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Contamination Level, Spatial Distribution, and sources of Potentially Toxic Elements in Indoor Settled Household Dusts in Tehran, Iran

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Abstract

Tehran, the capital city of Iran has been facing air pollution since several decades ago because of rapid urbanization and population growth and improper use of vehicles, and low quality of fuels. In this study, 31 indoor dust samples were collected passively from residential, and commercial buildings located in the central and crowded districts of the city and were analyzed after sample preparation for elements (As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Sr, V, Zn). Statistical data analyses were used in comparing their relationship in various uses and variations and source identification. Geochemical indices of Contamination Factor (CF) and Pollution Load Index (PLI) were used to evaluate the degree of contamination.

The mean concentration of Zn, Cu, and Pb (938, 206, and 176 $\mu\text{g g}^{-1}$), are 6, 5, and 3 times higher than their mean values for worldwide urban soils, respectively and Cd, Mo, and Ni showed about 1.5 times higher concentrations while As, Co, Cr, Mn, and Sr were within the range of reference soils. Be, V, and Sb showed remarkably lower mean values. Building use does not influence element levels in indoor deposited dust except for Pb and Zn. A comparison of indoor concentrations with previously published data for outdoor dusts showed that Mo, Cu, Pb, and Ni are more enriched while As, Cd and Zn are less enriched in street dusts. The CF values indicate the order of $\text{Hg} > \text{Zn} > \text{Cd} > \text{Pb} > \text{Cu} > \text{As} > \text{Ni} > \text{Cr} > \text{Co} > \text{V}$. For Hg, Zn, Pb, Cd, and Cu all or almost all of the samples showed very highly contamination. PLI showed values higher than 1, or contamination in all samples. The multivariate statistical analysis and specific geological location of Tehran indicated that mafic-intermediate volcanic rocks are the main sources for Cr, Cu, Fe, and Ni (PC1). As, Pb and V (PC2) are attributed to fossil fuel combustion in vehicles and residential buildings. Pb is a legacy metal remained from using leaded gasoline, which was phased out in the 1990s. Zn (PC3) is derived from vehicle tires.

Keywords: indoor settled dust, potentially toxic elements, contamination factor, pollution load index, urban metal source.

1. Introduction

Indoor air quality is receiving increasing attention due to its implication for general human health and the ecosystem (Esplugas et al., 2022; He et al., 2017; Olujimi et al., 2015; Yang et al., 2016). People are more than ever exposed to indoor dust by spending up to 90% of their time in enclosed environments in schools, homes, offices, etc. (El-Desoky et al., 2014; Adeniran et al., 2019; Rehman et al., 2020; Zhou et al., 2021; Abdulraheem et al., 2022; Gad et al., 2022). Indoor dust is heterogeneous and derives from various sources, it is composed of a complex mixture of numerous organic and inorganic contaminants (Maertens et al., 2004; Sánchez-Soberón et al., 2019; Melymuk et al., 2020) among which metal(loid)s are of great importance. Heavy metals can cause deleterious ecological and health impacts due to their potential toxicity, persistence, and bioaccumulation features (Albanese and Cicchella, 2012; Alloway, 2013; Cicchella et al., 2020; Rehman et al., 2020). The metal contaminants introduce into the environment through human activities and by adsorption on and absorption into the particulate matter, they are transported and finally, they are settled or enter the human respiration system (Wong and Thornton, 2006; Alekseenko and Alekseenko, 2014; Cicchella et al., 2020; Tashakor and Modabberi, 2021; Alotaibi et al., 2022; Ariapak et al., 2022; Tashakor et al., 2022). Urban settled and suspended indoor dust is demonstrated to contain significantly large amounts of hazardous metals as a result of anthropogenic inputs in addition to natural sources (Wong and Thornton, 2006; Sánchez-Soberón et al., 2019; Cicchella et al., 2020; Tashakor and Modabberi, 2021). They mostly show an increased concentration of pollutants as compared to the open space dusts (Hodas et al., 2016; Koehler et al., 2019; Alotaibi et al., 2022; Cao et al., 2020, 2022; Gad et al., 2022; Zhou et al., 2022)

