Research Paper: Investigating the Non-carcinogenic Risk and Hazard Quotient of Heavy Metals in High-traffic Districts of Tehran Metropolis, Iran

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ABSTRACT

Background: This study aimed to investigate the concentrations of heavy metals bound to airborne Particulate Matter (PM) in high-traffic districts of Tehran, Iran, and to determine the carcinogenic risk and Hazard Quotient (HQ) of these metals using a descriptive-applied method.

Methods: Six indoor/outdoor stations were established in three high-traffic districts of Tehran. Each station was sampled with six replicates in winter 2018 (36 samples in total). After extracting the metals from fiberglass filters by acid digestion based on the ASTM (the American Society for Testing and Materials method), the concentrations of heavy metals were determined by an Inductively Coupled Plasma (ICP-OES) device. The human health risk was evaluated according to the US EPA (Environmental Protection Agency) standard method. The obtained data were analyzed by the Spearman correlation and Multivariate Analysis of Variance (MANOVA) in SPSS.

Results: Districts 2, 3, and then 15 were the most high-traffic areas of Tehran in descending order. Average heavy metal concentrations were detected in order of Al>Fe>Pb>Mn>Cu>Zn>Cr>As>Ni>Cd. Also, the heavy metals concentrations were significantly different between indoor and outdoor environments. The correlations between heavy metal concentrations, carcinogenic risk, and HQ were significant in all three districts ($P<0.05$). Mean carcinogenic risk variables, HQ levels, and heavy metal concentrations in all three regions were in order of districts 15>2>3 and outdoors>indoors.

Conclusion: Based on the results, serious measures are recommended to control traffic congestion in Tehran to prevent cancer risk and other health hazards caused by heavy metal bonded TSP (total suspended particulate matter).

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1. Introduction

According to World Bank report [1], air pollution is the most lethal type of pollution and the fourth leading cause of early death worldwide. In addition, the International Institute for Cancer Research, affiliated with the World Health Organization, has classified suspended particles as group 1 of carcinogens regardless of their size or chemical composition [2]. Tehran metropolis in Iran is also one of the cities heavily affected by air pollution. In recent years, the Total Suspended Particulate matter (TSP) has been among the pollutants mostly threatening to Tehran citizens. TSP with a diameter below 2.5 µm (particulate matter [$PM_{2.5}$]) has been the most common cause of unhealthy air [3]. TSP can be a suitable carrier for establishing pathogens, particularly heavy metals, and can enter the respiratory tract of people with inhalation [4, 5]. Heavy metals are one of the most critical environmental pollutants [6]. These metals have the most significant impact on the health of citizens with such health hazards as cancer and declining child growth [4, 5]. Kidney disease is another adverse effect of exposure to heavy metals [6, 7]. High-traffic areas appear to be more contaminated with heavy metal pollution. Sources of these pollutions include vehicle components, curbstone ingredients, road equipment, and road maintenance activities so that traffic in central urban areas plays a vital role in exposing people to heavy metals [7, 8]. Road traffic emissions result from brake wear, tire wear, vehicle degradation, road pavement, and exhaust emissions [9-11].

Given that limited studies have been carried out on the subject of this research in Iran, the following previous studies are mentioned on air pollution with heavy metals and the subsequent health risks. Hosseini et al. [12] studied the health risk assessment of heavy metals in TSP of Kurdistan University of Medical Sciences, Kurdistan Province, Iran. They determined heavy metal concentrations in atmospheric TSP of Sanandaj City, Iran, and assessed the health risk of the metals for employees at Kurdistan University of Medical Sciences. The concentrations of heavy metals, including arsenic, cadmium, chromium, cobalt, zinc, iron, copper, manganese, and nickel, were determined by sampling air from April to September 2013. Health risk for cancer and non-cancer diseases due to inhalation of heavy metal polluted air was assessed for three groups of employees, dormitory, and non-dormitory students using the US Environmental Protection Agency (EPA) guidelines. Their results showed that iron concentration was uppermost in both dusty and non-dusty days of July. It was also reported that the overall cancer risk for all metals in all three groups was higher on dusty days than on non-dusty days, with fewer than two individuals per 1.0 million. The overall non-cancerous acute and chronic risks of these metals were lower than 1 for all three groups [12]. According to baseline values provided by the US EPA, they concluded that none of the above metals would increase cancer and non-cancer risks for residents of Kurdistan University of Medical Sciences during the study period [12].

Nourpour conducted a study to measure and evaluate heavy metal pollution risk in Enghelab Avenue air in Tehran [13]. They presented results of heavy metal measurements, including arsenic, iron, zinc, lead, cadmium, chromium, copper, manganese, and nickel in the context of GIS charts and maps to assess both permanent and temporary health risks for residents from February 2012 and June 2013. The total number of lifetime cancer developments from inhalation of heavy metals was estimated to be less than 53 individuals per 1 million people. The whole risk was assigned to four contaminants of chromium, arsenic, cadmium, and nickel. Salmanzadeh et al. investigated heavy metal pollution in dust deposited on Tehran streets and assessed the ecological risk [14]. The coefficient of enrichments for copper, cadmium, lead, and zinc was extremely high, showing the anthropogenic origin of these elements. Ecological risk calculations using the Hackanson method revealed that all the studied sites were of high ecological risk [15].

