chemical composition.[2]

Tehran Metropolitan is one of the most polluted metropolitan areas in the world. Recently, Tehran has been faced with the substantial challenge of air pollution, and in addition to the sources of contamination within the city, the phenomenon of dust storms with an external origin has further complicated the issue.[3] Particles with diameters below 10 µ (PM_{10}) and particles smaller than 2.5 µ ($PM_{2.5}$) in diameter could infiltrate into the depth of the lungs, adversely affecting human health.[4] These aerosols may also be suitable places for the residing of pathogenic agents (especially heavy metals) and may enter the respiratory organs while breathing. Due to their mutual effects, some of the aerosols in the atmosphere may also intensify the toxic effects of other

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pollutants.[5]

Population growth, unstable development, excessive use of natural resources, increased production of motor vehicles, and excessive consumption of gasoline and fossil fuels along with industrial expansion are among the anthropogenic factors of air pollution, especially in metropolitan areas, which lead to irreparable human health problems. Tehran metropolis is one of the most polluted cities in the world; however, few studies have been focused on the heavy metal pollution in this city so far. For instance, Hussein Saeedi *et al.* performed a research to determine the concentration of heavy metals in the air in the urban regions in Shahr-e-Ray (Iran). According to the findings, the annual mean concentrations of heavy metals such as chromium, nickel, and cadmium were higher in all the stations, while the mean concentration of lead was higher than the standard level in the industrial stations.[6]

In another study, Hosseini *et al.* evaluated the concentration of heavy metals in suspended particulate matter (PM) in the atmosphere of Sanandaj (Iran) and the effects on the employees and students of Kurdistan University of Medical Sciences. According to the obtained results, the highest concentrations of heavy metals on dusty and non-dusty days were observed in June, which belonged to iron. On the other hand, the lowest concentrations of heavy metals on dusty days belonged to cadmium in May, and the lowest concentration on non-dusty days belonged to cadmium as well, which was observed in September.[7]

In this regard, Parivarnia evaluated the risk of the contamination of nickel heavy metal in Shiraz dust. The mean concentration of nickel in the air was estimated at 32.6 ppm, and the ecological risk of nickel for the entire city of Shiraz was reported to be low.[8]

In a study conducted by Moradi and Mirzaei, which evaluated the concentrations of heavy metals from dust of the urban air based on the geo-accumulation index (Igeo). According to the obtained results, lead, copper, and zinc had human-induced origins, and iron and cadmium were partially affected by human activities. On the other hand, nickel and chromium were of completely natural origins. Vehicle traffic and industrial activities were reported as the possible causes of the increased heavy metal concentrations in Kashan.[9]

In a research conducted in Masjed Soleiman in Khuzestan province (Iran), it was concluded that the particles with the highest urban dust pollution were from lead, copper, zinc, and cadmium, and petroleum activities, traffic, and industrial activities were the major contributors to the increased concentrations of these heavy metals in the urban dust.[10] Based on the findings of Khademi *et al.* which determined the total concentration of the iron, zinc, lead, copper, and nickel in dusts of parts of Bushehr province, it was concluded that zinc, copper, and lead were of human origin, while iron and nickel were probably derived from non-human sources. Moreover, the growth of the industrialization and human activities was reported to increase the entry of heavy metal elements into the atmosphere of Bushehr province.[11]

According to their findings of Dimitriou and Kassomenos, traffic was the primary source of PM_{10}, which elevated the contents of arsenic, cadmium, and lead in both cities.[12] Another study, aiming to analyze the contents of the heavy metals in the dust inside apartments and streets in Albania. The results indicated that three Pb, Zn and Cu elements were enumerated amongst the air and soil pollutants and their contents were associated with traffic level and urbanization rate. The other measured metals were found having slight changes. The heavy metals took the following order in terms of concentration from high to low: Zn > Pb > Cu > Ni > Cr > Li > Fe. Based on the type of the announced samples and contents of these elements in the sampling environments, the following order was determined: indoor dust>street dust>ground dust.[13]

Darus *et al.* reported that the ground dust of the kindergarten environment was the path exposing the children to the risk of air pollution. The order of the heavy metals in terms of concentration from high to low was as follows: Fe > Al > Zn > Pb > Ba > Cu > Cr > Ni. On the other hand, the analysis of the principal components indicated that the indoor pollution resulted from an array of sources.[14]

Rashed evaluated the effects of urban traffic on the concentration of heavy metals in the dust samples in Egypt. According to the findings, the lead, magnesium, and iron contamination was at the highest level, while cadmium pollution was at the lowest level as documented in the dust samples collected from open and closed spaces, as well as streets. In general, the concentration ratios were widely different in the indoor and outdoor spaces depending on various heavy metals and places.[15]

The present study aimed to investigate the changes in the concentration of the heavy metals found in the aerosols of the indoor and outdoor environments of high-traffic regions in Tehran, Iran in fall 2018.