The particulate matters vary in size from 1 to 10000 micrometers and can be transported to long distances far from the source area, so they are effective means of pollutant transportation (Gustaffson et al., 2018; Kitagawa et al., 2021; Rehman et al., 2020; Zhou et al., 2022). Urban sources such as vehicular emissions, industrial activities, urban construction, weathering and deterioration of road paving materials and building facades, as well as waste incineration, are responsible for the import and accumulation of heavy metals in urban dust (Gunawardana et al., 2012; Pan et al., 2017; Jose & Srimuruganandam, 2020; Cowan et al., 2021). The outdoor dusts enter the buildings through windows and seals and are mixed with the particulates produced indoor. Sources of indoor dust may include those contributed from indoor activities (e.g., cooking and cleaning, smoking, maquillage used, electronic products used), buildings (e.g., constituent materials, ventilation), and bioaerosols which are deposited on all kinds of surfaces in closed spaces (Sánchez-Soberón et al., 2015; Patino and Siegel 2018; Doyi et al., 2019; Odediran et al., 2021; Alotaibi et al., 2022; Ariapak et al., 2022; Gad et al., 2022).

Tehran the capital city of Iran holds a population of around 9 million and it is the most crowded city in Iran. A huge number of automobiles and an old-fashioned public transport system, using fossil fuels and atmospheric inversion in cold seasons placed this megacity as the most polluted city in the country such that the clean days, according to the Iranian Clean Air Act, were not higher than 3 in the Iranian year 1401 (21 March 2022 to 21 March 2023).

Most of the studies in Tehran were focused on soil, sediment, and street dust (e.g., Dehghani et al., 2017, 2018; Ariapak et al., 2022 and a few others written in Persian). This research aims to study for the first time, the potentially toxic elements (PTEs) contamination and its intensity in indoor dusts of crowded districts of Tehran municipality and to deduce the sources of main PTEs to compare the results with previously published data on open space areas. In this research, statistical analyses and geochemical indices are used to decipher the concentrations and their probable impacts.

2. Materials and Methods

2.1 Study area and sampling locations

This research was carried out in Tehran, the capital city of Iran (Fig. 1). Tehran (35°30-57' N, 51°4-46' E) is the largest and the most populated city in Iran and one of the biggest cities in Western Asia. Based on the latest statistical census of Iran reports (Iran 2016), the Tehran metropolis has more than 8.7 million inhabitants and according to informal data, it is more than 9.4 million. The municipality spreads over an area of about 730 km² with an estimated population density of almost 11,000 people per km². The mean elevation of Tehran is 1,300 m above sea level. Tehran has a semi-arid, continental climate with an average annual precipitation of about 229 mm and a mean temperature of 17.5°C. The prevailing wind direction is west to east (Menhaj Bena et al., 2021).