There have also been numerous studies on heavy metals arising from car fuels in other countries, some of which have also investigated the carcinogenesis risk of heavy metals [15, 16]. Zmijková et al. researched human health risks due to heavy metal bonded TSP in the Moravian-Silesian region of the Czech Republic [15]. The human health risk was assessed using the US EPA guidelines using the Hazard Quotient (HQ), Hazard Index (HI), and excess lifetime cancer risk-ELCR (excess lifetime cancer risk). Their results indicate that pollution and carcinogenic risks increase during winter. The potential non-carcinogenic hazards of Particulate Matter (PM) and their associated metals were insignificant. Xu et al. [16] assessed the health risk of personal exposure to the typical anthropogenic $PM_{2.5}$ emissions in South West Africa and concluded that Pb and Mn heavy metals can cause high non-cancer risks, and Polycyclic Aromatic Hydrocarbons (PAHs) can cause severe cancer risk among those exposed. Briffa et al. [17] presented a review study on the toxicological effects of environmental heavy metal pollution on humans. The review, while discussing the

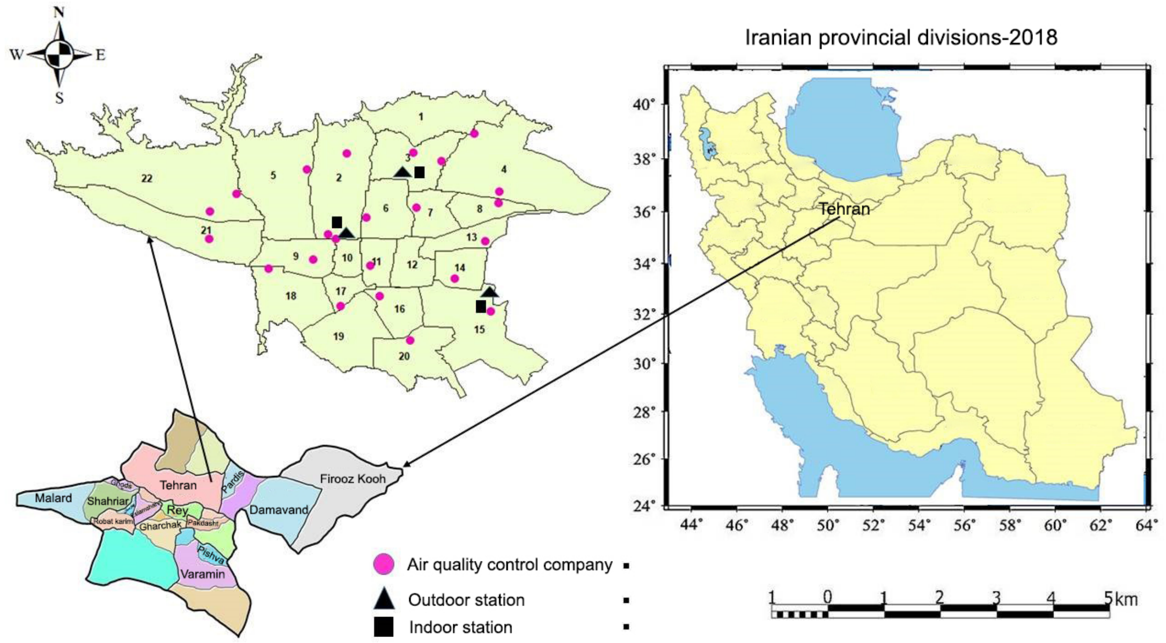

Figure 1. Geographical location of the study area and research sampling stations in Tehran metropolis

entering ways and fate of heavy metals in the environment, presents the disquieting factor of possible disease due to bioaccumulation of the metals in humans. Radulescu et al. [18] conducted a study on assessing heavy metal hazards to public health for $PM_{2.5}$ in urban areas of Romania, using particles of smaller diameters with more destructive effects. They concluded that average heavy metal (Cr, Ni, Cu, Mn, Al, Zn, and Fe) concentrations were higher due to traffic and both domestic and industrial activities. Hence, proximity to industrial centers, fuel combustion, and pollutant sources could significantly increase metal contents in PM, leading to elevated adverse effects on health. These metals were found to have synergistic effects in industrial and high-traffic areas.

The importance of this study is to identify the health risk of high-traffic areas associated with heavy metal emissions into the air. The results of this study can provide recommendations and guidelines to focus on controlling traffic-related heavy metal pollution in high-traffic areas based on a leading and trustable scientific approach. This study sought to fill the existing research gap. There has not ever been integrated objective research to investigate changes in the concentrations of toxic heavy metals in indoor and outdoor air of Tehran metropolis, Iran, to determine the carcinogenesis risk and HQ levels. The present research aimed to investigate the concentrations of heavy metals transported by TSP (aerosols) in high-traffic districts of Tehran metropolis and to evaluate the carcinogenic risk and HQ levels of these metals during winter 2018.