Geographical location of the studied region

Tehran is situated in 51º17'-51º33' of the eastern longitude and 35º49' of the northern latitude. Tehran city covers an area of 733 square kilometers.[16] The population of the city is over eight million (8,693,706). Tehran is located in a stretch of lands between mountain and desert, and the surface waters of the slopes of Alborz Mountain are guided toward the south. In this district, Alborz Mountain takes a crescent-like form. The same arrangement of mountains in the periphery of Tehran and the city's establishment within the crescent-shaped space of the mountains are an effective barrier to the infiltration of the western winds (dominant winds in Tehran) into the indoor spaces, which make the air more stagnant therein in contrast to its surrounding plains. Air immobility (especially in winter and during air inversion) leads to the severe accumulation of pollution in the narrow mountainous spaces on the eastern side of the city, preventing the natural upward ascension of hot air and discharge of the pollution. This phenomenon leads to photochemical smoke mists in the early morning.[17]

Changes in the air quality of Tehran in 2018

In 2018, the Air Quality Control Agency used its 21 active stations to measure and monitor the air quality of Tehran, which was reported in the form of AQI. It is notable that the prevailing wind pattern in Tehran is western and northwestern. According to meteorological reports, the reason for this phenomenon is the presence of a local high-pressure area in the region. Wind is a prominent factor contributing to the reduction or increase of the concentration of air pollutants. The month with the most polluted days were observed to be December (11 days), February (10 days), and January (seven days), respectively. Moreover, the air quality was deemed unhealthy for sensitive groups in 16 days in the year 2018 in terms of the O_3 index and one day regarding the PM_{10} pollutant.

In recent years, particulate pollutants (especially particulates with lower diameter than 2.5 µ) have been identified as the main pollutants in Tehran. According to reports, 44 days in the year 2018 were considered to be in poor condition in terms of the $PM_{2.5}$ pollutants. These particles are mostly produced through combustion processes, especially in motor vehicles such as diesel cars. Following that, they accumulate in the city air if the weather conditions are stable for several consecutive days, as well as the occurrence of dust storm. In 2018, 75% of the polluted days were due to this contaminant. In addition, the highest monthly concentration values were observed in December and January, respectively due to cold air, increased atmospheric stability, and temperature inversion, which could be attributed to the accumulation of pollutants in the city.[9]

Materials and Methods

To assess the total aerosols in high-traffic regions and determine the concentration of the heavy metals carried by these particles, we used the statistics of Tehran's traffic control center system, as well as the online maps from Google search engine (Google Maps) for the traffic status in Tehran. Following that, the regions with the highest traffic during the previous seasons and various days of the year on average and heavily congested spots were selected. During the previous seasons of 2018, districts two, three, and 15 of Tehran municipality were pinpointed to be containing the routes with the highest traffic based on the statistics of Tehran Traffic Control Center (Table 1).

Table1. First three ranks of districts with highest traffic in metropolitan Tehran

Rank	Route name	District
1	Sheikh Fazl Allah Nouri Highway (south-north) from its exit to Yadegar-e-Jonoub to its entry from the north Yadegar	2
2	Shahid Hemmat Highway (west-east) from its exit to northern Chamran to its exit to southern Sheikh Baha'ei	3
3	Basij Highway (south-north) from U-turn to the exit into eastern Rahimi	15

Based on the mentioned statistics, Sheikh Fazl Allah Nouri Highway (west of Tehran) was the most congested route in Tehran within the distance from its exit into southern Yadegar-e-Imam to its entry of Yadegar-e-Imam. The second rank belonged to Shahid Hemmat Highway, where the highest traffic was documented within the distance from its exit to the northern Chamran to its exit into the southern Sheikh Baha'ei. The third rank of the region with the highest traffic belonged to Basij Highway for the distance from the U-turn to its exit into the eastern Rahimi (Fig. 1).