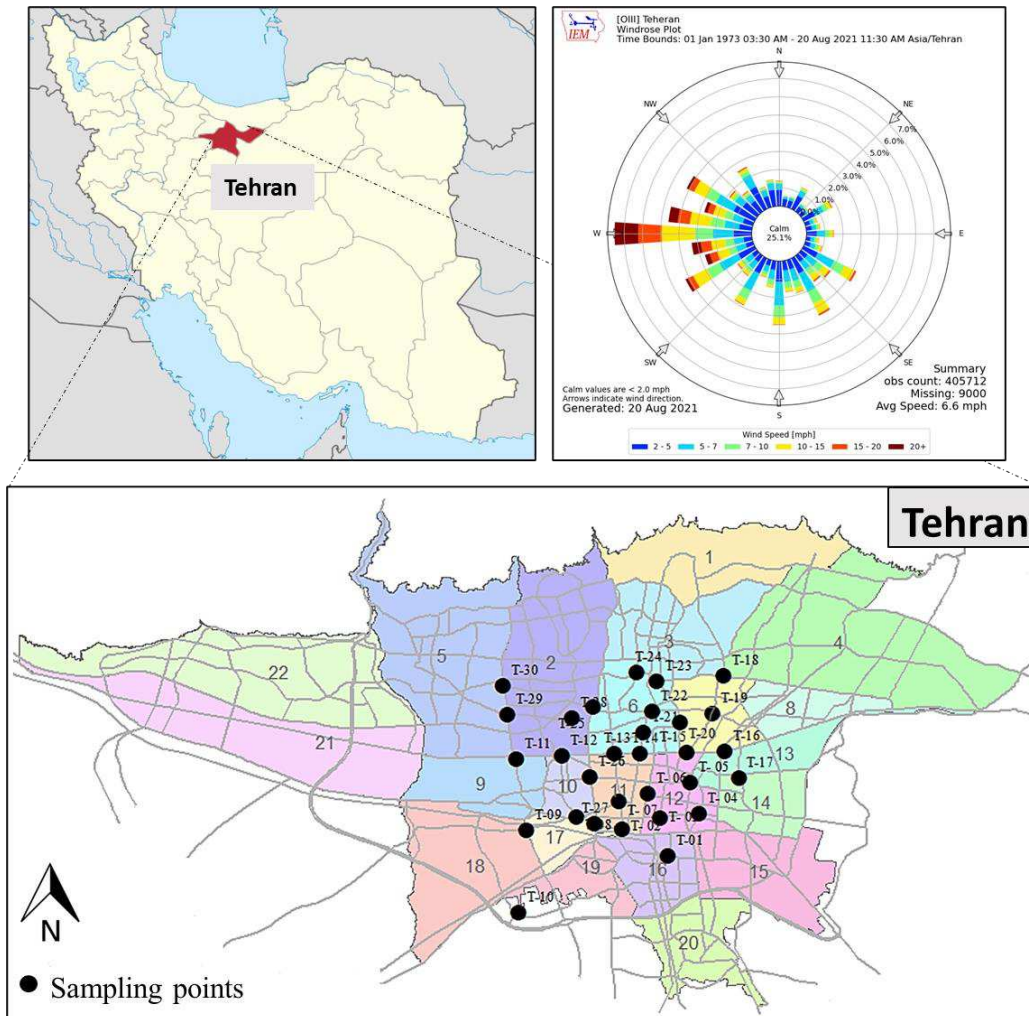


Fig. 1. The location of Tehran, the study area, and the locations of the sampling sites in central districts of Tehran city (bottom), along with the wind rose diagram (top right).

Tehran is facing serious air quality problems resulting from dust and particulate matter as well as fossil fuel-related pollution. It is believed that traffic emission is a major source of air pollution in this city (Dehghani et al., 2018) among many others. According to Tehran news agencies, Tehran has a capacity of 750,000 vehicles, while more than four million registered cars are traveling daily in this city. In addition to rapid and unplanned urbanization in recent years as well as significant industrial development, topography has been a contributor to poor air quality. The megacity of Tehran is surrounded by the Alborz Mountain Range from the north and northeast which acts as a barrier against the flow of air and dissipates the dust particles. Consequently, it prevents pollutant dispersion and leads to the accumulation of dust particles on the southwestern slopes of the mountain, where Tehran city is located (Dehghani et al., 2018).

An oil refinery, three power plants, and a cement plant are the main industries inside and in close vicinity of the city. The cars are using unleaded gasoline and buses and trucks are using gas oil. The main fuel of the residential – commercial buildings is natural gas.

2.2 Sampling

Tehran consists of 22 municipal districts. Sampling sites were selected from the most densely populated central districts (Fig. 1). There are old neighborhoods within the city center that receive the heaviest load of daily traffic. A total of 31 indoor dust samples (composite samples) were collected from residences ($n = 14$), offices ($n = 5$), shops ($n = 8$), and storerooms ($n = 4$). The areas for indoor dust sampling were selected to cover the study area of Dehghani et al. (2017) who studied street dusts and sediments. The surveyed sites were selected based on the landlord's willingness to participate in this study. Indoor airborne deposited dust samples were passively collected in three plastic Petri dishes at each sampling point, over a period of three months in 2020 (July-September). The Petri dishes were laid at a height of at least 1.5 m above ground level and protected from any external contamination such as heavy debris. It is stated that only the particles suspended at elevations below 3 m contribute to the exposure paths of elements in the human body (Del Rio-Salas et al., 2012). The collected data for each sampling point included smoking habits, type of fuel used indoors for cooking and/or heating, renovation history, proximity to industry, approximate age of the property, etc. Each collected sample was then transferred to a separate labeled clean polyethylene bag after the removal of any improper elements such as hairs or fibers. Samples were then transferred to the laboratory and stored at room temperature until analysis.