2. Materials and Methods

Study Area

Tehran is located at 51º 17' to 51º 33' E and 35º 49' N latitudes, with an area of 733 km^2. According to the census of 2016 [19], this city is populated by 8693706 people (Figure 1). Tehran is situated in a zone between mountains and deserts, and the surface waters of the Alborz Mountains range are directed to the south. The Alborz Mountains are crescent-shaped in this area. Also, the mountains around Tehran and the city's location in the crescent-shaped space of the mountains effectively impede the penetration of western winds (Tehran dominant winds) into the urban area, making Tehran air more stable than the adjacent plains. Immobile air, particularly during inversion of air in winter, leads to intense accumulation of contamination in the narrow spaces of the eastern mountains of Tehran, preventing the natural rise of warm air and discharge of contaminants. This phenomenon results in the formation of photochemical smoke during the morning [20].

Research methodology

To measure TSP in the air of high-traffic districts and determine the concentrations of heavy metals transported by these particles, we drew up the annual statistics of the Traffic Control Center of Tehran City and online Google map traffic from traffic status in Tehran. Then, we selected the districts with the highest traffic during

Table 1. Top three traffic-prone districts of Tehran metropolis [21]

Rank	Routs	District
1	Sheikh Fazlollah Nouri Highway (south-north) from exit to South Yadegar to entry from North Yadegar	2
2	Shahid Hennat Highway (west-east) from exit to North Chamran to exit toward South Sheikh Bahaei	3
3	Basij Highway (south-north) from the roundabout to exit toward East Rahimi	15

previous seasons and on different days of the year with the highest traffic congestion. According to the statistics of Tehran Traffic Control Center [21], districts 2, 3, and 15 of Tehran municipality were the most traffic-prone areas of Tehran during previous seasons in 2018 (Table 1, Figures 1 and 2).

According to the statistics, part of Sheikh Fazlollah Nouri Highway, west of Tehran, from Ydegare Imam south exit to the entry of Ydegare Imam was the most traffic-prone area of Tehran. The second rank belonged to Shahid Hemmat Highway, from exit to North Chamran to South Sheikh Bahai. The Basij Highway from the roundabout to exit towards the East Rahimi was the third congested area (Figure 2). Accordingly, two stations (one outdoor and one indoor) were selected in each of the above traffic zones so that a total of six stations (three indoors and three outdoors) were designated in three high-traffic districts (Figure 2). Through coordination with the Deputy Director of Monitoring in the Tehran Department of Environmental Protection, the stations were localized as follows:

Station I (outdoor): District 2, Azadi Ave., Imam Khomeini intersection;

Station II (indoor): District 2, Farhadieh strait, Sharif University clinic pharmacy;

Station III (outdoor): District 3, Vanak Square off Hemmat Street;

Station IV (indoor): District 3, Tavanir Ave., Behsima Clinic;

Station V (outdoor): District 15, Afsarieh junction to Tehran Pars;

Station VI (indoor): District 15, Second 15 m (Afsarieh II), Javad-ol Aemmeh (as) Charity Clinic.

Sampling of heavy metal-containing TSP in indoor and outdoor air (gravimetric method)

Thirty-six samples, each with six replicates, were taken from the six selected stations in two indoor and outdoor environments of three high-traffic districts in winter based on the EPA standards [23, 24]. The sampling lasted from 6 AM to 8 AM and from 4 PM to 6 PM (2 hours at a time) during peak traffic hours in Tehran. Each station was sampled in each month of winter, with

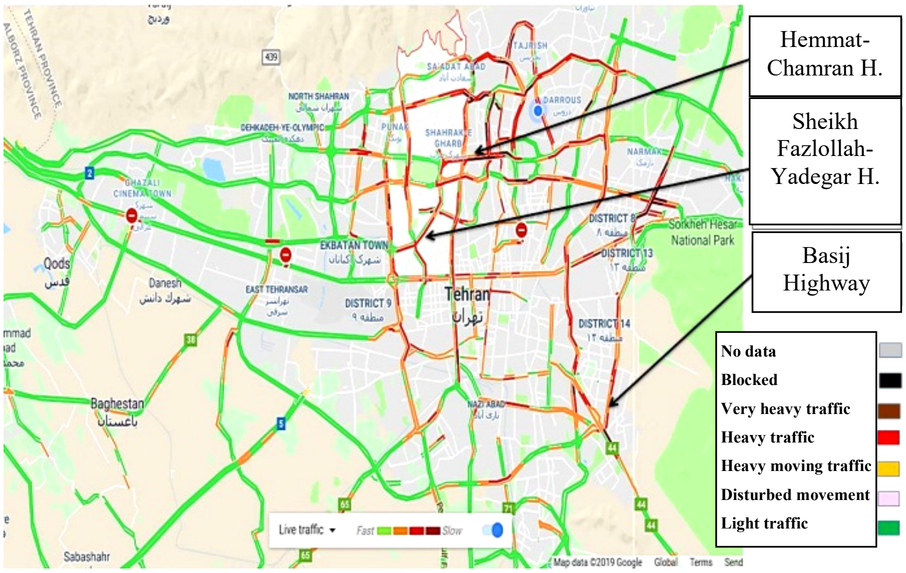

Figure 2. Online traffic map of Tehran City, Winter 2018 [22]

two replications in the mornings and evenings, resulting in 36 samples from all stations during winter. The collected data were examined quantitatively and qualitatively in Excel software, and the mean concentration of each heavy metal per district was calculated together with plotting the corresponding graphs.