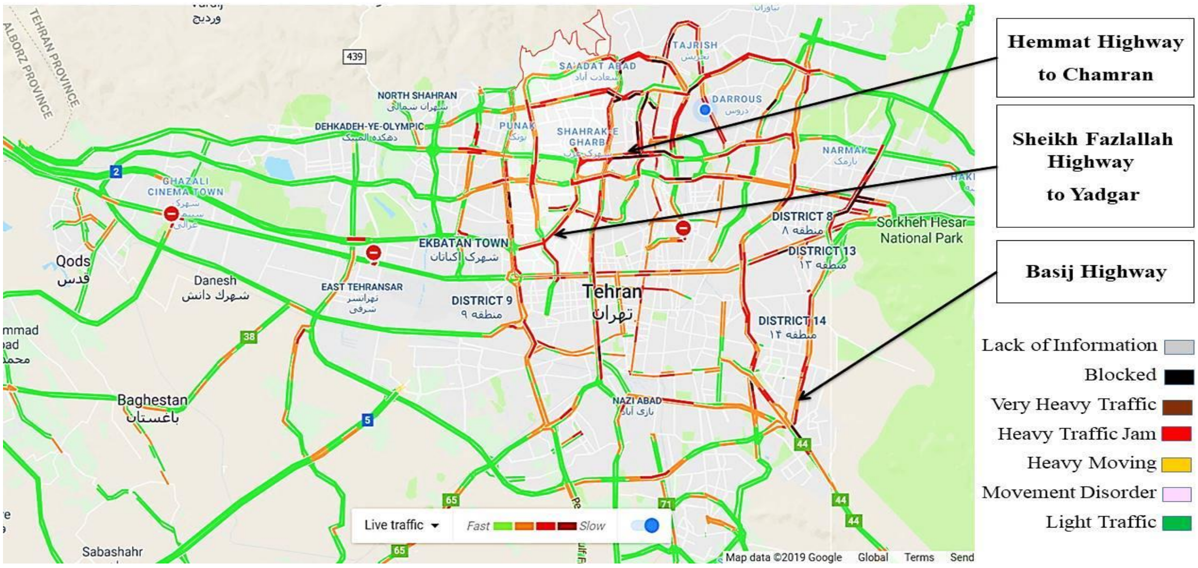

Fig. 1. Online map of Tehran's Traffic, Fall 2018 (Source: www.google.com/maps/place/Tehran)

Two stations were selected in each of the mentioned high-traffic regions, including one station in the open space and another station in the closed space, so that six stations (three indoors and three outdoors) were specified in three high-traffic regions (Fig. 2).

- The first station (outdoor): District two, Azadi Street, Yadegar-e-Imam junction;
- The second station (indoor): District two, Farhadiyeh narrow pass, drugstore of Sharif UniversityClinic;
- The third stations (outdoor): District three, Vanak Square from Hemmat Streetside;
- The fourth station (indoor): District three, Tavanir Streetfrom the clinic to Sima;
- The fifth station (outdoor): District 15, Afsariyeh three-way toward Tehran Pars;
- The sixth station (indoor): District 15, the second 15-meter street (Second Afsariyeh), Javad Al-A'emmeh Charitable Clinic.

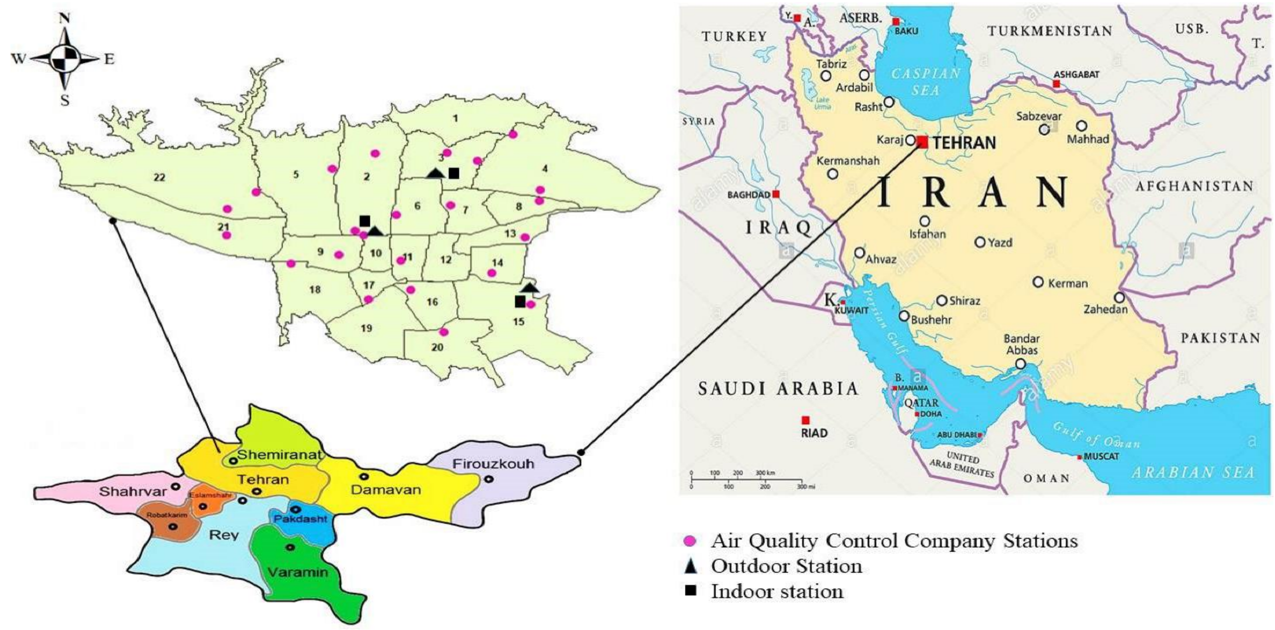

Fig. 2. Geographical location of study area and sampling stations in Tehran metropolitan