2.3 Analytical procedures

The dust samples were air-dried at room temperature and were passed through a 63 μm (220 mesh) nylon sieve. Acidic digestion and analytical determination were based on the methods described elsewhere (Mari et al., 2018; Rovira et al., 2018). Briefly, 0.5 g of dust sample was weighed and transferred into Teflon vessels with 10 mL HNO_3 (65% Suprapur, E. Merck). Then the samples were placed in a microwave digester (Milestone Start D) with the following temperature program: 10' until 110°C, 5' at 110°C, 10' until 170°C, 5' at 170°C, 10' until 200°C and finally 15' at 200°C. Digested extracts were cooled at room temperature, filtered, and made up to 25 mL with ultrapure water. Concentrations of selected elements (As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Sr, V, Zn) were measured for trace and major elements respectively by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Perkin Elmer NexIon 350D) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Perkin Elmer Optima 8300).

2.4 Quality control and accuracy of the measurements

Duplicate samples, blanks, and reference material (Loamy Clay soil (LCS, NIST, US)) were analyzed for every 8 samples. Coefficients of variation were below 18% and standards recovery rates ranged from 71 to 157%. Limits of detection were set at 3 times the standard deviation of the respective blanks. Detection limits were set at 0.01 mg/kg for Be; 0.02 mg/kg for Hg, Cd, Co and V; 0.03 mg/kg for As and Cr; 0.05 mg/kg for Ni; 0.07 mg/kg for Mo; 0.16 mg/kg for Sr; 0.20 mg/kg for Pb; 0.30 mg/kg for Se; 2.13 mg/kg for Fe; 3.28 mg/kg for Zn; 4.65 mg/kg for Cu; 5.19 mg/kg for Al and 8.39 mg/kg for Mn.

2.5 Statistical analysis

The geochemical results were analyzed for descriptive and multivariate statistics using Microsoft Excel and SPSS 23.0 software. Exploratory data analysis was run to generate bar charts and boxplots to support the statistical description of data. The Shapiro–Wilk’s test was carried out to control the normality assumption of the data which showed non-normal distributions of concentration for the majority of the analyzed elements ($p < 0.05$). Therefore, non-parametric statistics were used for analyzing the data. The Kruskal-Wallis H test was applied to compare dust heavy metal concentrations across the four different sampling environments (houses, offices, shops, and storerooms). This is a non-parametric test equivalent to one-way ANOVA which allows us to determine if there are statistically significant differences between more than two independent groups. A p -value of < 0.05 indicates a significant difference in the compared groups (Dahiru, 2008). The degree of correlation between the measured elements was identified using the Spearman correlation matrix ($p < 0.05$, $p < 0.01$). Principal Component Analysis (PCA) was performed to quantify the contribution of possible sources of every metal in the analyzed dust samples. PCA is an ordination multivariate statistical method for reducing the dimensionality of a large number of variables down to a smaller number of principal components to provide information about confuses in the measured data sets (Yoshinaga et al., 2014; Paula et al., 2018).

2.6 Geochemical Indices of Contamination

Many geochemical indices are frequently used in the analysis of the degree of contamination however they mostly convey the same notion and mislead to overestimation or underestimation of the contamination degree.

The single index of the Contamination Factor (CF) is a widely used geochemical and more reliable indicator to evaluate the level of contamination (Hakanson, 1980). CF is the quotient of the concentration of each element in a sample (C_n) and the concentration of the same element in the reference material (B_n) (Eq. 1):

$$CF = C_n/B_n \quad (\text{Eq. 1})$$

In this study, the Upper Continental Crust (UCC) concentration of elements given by Taylor and McLennan (2001) was used as the reference value, or UCC (B_n). To evaluate the degree of contamination, CF is classified into four classes, from unpolluted to very polluted, as follow (Hakanson, 1980). In summary, values of CF below 1 are classified as low contamination; values between 1 and <3 and between 3 and <6 are classified as moderate and considerable contamination, finally, CF values equal or higher than 6 are defined as very high contamination.