Sampling tools and laboratory supplies

In this research, the following instruments and materials were used for environmental sampling and the filtration method to measure TSP concentrations [25]:

- Fiberglass filter (4.7-inch sheets)
- Filter holder
- Hi-volume sampler pump
- Flowmeter
- Connecting Teflon tubes and warheads with no leaks at the joints
- Stands and clamps

Laboratory instruments and materials for analyzing samples included:

- Measuring scale (0.01 mg precision)
- Desiccator
- Digestive acids: nitric acid (1 + 1) and hydrochloric acid (1 + 1)
- Hot plate
- Necessary laboratory tools (clamps, stands, and glassware)
- Inductively Coupled Plasma (ICP) device

Total Suspended Particulate (TSP) measurement

To measure TSP, sampling was performed using an environmental sampling pump (Model TFIA-2, high volume air samplers, Staplex, USA). The pump was portable and equipped with a tripod for mounting. The sampling time (day-hour-minute) and initial flow of air passage were specified after turning on the device. After sampling, the end of sampling time (day-hour-minute) and secondary flow were recorded before turning off the device. Average primary and secondary flows yield the mean flow in cubic feet (ft^3) per minute (CFM). The volume of sampling air was obtained via multiplying mean flow (CFM) by sampling time (min) (Equation 1). Air volume was then converted to cubic meters (Equation 2).

1. Sampling air volume (ft^3) = mean flow (CFM) × sampling time (min)

2. $1\ m^3 = 35.315\ ft^3$

To calculate TSP concentration ($\mu g/m^3$), the particle weight (μg) was divided by the air volume (m^3). It should be noted that the volume of sampled air was used to calculate the concentration after standardization according to the sampling conditions of each district. TSP contents were measured by gravimetry based on the type of pump. This method is used to determine the concentrations of most organic and mineral dust in the air. To this end, the weighted filter was inserted into the holder filter, connected to an air-sampling pump, and the airflow was passed over the filter. After sampling, dust-containing filters were placed in a desiccator for 24 h and weighed on a sensitive scale (a precision of 0.01 mg) followed by measuring the dust content on the filter. The weight of the dried filter in the laboratory was considered the secondary weight. The difference between the primary and secondary filter weights is equal to the weight of TSP in the sampled air. According to the sampled air volume, TSP concentration was calculated in $\mu g/m^3$. Samples collected on fiberglass filters were prepared, acidified, and digested according to the American Society for Testing and Materials (ASTM) standards for measuring heavy metals [25]. To do this, TSP collected on the filters was first digested in the related acids. After burning the samples and ash formation, heavy metals were prepared and extracted using nitric acid (1 + 1) and hydrochloric acid (1 + 1) (ASTM, 1997).

Preparation and Acid Digestion With HCL-HNO_3

The fiberglass filters were transferred to the laboratory, dried in a desiccator, and weighed. To prepare the samples and transfer them to the heavy metal reading apparatus, the acid digestion steps were first performed on TSP-holding filters containing metallic fume. The filter was first transferred to a 100-mL beaker with polyethylene pincers. Then, 2 mL of HNO_3 (1 + 1) and 10 mL of HCL (1 + 1) were poured on the filter. The beaker was capped with a watch glass and placed on a hotplate at 140 °C to reach a volume of 25 mL. The ash making was stopped after digestion of the filter, evaporation of acid, and formation of a white precipitate on the beaker bottom. After cooling, 10% nitric acid (10 mL) was added to the beaker, and the sample was prepared for injection into the ICP [25].

Measurement of heavy metals by ICP

Heavy metals were measured by the ICP device that analyzes elements through emission spectroscopy and atomization via plasma based on the use of plasma as a source of excitation for quantitative and qualitative analysis of heavy metals. In this method, a flow of argon gas is ionized by a magnetic field with a radio frequency of 27-40 MHz and generates a temperature of about 10000 K. The sample is sprayed into the argon plasma by a nebulizer, then converted to atomic (ionic) particles, and emitted at a high temperature. In returning to the base state, a spectral wavelength line is emitted proportional to the excited balance, which is different for each element, and qualitative elemental analysis is performed accordingly.

After transferring samples to the ICP-OES device (OES-730, Varian), the element and concentration of heavy metals were determined in each sample. The mean concentration of each element was calculated in each district, and the extracted data were arranged separately for the two indoor and outdoor environments (Table 2).

Carcinogenic risk assessment of heavy metals

After determining mean concentrations of heavy metals extracted from airborne TSP in the laboratory, human health risk was assessed for each heavy metal from each station in accordance with the US EPA (2000) along with estimations of HQ and HI indexes [24] using the Equation 3:

3. $LCR = CDI \times URF$

In this Equation, LCR is lifetime carcinogenic risk, CDI is chronic daily uptake (mg/kg/d), and URF is a unit risk factor (kg/mg/d). The CDI was calculated according to Equation 4:

4. $CDI = C \times DI/BW$

In this Equation, CDI is chronic daily intake (mg/kg/d), C is the concentration of pollutant (heavy metal) in inhalation air (μg/m^3), DI is average daily air intake (20 m^3/d), and BW is body weight (70 kg).