Suspended particle sampling using the gravimetric method

Sampling was carried out at the six selected stations in the two indoor and outdoor environments located in three high-traffic regions in six replications in fall (total: 36 samples) based on the standards of the American agency of environmental conservation. Furthermore, sampling at the six selected stations in both indoor and outdoor locations in three high-traffic areas was performed in six replications in fall (total: 36 samples) in accordance with the standards of the Environmental Protection Agency (EPA). The samples were obtained in the outdoor environments during the peak traffic h in Tehran (6 a.m.-8 a.m., 4-6 p.m. for 2 h at a time). Each station was sampled every month (October, November, and December) during fall, and one day (Saturday, Monday or Wednesday) with two replications in the morning and evening, resulting in 36 samples obtained during the autumn season. Sampling was performed simultaneously by six experts at the six stations. For indoor sampling, samples were collected at the working shifts of the medical personnel (8 a.m.-6 p.m.) at 1-1.5 m above the ground level. The air sampler was operated at the flow rate of five L/min, and the total volume of the passing air was 2,400 L. After each sampling, tubed fiberglass filters were placed in polyethylene containers and sent to the Spectrometry Laboratory of Razi Institute of Applied sciences (located in Tehran, 21 kilometers from Karaj Road, Shahr-e-Qods entrance, Shahid Haj Qasem Asgari Boulevard, Farnan Street, No. 27), where they were analyzed with the assistance of chemistry experts.

Sampling instruments and laboratory supplies

Sampling was performed using the filtration method for the measurement of particle concentrations and environmental sampling instruments. The materials required in the present study included fiberglass filter (8×10 inch plates), a filter holder, a high-volume sampler pump, a flowmeter, connective tubes and caps made of Teflon to prevent leakage in the connection points, base and clamp, a calibration kit (model: PSI-TLOC2), 0.01-milligram scale (model: DJ-V300 A, AND, made in China), a desiccator, digestive acids (nitric acid and chloridric acid; Merck, Germany), a hot plate(model: Analog Alpha Magnet, Sun Lab, Iran), necessary laboratory tools, such as clamps, stands, and glassware, and inductively coupled plasma (ICP) (device model: OES-730, Varian, USA).

Calibration of the air sampling pump

In order to calibrate the suspended particles, we used the sampling devicePSI-TLOC2 calibration kit (made in India, Polltech Instruments, Pvt. Ltd). The method that the intended kit employs is that a series of barriers that are arranged in orifice plates in the free flow of fluids, the volume flow of which is calculated from the pressure drop developed by these barriers. The kit has a rectangular conversion plate, a cylinder with a single circular hole (orifice), a rubber tube, and a set of five perforated resistor plates (with 17, 13, 10, 7, and 5 holes) for the flow variations using the pores. In the present study, the experts calibrated the sampling devices based on these procedures.

Fiberglass filters

The filters used in the current research were selected from fiberglass owing to their high accumulation efficiency, high heat resistance, and proper resistance to contaminants. Fiberglass filters are less resistant to air discharge and are used when large volumes of aerosols are sampled. Fiberglass filters have been commonly used in studies for the sampling of total environmental particles.

Preparing filters

The filters were placed in a desiccator 24 hours prior to sampling, and the scale in the calibrated filters was weighed. Before sampling, the filters were washed with HCl and HNO_3, followed by distilled water, and dried under gentle air flow in a range hood. After sampling, the particulate filters were rapidly placed inside polyethylene containers, covered with aluminum foil, and transferred to the laboratory. The samples were preserved in the freezer at the temperature of -20 °C until digestion.

Aerosols assessment (TSP)

To assess the total suspended particles, sampling was carried out using an environmental sampling pump (high-volume air sampler; model: TFIA-2, Staplex, USA). The pump was portable and had three bases for establishment. After turning on the device, the sampling period (day, hour, and minute) and initial flow of the passing air were specified. Before turning off the device and upon the termination of sampling (day, hour, and minute), the secondary flow was also registered. The mean value of the initial and secondary flow provided the mean flow in cubic feet per minute. In addition, the volume of the sampled air was obtained in cubic feet by multiplying the mean flow in cubic feet per minute during the sampling period. Finally, the air volume was transformed into cubic meters (Eqs. 1 and 2).

$$V = T.F \tag{1}$$

$$1m^3 = 35.315\ Ft^3 \tag{2}$$

To calculate the concentration of the aerosols (μg/m^3), the particle weights were divided by the air volume in m^3. The concentration of the suspended particles was measured in μg/m^3 based on the volume of the sampled air. The collected samples on the fiberglass filter were also prepared and subjected to acidic digestion based on the standards of the American Society Materials and Testing (ASTM) for the assessment of the heavy metal concentrations. To do so, the aerosols collected on the filters were seminally digested by the corresponding acids. After the burning of the samples and formation of the ashes, heavy metal preparation and extraction processes were carried out using nitric acid (1+1) and hydrochloric acid (1+1). To further elaborate, 1+1 in the name of the reagent solution (e.g., dilute HCl [1+1]) showed one volume of the concentrated hydrochloric acid and mixing with one volume of water, and regardless of the volume, 50% dilution was achieved. For instance, 10 mL of the acid mixed with 10 mL of water provided a 1:1 dilution, 1+1 dilution or 50% dilution.[18]