Pollution Load Index (PLI) as one of the cumulative geochemical complex indices was applied based on the single index of CF (Tomlinson et al., 1980). PLI is an integrated index calculated using equation 2 for each sampling site.

$$PLI = \sqrt{CF_1 \times CF_2 \times \dots \times CF_n} \quad (\text{Eq. 2})$$

The values of PLI being below 1 indicates no pollution, while values close to or equal to 1 shows natural accumulation or baseline levels. PLI values above 1 describe soil and dust pollution (Tomlinson et al., 1980).

3. Result & Discussion

3.1 Bulk chemical composition of indoor urban dust samples

Descriptive statistics of the analyzed elements in the indoor deposited dust samples in Tehran are shown in Table 1, with a comparison to the published data from different cities around the world. The concentration median is less sensitive to outliers than the mean and it has been defined as a more robust parameter for skewed geochemical distributions. However, since most of the reviewed studies only reported mean values, we used this measure for the comparison. To facilitate an understanding of the environmental quality and dust conditions, the results were also compared with the mean concentrations of elements in soils of urban landscapes which has established by Alekseenko and Alekseenko (2014) based on the concentration of elements in urban soils of more than 300 cities and settlements in Europe, Asia, Africa, Australia, and America. Alekseenko and Alekseenko (2014) concluded that the abundances of chemical elements in urban soils are extremely irregular but their general patterns are inherited from the Earth's crust and repeat those in the Earth's soils.

For overall data, Zn revealed the highest median concentration ($839 \mu\text{g g}^{-1}$) followed by Mn ($640 \mu\text{g g}^{-1}$), Sr ($319 \mu\text{g g}^{-1}$), Cu ($199 \mu\text{g g}^{-1}$), Pb ($153 \mu\text{g g}^{-1}$), Cr ($69 \mu\text{g g}^{-1}$), V ($56 \mu\text{g g}^{-1}$), Ni ($46 \mu\text{g g}^{-1}$), Co ($12 \mu\text{g g}^{-1}$), As ($11.3 \mu\text{g g}^{-1}$), Mo ($4 \mu\text{g g}^{-1}$), Cd ($1.2 \mu\text{g g}^{-1}$), Be ($0.6 \mu\text{g g}^{-1}$) and Hg ($0.2 \mu\text{g g}^{-1}$). The mean concentration of Zn ($\sim 938 \mu\text{g g}^{-1}$), Cu ($\sim 206 \mu\text{g g}^{-1}$), and Pb ($\sim 176 \mu\text{g g}^{-1}$) in the analyzed dust samples were respectively 5.9, 5.3, and 3.2 times higher than their mean values in the worldwide urban soils (Zn 158, Cu 39, and Pb $55 \mu\text{g g}^{-1}$). A significant concentration of Zn > Cu > Pb in the urban street dust of Tehran are also reported in previous studies (Rezayani, et al. 2022; Ali-Taleshi 2020). Salmanzadeh et al. 2015, have shown that the mean concentration of Zn, Cu, and Pb in the street dust samples from eastern and southern parts of Tehran surpasses those in major cities in developing countries such as Mutah and Kuala Lumpur and even the minimum contents of these elements exceed those of the Earth's upper crust. It proves that these concentrations may result from anthropogenic sources. Cd, Mo, and Ni also showed relatively higher mean concentrations of about 1.5 times in the studied dust compared to those in the reference urban soils. While As, Co, Cr, Mn, and Sr were within the mean values in the reference urban soils, generally lower, Be, and V concentrations showed remarkably lower mean values.

Arsenic, Hg, and Sr have scarcely been monitored in the indoor dust of different cities. As shown in Table 1. Cd in indoor dust of Tehran has higher concentrations than that in most of the cities including Istanbul (Turkey), Ilorin (Nigeria), Tokyo and Hiroshima (Japan), Birmingham and Plymouth (UK), and Selangor (Malaysia), however, it is in range of the metropolitan cities of Toronto (Canada) and Sydney (Australia). The same results were reported by Asvad et al. (2023) in Zabol and Ahvaz, Iran. The concentration of Cd in the studied samples is in accordance with the mean value of 1.6 mg kg^{-1} reported for 10 Iranian cities (Tashakor et al., 2021). Analyzing Cd in urban soils of Tehran has shown an enrichment up to 17-37 times higher than the mean earth crust with 88.69 % anthropogenic contribution (Eghbal et al. 2018).