The risk ranges are categorized as LCR values of>10^{-4}, 10^{-4} - 10^{-5}, and 10^{-5} - 10^{-6} meaning definite, probable, and possible risks, respectively.

Assessment of non-carcinogenic HQ

Other heavy metal non-carcinogenic health hazards were calculated as the non-carcinogenic HQ (hazard index, HI) through different contacts for individual heavy metals found in the air by Equation 5 [23].

5. $HQ = CDI/RfD$

In this Equation, HQ is hazard quotient, CDI is chronic daily uptake (mg/kg/d), and RfD is the reference dose (mg/kg/d). A population is in the safe status when HQ<1.

Then, HI was calculated to evaluate the final non-carcinogenic risk caused by the effects of several heavy metals using the Equation 6:

6. $HI=\sum^{n}_{i=1}HQi$

It should be noted that the health risk assessment for carcinogenic and non-carcinogenic exposure to heavy metals was calculated through three main routes of ingestion (HIing), inhalation (HIinh), and dermal (HIder) according to Equation 7 [23]:

7. $HI_{total} = HI_{ing} + HI_{inh} + HI_{der}$

- If HI<1, there is no significant risk for adverse health and non-carcinogenic effects.

- If HI>1, there is a chance of non-carcinogenic adverse effects. Table 3 summarizes the extraction of calculated values.

Statistical analysis

To compare the relationship between the research variables, we performed a Multivariate Analysis of Variance (MANOVA) and the Spearman correlation coefficient calculation. The analyses were done in Excel and SPSS v. 20.

3. Results and Discussion

The data in Tables 2 and 3 were transferred to Excel and SPSS v. 20 software and analyzed by descriptive and inferential statistics. Data were then analyzed using MANOVA. Figure 3 depicts the descriptive statistics of mean heavy metal concentrations in outdoor and indoor spaces of the studied districts. According to Figure 3, heavy metal concentrations were lower in all indoor environments than in outdoor environments of all the three zones (2, 3, and 15), except for Al (Aluminum), with slightly increased average values in indoor environments.

Average concentrations of heavy metals in the open and closed areas of these districts are displayed in Figure 4. It should be noted that traffic congestion was higher in District 2 than in the other districts during the study. How-

Table 2. Average Concentrations (μg/m³) of heavy metals detected in six stations of high-traffic districts (D.) in Tehran Metropolis, Winter 2018

	Indoor			Outdoor		
	D. 2	D. 3	D. 15	D. 2	D. 3	D. 15
Pb	0.193	0.167	0.293	0.144	0.125	0.256
Mn	0.135	0.122	1.092	0.117	0.129	0.194
Ni	0.042	0.017	0.028	0.031	0.011	0.026
Cd	0.051	0.002	0.043	0.021	0.002	0.012
Zn	0.149	0.105	0.167	0.099	0.078	0.131
Cu	0.189	0.101	0.247	0.115	0.091	0.195
Fe	1.465	1.054	1.86	1.459	1.051	1.857
As	0.023	0.008	0.036	0.037	0.012	0.031
Al	1.66	1.841	1.976	1.86	1.841	1.971
Cr	0.079	0.019	0.074	0.079	0.064	0.124

ever, concentrations of heavy metals were uppermost in District 15, followed by District 2 and then 3. As shown in Figure 4, average concentrations of heavy metals in the outdoor and indoor environments were in the order of Al>Fe>Pb>Mn>Cu>Zn>Cr>As>Ni>Cd. The difference between the outdoor and indoor environments was significant concerning the elements (Zn, Cu, Pb, Mn) from fossil fuel combustion (especially gasoline).

According to Table 3, cancer risk statistics and the non-carcinogenic HQs of heavy metals are depicted in Figure 5. According to Figure 5, indoor cancer risk is lower than outdoor environments in all areas in winter. Also, outdoor cancer risk and non-carcinogenic HQ of heavy metals are significantly higher in District 15 compared to the other districts, followed by districts 2 and then 3 of Tehran metropolis. This finding means that the highest and lowest non-carcinogenic HQs of heavy metals were recorded in districts 15 and 3, respectively. Cancer risk and HQs in District 3 differed significantly from the other two districts. Both cancer risk and HQs in the three Districts (D) were in the order of D. 15>D. 2>D. 3.

The Spearman correlation coefficient

The Spearman correlation coefficient (Spearman, 1923) was used to determine the correlation between heavy metal concentrations and human health risk, as well as significant relationships between heavy metal concentrations in high-traffic districts of Tehran and carcinogenic risk and non-carcinogenic HQs. Correlation results were extracted according to Table 4.