Total heavy metal digestion

After transferring the fiberglass filters to the laboratory, they were dried in the desiccator and re-weighed. Those containing the suspended particles and metal fume were initially subjected to acidic digestion as explained below, so that the samples could be prepared and transferred to the heavy metal reader device.

Initially, the filter was transferred to a 100-cc beaker using polyethylene forceps. Afterwards, 1-N HNO_3 (2 mL) and 1-N HCl (10 mL) were poured, and the beaker was capped using a watch glass and placed on a hot plate, the temperature of which was set at 140 °C, so that the volume could increase to 25 mL. After the digestion of the filter and acid evaporation, a white deposit was formed at the bottom of the beaker, at which time the ash production process was ceased. The beaker was allowed to cool down, 10 cc of 10% nitric acid was added, and the sample was ready to be injected to the ICP device.

Heavy metal assessment using the ICP device

To measure the concentration of the heavy metals, ICP was utilized to perform the elemental analysis through emission spectroscopy and the plasma-based atomization process. In this method, plasma was used as a stimulation source for the qualitative and quantitative analysis of the heavy metals. In addition, an argon gas current was ionized in a magnetic field with the radiofrequency of 27-40 MHz, and the approximate heat of 10,000 kelvins was produced. Following that, the sample was sprayed by a nebulizer into the argon plasma and transformed to atomic (ionic) particles at higher temperatures, after which emission began. In returning to the base state, the spectrum line featuring a wavelength proportionate to the stimulated level started emitting; the wavelength was different for each element. The quantitative analysis of the elements was performed based on the same simple process. After transferring the samples to the ICP-OES device (model: OES-730, Varian Company), the type and concentration of the heavy metals present in each sample were determined.

Statistical analysis

The data in Table 1 were transferred to the Excel software and SPSS version 20, and the statistics were subjected to descriptive and inferential analyses. Moreover, the data were evaluated using multivariate variance analysis (MANOVA).

Results and Discussion

The concentration of each element was calculated in each region, and the extracted data were arranged separately within the format of tables for the indoor and outdoor environments. Table 2 shows the mean concentration of the heavy metals in the selected stations in the high-traffic regions in Tehran.

As is shown in Figs. 3 and 4, the order of the heavy metal concentrations in the studied outdoor environments was as follows: Al>Fe>Pb>Mn>Cu>Zn>Cr>As>Ni>Cd.

Table 2. Heavy metal concentrations (g/m^3) in six stations

	Outdoor environment			Indoor environments		
	District 2	District 3	District 15	District 2	District 3	District 15
Pb	0.977	0.763	1.092	0.539	0.241	0.816
Mn	0.433	0.417	0.392	0.261	0.255	0.221
Ni	0.028	0.042	0.017	0.026	0.039	0.015
Cd	0.036	0.023	0.008	0.031	0.017	0.003
Zn	0.289	0.197	0.095	0.221	0.139	0.047
Cu	0.327	0.263	0.141	0.192	0.127	0.091
Fe	1.86	1.465	1.054	1.841	1.44	1.04
As	0.043	0.051	0.002	0.035	0.042	0.002
Al	1.647	1.66	1.776	1.639	1.63	1.761
Cr	0.074	0.079	0.019	0.065	0.069	0.011

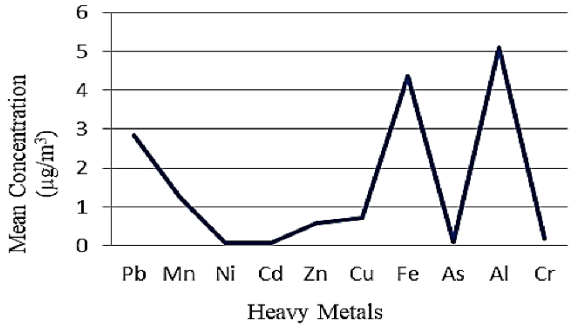

Fig. 3. Mean concentrations of heavy metals in outdoor stations

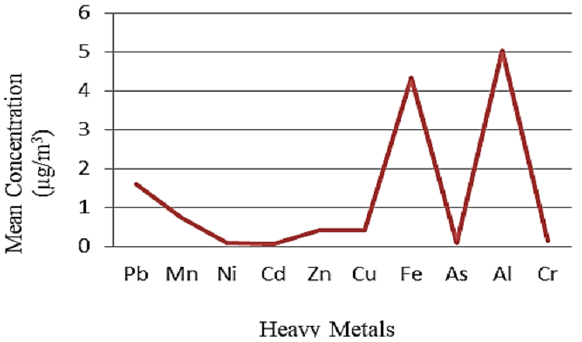

Fig. 4. Mean concentrations of heavy metals in indoor stations

The order was found following a similar pattern in the studied indoor environment, along with a slight reduction in the values, with the exception of the elements resulting from fossil fuel consumption, especially gasoline, which included lead, magnesium, zinc, and copper. Furthermore, a significant difference was observed between the indoor and outdoor environments in terms of heavy metal concentrations (Fig. 5).