Table 3. Heavy metal carcinogenic risk and total Hazard Index (HI) in high-traffic districts of Tehran metropolis, Winter 2018

Districts	Stations	Total HI	Total Risk lifetime Carcinogenic Risk (LCR)
15	Outdoor	1.46E-04	1.15E-08
	Indoor	2.82E-05	4.61E-09
2	Outdoor	1.21E-04	7.36E-09
	Indoor	3.12E-05	5.29E-09
3	Outdoor	2.09E-05	2.79E-09
	Indoor	1.13E-05	1.82E-09

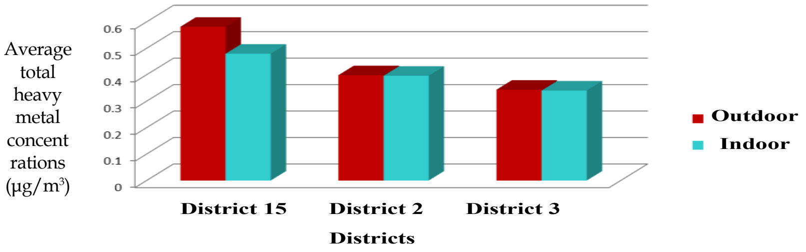

Figure 3. Average heavy metal concentrations in outdoor/indoor spaces of high-traffic districts in Tehran, Winter 2018

According to the Spearman test results (Table 4), a significant value of 0.018 was obtained for the two variables of heavy metal concentrations and carcinogenicity risk in the above matrix. Similarly, a significant value of 0.009 was achieved for two variables of heavy metal concentrations and HQ levels. This value is compared to 0.025 due to the two-tailed test range. Since the criterion is $P<0.025$, there is a definite correlation between mean heavy metal concentrations, carcinogenic risk, and HQ values in the studied districts.

The correlation is direct and incomplete because the values of these correlations are 0.664 and 0.713 for carcinogenic risk and HQ, respectively, and $0<r<1$ in both cases. This result means that carcinogenic risk and HQ increased relatively with rising heavy metal concentrations in high-traffic districts.

MANOVA results

ANOVA can be used to compare equal means of multiple groups. Table 5 presents MANOVA results for the difference between the examined "open spaces" and "closed spaces" in terms of carcinogenicity risk and HQs of heavy metals.

As shown in MANOVA Table, a significant value of>0.05 was obtained for carcinogenic risk in indoor and outdoor environments in all conditions, meaning that the two environments were not significantly different regarding carcinogenic risk ($P>0.05$). In terms of mean concentrations of heavy metals, however, the indoor and outdoor environments had significant differences in the studied districts. So, a significant value of 0.002 for both environments indicates a substantial difference between the two environments ($P<0.05$). Also, significant values of 0.018 and 0.005 were obtained for the HQ levels in indoor and outdoor environments, respectively, both of which are<0.05; that is, both indoor and outdoor HQ levels are significantly different ($P<0.05$).

The statistics of Tehran Traffic Police indicate that out of 20 million registered cars in the country, the share of Tehran is one-fifth (equal to 4 million vehicles) plus 3 million motorcycles (8 times the capacity of sidewalks) [21]. Vehicles release considerable amounts of heavy metals in air, water, and soil; thus, heavy metal emissions from vehicles are one of the major sources of metal pollution in urban and high-traffic environments [21, 26-28]. Based on the annual report of Tehran Air Quality Control Company (2018), total TSP pollutants were in unfavorable conditions in Tehran metropolis during different seasons of 2018, with unhealthy days mostly recorded from autumn to winter [21]. The transfer and distribution of pollutants are proportional to the wind speed, and the higher the

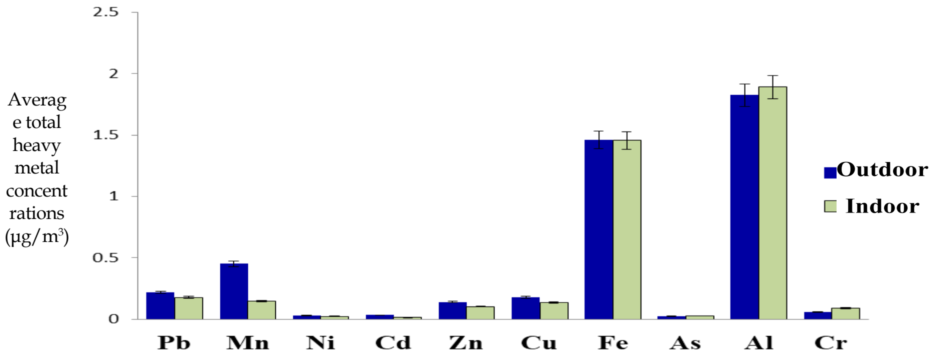

Figure 4. Average heavy metal concentrations in outdoor/indoor spaces of high-traffic districts in Tehran, Winter 2018

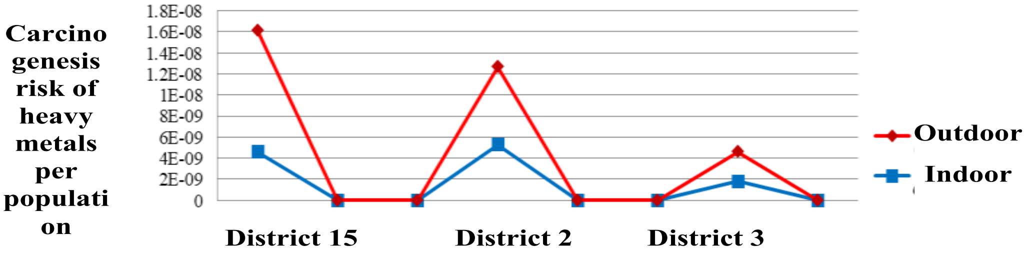

Figure 5. Carcinogenesis risk of heavy metals in outdoor/indoor spaces of high-traffic districts in Tehran, Winter 2018

wind speed and the turbulence of atmospheric currents, the lower the concentration of pollution [29, 30]. As the dominant wind direction is west-to-east in Tehran, TSP concentration is greater in the southern and central parts of the city. However, the prevailing wind conditions are not the type of model determining the distribution of pollutants, but wind speed determines pollutant distribution. In the event of wind speed, the smoke cannot rise, and the inversion of air leads to only horizontal transference [31].