Fig. 6 shows the comparison of the mean concentration of the heavy metals in the open and closed spaces in the three studied regions, as well as the mean concentration of the heavy metals in traffic with various volumes in the studied regions. As can be seen, the concentration of the heavy metals was lower in the entire indoor environments (closed spaces) compared to the concentration of the same metals in the outdoor environments (open spaces) in all the studied regions (Districts two, three, and 15). Evidently, the indoor and outdoor environments slightly differed in terms of some heavy metals, such as aluminum, iron, arsenic, nickel, chromium, and cadmium. On the other hand, the concentration of heavy metals such as lead, magnesium, copper, and zinc significantly decreased in the indoor spaces compared to the open spaces. It is also notable that the traffic volume in District two was higher than the other regions during the study period, so that the districts could be ranked as follows in terms of the mean daily traffic: District 2>District 3>District 15.

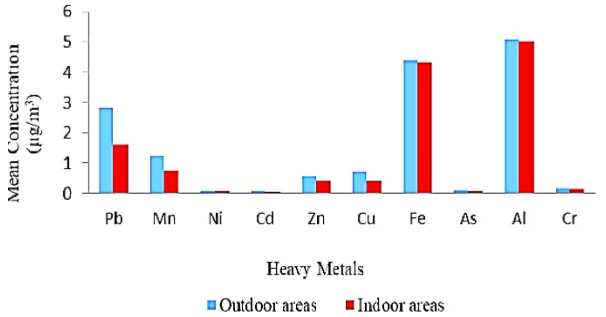

Fig. 5. Mean concentration of heavy metals in outdoor and Indoor stations

When the objective of the comparison is to determine the equality of the mean values in several groups, variance analysis could be used. The statistical assumptions in the variance analysis test of the study variables were arranged, so that the null hypothesis would maintain the mean differences of the studied differences insignificant; as a result, the hypothesis was rejected when μi#μj was held for a minimum of one mean value. The H_1 hypothesis was the opposite of the following assumption:

$\{H0: \mu1 - \mu2 - \mu3\}$

$\{H1: \mu1 \# \mu2 \# \mu3\}$

In the present study, variance analysis was used for the comparison of the concentration of heavy metals in the open and closed spaces as an equivalent method to the t-test. The H_0 hypothesis assumed that the concentration of heavy metals had no difference between the indoor and outdoor environments (μ), and the concentrations were equal in both environments. Conversely, the H_1 hypothesis assumed that the concentration of the heavy metals in the air of the indoor and outdoor environments had no significant difference.

Based on these assumptions, MANOVA was applied for data analysis. In the variance analysis, follow-up tests were also utilized to calculate the intergroup differences. Moreover, Tukey's test was used, and the statistical descriptions were provided (Table 3).

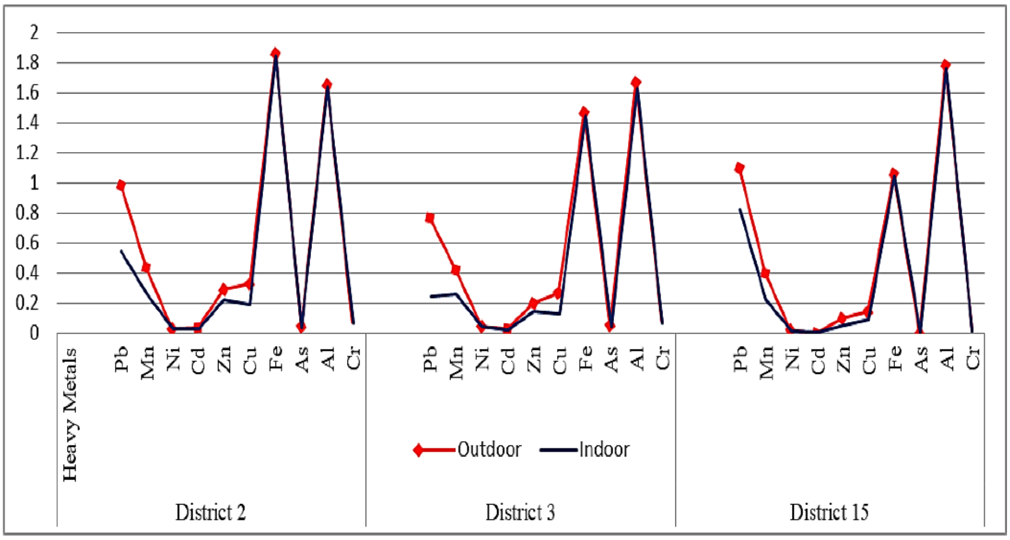

Fig. 6. Mean concentration of heavy metals in indoor and outdoor spaces of high-traffic areas