Analysis of our data for all the three studied districts revealed significantly different concentrations of heavy metals between indoor and outdoor environments in each district, with higher mean heavy metal concentrations in closed than open environments, which is in line with that of Nasir et al. [32] findings in Pakistan. Their study aimed at measuring the amounts of indoor and outdoor heavy metals, showing higher outdoor than indoor concentrations of metals.

Another finding of this study revealed that Pb, Zn, and Cu contaminants were correlated with traffic levels. The average concentrations of extracted heavy metals in open and closed environments were in order of Al>Fe>Pb>Mn>Cu>Zn>Cr>As>Ni>Cd.

The lead level was higher in District 15 (Afsarieh Ave.) than in the two other districts. The pollution which moves with the prevailing west winds of Tehran, together with the geographical position of this high-traffic district (the east of Tehran), leads to the concentration of more pollution in this area at different day hours [33]. The aforementioned natural factors, along with heavy traffic, resulted in increased heavy metal concentrations in Afsarieh Ave. compared with the other two districts.

According to the World Health Organization (WHO), about 4.2 million deaths occur annually due to stroke, heart disease, lung cancer, and chronic respiratory diseases caused by air pollution. Short-term exposure to pollutant TSP (carrying heavy metals) may exacerbate symptoms of cardiopulmonary and respiratory, the need for medication, and hospital admission. Long-term exposure also causes early death and worsening of cardiopulmonary disease [34].

According to ranges set by the WHO, if the risk of carcinogenicity for heavy metals is estimated to be 10^{-6}, there will be an LCR of one in a million people. For risks smaller than 10^{-6}, there will be no concern for the population residing in area [35].

Table 4. The spearman correlation coefficients of heavy metal concentrations with carcinogenic risk and HQ in high-traffic districts (2, 3, and 15) of Tehran Metropolis, Winter 2018

Correlations			Districts	Mean Concentration of Heavy Metals	Carcinogenic Risk	HG Risk Share
r Spearman	District	Correlation coefficient Sig. (2-tailed)	1.000 -			
	Mean concentration of heavy metals	Correlation coefficient Sig. (2-tailed)	- 0.710** 0.010	1.00		
	Carcinogenic risk	Correlation coefficient Sig. (2-tailed)	-0.532 0.075	0.664* 0.018	1.000	
	HG risk share	Correlation coefficient Sig. (2-tailed)	-0.680* 0.015	0.713** 0.009	0.769** 0.003	1.000

** and * Significant correlations at 0.01 and 0.05 levels (two-way), respectively.

Table 5. Comparing MANOVA results between indoor/outdoor environments in high-traffic areas of Tehran Metropolis, Winter 2018

Factors	Sum of Squares	df	Mean of Squares	F	Sig.
HQ-Outdoor	-8E3.314	1	-8E3.314	22.304	0.018
HQ -Indoor	-9E4.829	1	-9E4.829	58.833	0.005
Outdoor risk	0.000	1	0.000	0.000	1.000
Indoor risk	0.000	1	0.000	0.000	1.000
Outdoor metals	0.905	1	0.905	97.471	0.002
Indoor metals	0.702	1	0.702	121.144	0.002

In this study, the lowest and highest LCR values (10^{-8} - 10^{-10}) of heavy metals were calculated in the air of the studied districts. Therefore, exposure to the amounts of heavy metals calculated here does not pose a risk of cancer to the indoor and outdoor populations of the three districts, with a cancer risk of a maximum of one per 100 million people. In this regard, minimum and maximum HQ levels of 10^{-4} - 106^{-6} (HQ<1) were calculated in the open and closed environments located in high-traffic areas of 2, 3, and 15 districts. Outdoor HQ level of District 15 was higher than those of the other studied districts, which reached a maximum level of 10^{-4}, meaning that one out of every 10000 people is exposed to lifetime health and non-carcinogenic effects of heavy metals.

Because industrial centers and large factories are located in the west of Tehran, the prevailing western wind speed and direction caused the accumulation of airborne TSP and increased heavy metal concentrations within Afsariyeh Ave. (District 15) in the eastern side of Tehran. In addition, the timeworn Afsariyeh zone, adjacency to heavily populated central and contaminated areas of 12 and 16, the existence of over 1200 wrecker shops and other polluting industries, high traffic on Azadegan Highway, Imam Reza (AS), Basij and Afsaryeh junction, high fossil fuel consumption, the old-fashioned transport fleet, and the construction of bridges and connecting highways all resulted in higher air pollution in District 15 of Tehran. This finding agrees with Sefidkar [36], who investigated "spatial analysis of Tehran air pollution using spatial statistics methods in 2011". Similarly, Dimitriou et al. [37] measured heavy metal concentrations in the northern cities of Dortmund and Billy Field in Iran and assessed carcinogenic risk through inhalation and circulation. They found that traffic was the main source of PM_{10} and elevated the contents of As, Cd, and Pb in both cities.