Table 3 shows the standard deviation and data scattering from the mean point. To determine the correlations between the data of the indoor and outdoor stations in the high-traffic regions, Pearson's product moment correlation-coefficient was conducted in SPSS. Since the higher correlation-coefficient modulus between the two variables was reflective of their more significant association, a positive, significant correlation (unidirectional) was observed between the indoor and outdoor stations in terms of the heavy metal concentrations (Table 4).

Table 3. Mean heavy metal concentrations in indoor and outdoor stations

N	Mean ± Standard deviation	Sampling sites
30	0.4285± 0.61092	Indoor stations
30	0.5090± 0.62033	Outdoor stations
30	3± 0.83045	High traffic regions

Table 4. Correlation of indoor and outdoor spaces in heavy metal concentrations

Pearson product moment correlation (r)		Stations: Indoor	Stations: Outdoor	Regions
Indoor	Pearson correlation	1	0.978**	-0.057
	Sig. (2-tailed)		0.000	0.764
	N	30	30	30
Outdoor	Pearson correlation	0.978**	1	-0.075
	Sig.(2-tailed)	0.000		0.694
	N	30	30	30
Regions	Pearson correlation	-0.057	-0.075	1
	Sig. (2-tailed)	0.764	0.694	
	N	30	30	30

**Correlation significant at 0.01 (two-tailed)

Our findings were indicative of the association between the studied environments. Therefore, the two-way variance analysis and corresponding follow-up tests were carried out, and the results were extracted (Table 5). According to the information in Table 5, the significant values were equal to zero and 0.001 for the outdoor and indoor environments in the high-traffic regions, respectively. In both cases, the P-value was less than 0.05; as such, the null hypothesis was rejected, and H_1 was accepted regarding the significant difference between the indoor and outdoor studied stations in terms of heavy metal concentrations (P<0.05).

Table 5. Variance analysis of heavy metal concentrations in indoor and outdoor stations

Environments	SS	Df	MS	F	Sig.
Outdoor	7.772	1	7.772	18.915	0.000
Indoor	5.509	1	5.509	13.804	0.001

According to the results of Tukey's follow-up tests, the groups (Districts two, three, and 15) were not identical in terms of the size and could not be classified into separate categories (Table 6). According to the information in Table 6, the significant value was calculated to be 0.951, and the P-value of more than0.05 indicated no significant difference between Districts two, three, and five in terms of homogeneity, and they could not be classified into one group. With regard to the concentration of heavy metals, no common category could be considered for any two regions, and the three studied districts of Tehran were placed in a single category.

Table 6. Tukey's test results on homogeneous zone classification and comparison of districts 2, 3, and 15

District	N	Subset for alpha=0.05	
			1
District 3	10	-	0.3999
District 15	10	-	0.4007
District 2	10	-	0.4850
Sig.			0.951

According to the annual reports issued by Tehran Air Quality Control Company, the status was unfavorable in terms of the total suspended particles and pollutants in metropolitan Tehran during various seasons of 2018, and the unhealthy days reached the maximum rate during fall until early winter.[3] According to the statistics of Tehran Traffic Police, there are 20 million licensed plates in the entire country, a fifth of which (4 million vehicles) is in Tehran. In addition, there are three million motorcycles in Tehran, while the total length of Tehran roads is 2,911 km, and the number of cars is eight times the capacity for traffic.[19]

According to the literature, copper and zinc are produced by the depreciation of vehicle parts (e.g., tires, brake pads, and engine oil).

Examination of the atmospheric dust in Isfahan (Iran) by Mahmoodi indicated that the most important sources of zinc, lead, and cadmium production were vehicles, while copper and nickel were produced due to vehicle traffic, and manganese was mainly produced due to the activities of Mobarak iron and steel industries.[20]

With regard to the higher mean concentration of aluminum and iron extracted compared to the other elements in the present study, it could be stated that iron is the fourth most abundant element in the earth's crust.[21] In addition, aluminum is the most abundant metallic element, constituting 8.1% of the earth's crust. In nature, aluminum is the third element after oxygen and silicon, which is absent in the pure form and is mainly found in the form of the combination of hydroxide, silicate, sulfate, and phosphate.[22] In the case of anthropogenic minerals, aluminum is used in various building materials, automobiles, aerospace, and manufacturing of used metal alloys. Furthermore, aluminum is used in water purification, painting, explosives, petroleum refining, rubber production, pharmacy, and glass processing.[22] The natural abundance of aluminum in the earth's crust and release of its constituents are constructed on large scales in Tehran and other industrial human activities, and along with vehicle emissions and depreciation of vehicle parts, it could explain the high mean concentration of this metal in Tehran's air. However, the definite reason for the excess of these elements in the air requires further investigations.

According to the results of the present study, the surrounding regions of the studied stations (Azadi-Yadegar route, Vanak-Hemmat route, and Afsariyeh St.) were highly congested and had heavy traffic. On the other hand, the results of samplings indicated that the climatic conditions and natural factors played a determinant role in the quality of the complicated behavior of pollutants, so that air pollution intensively increased during the fall of 2018. This was due to the inversion phenomenon as a large quotient of metropolitan Tehran's air pollution was caused by the large volume of congestion and motor vehicle traffic, as well as the wasteful use of fossil fuels, especially gasoline. These parameters played a key role in the pollution of the mentioned regions, along with stagnant population density and various human activities.

In addition to the high volume of traffic on the streets and passages of the studied areas, which bore the largest share of the emitted particulate matter and other pollutants in Tehran's air, most manufacturing plants and workshops are either concentrated in the western parts of Tehran or located in the suburbs to the west of Tehran; such examples are Iran Wool Factory in District 21, various metal and machinery industries, Pars Oil Company, sand factories, Pars Metal Factory in District 22, more than 1,200 active industrial units in Shahriar, and more than 5,000 industrial units (e.g., coal stoves) in Baharestan area, all of which are located in the western wind corridors. Due to the westward winds in Tehran, the activity of these industrial units has caused the dispersion and distribution of pollutants to the eastern, central, and southern parts of the city. Even the pollutants from Montazar-al-Ghaem Power Plant in Alborz province are directed toward Tehran by winds. For instance, in the eastern and southeastern Tehran, the focus of pollutant industries such as Shahr-e-Rey refinery to the south and cement factories to the east, Kahrizak landfill, large market, and other commercial centers, population density, high vehicle traffic, long hours of traffic, and high fossil fuel consumption, along with the lack of updated clean technologies and outdated transport system largely contribute to Tehran's air pollution with particulate matter, especially in the east, center, and south of Tehran metropolitan area.

According to the findings of the current research, Azadi Street from southern Yadegar toward Enghelab Avenue, Vanak Street from Hemmat Highway toward Chamran, and Afsariyeh Street on the route to Basij Highway were located in Districts two, three, and 15 of metropolitan Tehran and had the first three ranks in terms of urban traffic in Tehran during the study period. Each of these districts has heavy traffic 25-27% of the hours per day. The results of the analyses during fall regarding the total suspended particles collected from the sampled indoor and outdoor spaces inside the studied region indicated the following order in terms of the mean heavy metal concentrations: Al>Fe>Cu>Mn>Zn>Pb>Cr>As>Ni>Cd.

Conclusion

According to the results, the highest and the lowest concentrations of heavy metals were pertinent to aluminum and cadmium, respectively. In fall, out of the total suspended particles, the mean concentration of the heavy metals extracted from the aerosols in the indoor and outdoor spaces was 37% and 38% in District two, 31% and 33% in District three, and 30% and 31% in District 15, respectively. Based on the results of the statistical tests using MANOVA, a significant difference was observed between the indoor and outdoor environments. Amongst the extracted elements, copper, zinc, and lead were found with definite anthropogenic sources. On the other hand, the mean concentrations of copper, zinc, magnesium, and lead in the indoor environments significantly reduced compared to the external environments. The changes in these heavy metals and their extraction stages indicated that the mentioned heavy metals were substantially associated with the traffic level, traffic density of the moving sources, and urbanization. The components in car batteries, engine lubricants, and other auto parts (e.g., tires, brake pads, and fuel) contribute to the release of lead, zinc, copper, nickel, cadmium, and manganese. Moreover, the activities of battery-producing industries in Tehran Khavaran Road, Tehran Oil Refinery, and military industries in this metropolitan largely contribute to the presence of these heavy metals. Other elements such as manganese, iron, nickel, cadmium, chromium, aluminum, and arsenic had insignificant and trivial changes in the samples collected from the open and closed spaces in the traffic stations and residential areas. The high concentration of lead resulting from heavy traffic and dominant wind direction was alarming in Afsariyeh Street (District 15) as the worn-out urban texture of this district adjacent to the central and polluted municipality areas of 12 and 16, activity of more than 1,200 wrecking workshops, and other polluting industries, excessive car traffic on Azadegan Highway, Imam Reza (AS), Basij, and Afsarieh intersection, high fossil fuel consumption, outdated transport fleet, and construction of bridges and highways also contribute to the higher air pollution in District 15 of Tehran. Based on our findings and considering the confirmed side-effects of the heavy metal pollution on the health of the citizens residing in industrial metropoles, proper measures are required for the control of the traffic volume in Tehran.

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