The nonparametric Spearman correlation coefficient showed significant relationships between average concentrations of heavy metals in the studied areas and carcinogenicity and HQ risks. There was a direct and incomplete (0<r<1) correlation between the above variables (average heavy metal concentrations and their health risk). This finding means that carcinogenicity and HQ risks will increase proportionately with rising concentrations of heavy metals in high-traffic districts. These results indicate the direct and effective role of heavy metal concentrations in intensifying the population's health risk in the studied zones. Therefore, heavy metals along with $PM_{2.5}$ will inevitably have health effects on residents, especially children, cardiopulmonary patients, and the elderly in districts 15, 2, and 3 of the Tehran metropolis. This finding conflicts with the results reported by Hosseini et al. [12], who assessed the health risk of heavy metals in Sanandaj City in Iran for the employees at Kurdistan University of Medical Sciences and concluded that none of the metals would increase cancer and non-cancer risks among the employees. This discrepancy in the results can be related to the difference in the concentration of pollutants and climatic and geographical conditions of the two cities studied. The results of research by Laumbach and Kipen [38], entitled "breathing health, the impact of air pollution: updating biomass, smoke, and traffic pollution issues", are also consistent with our findings on the harmful effects of airborne TSP containing heavy metals on human health.

The findings of this study are also in line with those of Bayat and Pardakhti [39]. They studied the health risk assessment of TSP in Tehran metropolis by examining the effects of Air Quality Index (AQI) index contaminants in Tehran and considered airborne TSP the most cause of death. According to MANOVA analysis, the difference between indoor and outdoor environments was significant in heavy metal concentrations. Also, the two indoor and outdoor environments were not significantly different concerning carcinogenic risk but were significantly different in terms of HQ levels ($P<0.05$). HQ levels of all three routes (ingestion, inhalation, dermal) were greater in outdoor areas located in District 15, followed by districts 2 and 3 of Tehran metropolis. This finding is consistent with that of Zmijková et al. [15], who investigated "human health risk assessment from heavy metal bonded TSP". They concluded that pollution and carcinogenic risks increased during winter. Al-Madanat et al. [40], in research on the indoor and outdoor air heavy metal pollutants in Al-Kark City, Jordan, reported different results. They mentioned that indoor pollutants were sometimes more hazardous than outdoor air. They considered the relationship between outdoor and indoor dust. They found that V, Ti, Mn, Pb mainly originated from heavy vehicles. At the same time, Ni, Cr, and Cu had higher concentrations in dust samples of residential (indoor) areas than outdoor air. The conflict may attribute to the different climatologic and geographical conditions.

4. Conclusion

The current study was conducted to determine the concentrations of TSP-bond heavy metals in the air of open and closed environments in high-traffic districts of Tehran metropolis in winter 2018, aiming at evaluating the health risk of these metals to humans. Research findings and online Google maps of Tehran traffic demonstrated that traffic congestion in most of the year was near the stations of this research, including Azadi Ave. from the south Yadergar to Enghelab Sq. (west zone), Vanak Ave. from Hemmat highway towards Chamran (north zone), and Afsariyeh Ave. along Basij highway (east zone), located in districts 2, 3, and 15 of Tehran metropolis, respectively. These were the first three high-traffic districts in order of D. 2 traffic>D. 3 traffic>D. 15 traffic, with an average daily traffic load of about 25%-27%.

The synergistic effect of climatic, geographical, and anthropogenic factors causes high air pollution and higher TSP concentrations in the studied districts of Tehran metropolis. The high volume of vehicle traffic and the excessive consumption of fossil fuels, particularly gasoline, had the highest contributions to air pollution in Tehran metropolis, which was also intensified during winter following the inversions of air. In addition, geographical location such as being surrounded among the crescent of Alborz Mountains as a barrier to air passage, roughness, and an altitude difference of north to south in Tehran causes incomplete fuel combustion and aggravation of pollution problem, rainfall deficit, lack of green space and plant filtration, population density, pollutant industries, and all sorts of human activities that played important roles in the air pollution of the above zones. In summary, the results of average air concentrations of heavy metals in indoor and outdoor environments of districts 2, 3, and 15 in winter were in order of Al>Fe>Cu>Mn>Zn>Pb>Cr>As>Ni>Cd, with indoor>outdoor and D. 3>D. 2>D. The heavy metal risk assessment in this study can be summarized in the following order of indoor carcinogenic risk<outdoor carcinogenic risk, and indoor HQ<outdoor HQ. Based on the results of this study, to improve the environmental quality, it is essential to identify exposure hazards in a systematic manner, called risk assessment, in high-traffic districts. For corrective actions, it is also necessary to review and update the health risks annually.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

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Authors' contributions

Data collection, data analysis, writing the initial draft of the paper: Azam Mahdipour; Supervision, methodology: Mojgan Zaeimdar; Revisions and data analysis: Mohammad Sadegh Sekhavatjou; Comments and advisor: Seyed Ali Jozi.

Conflict of interest

The authors declared no conflict of interest.

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