This study showed that the mean concentration of Cr in indoor dust samples of Tehran was either in the range or lower compared to elsewhere in the world, except for Ilorin. This result is in line with previous findings indicating low abundances of Cr in Tehran dust (Dehghani et al., 2017, 2018, Ariapak et al., 2022). Lei et al. (2021) reported that Zn, As, Cu, Cd and Pb are the most abundant elements and from anthropogenic emissions in Beijing which is in good accordance with our data in this research.

Generally, Cu levels in indoor dust of other cities were lower than those of Tehran, except for the cities in the UK and Japan (Table 1). A similar result regarding the content of Cu in urban street dust of Tehran is stated by Dehghani et al. (2018).

The concentration of Ni in urban indoor street dust particles shows large variation among cities which indicates the possible influence of geogenic factors such as atmospheric inputs and the weathering of crustal materials (Aghadadashi et al. 2019). Jafari et al. (2018) have shown that Ni distribution in Tehran's surface soil and street dust samples does not follow the pattern of traffic density in the city. The result was the same for Cr and Co too. In contrast, an increase in traffic volume has displayed raises in the Pb and Zn contents in dust samples (Jafari et al., 2018). Urban contamination with Pb particularly in metropolitan cities is well documented (Ajmone-Marsan & Biasioli, 2010; Johnson et al., 2011). When compared to other cities, the concentration of Pb is relatively high in the indoor dust of Tehran. It is believed that the concentration of Pb is a function of the size and population of cities and it is mainly attributed to automobile exhaust and leaded fuel combustion.

Compared to the indoor Zn concentrations in other urban areas around the world (Table 1), it was observed that Tehran's indoor dust contains the highest amounts of Zn after Warsaw (Poland). Zn is an important urban element that has displayed significant concentration in surface soil and street dust of many cities (Tong and Lam, 2000). Vanadium showed similar levels in all the sampling sites.

The quality of household dusts is significantly influenced by outdoor air conditions. It is stated that local emissions have the largest contribution to Tehran particulate matter (PM) concentrations, even though cross-border dust sources mainly dust particles formed in Iraq and Syria are also responsible for nearly 28% of the emitted PM values in Tehran (Farahani & Arhami, 2019). During the dust storms, high amounts of PM in Tehran are originated from the large western and southern deserts of the country (Jafari et al., 2018). By applying the positive matrix factorization (PMF) model, Soleimani et al. (2019) concluded that road dust and atmospherically aged aerosols are respectively the most and the least contributor to ambient coarse PM in central Tehran. According to Ali-Taleshi et al. (2020), the mean concentration of elements in Tehran's atmospheric dust does not show any difference in the warm and cold seasons. A previous study on heavy metals in urban dust of different land uses in Tehran (Mihankhah et al. 2020) showed that commercial land use contains the highest abundances of all elements followed by, industrial, residential, and green lands. The highest average PM concentration on normal days in Tehran is related to the central parts while the lowest is measured in the East stations (Dehghani et al., 2018).

Outdoor air PM can enter indoors through open doors, windows, and other openings in the buildings as well as infiltration of aerosols through air-ventilation systems (Wang et al. 2016). In addition to outdoor ambient and street dust, the number of residents in each house and their different activities are considered to be important factors determining indoor air pollution levels (Kurt-Karakus 2012). This seems to be particularly the case during the COVID-19 pandemic when longer stays and working at home have increased indoor PM values and heavy metal concentrations (Du et al. 2020; Ezani et al. 2021; Liang et al., 2022). The building's air tightness and construction materials can also be responsible for the variation in concentrations of elements between different houses (Chattopadhyay et al. 2003). It is also suggested that the age of buildings can affect the accumulation of some metals in indoor dust (Shi 2020; Kelepertzis et al., 2019). Interior paint has been recognized to be an influencing factor so that higher concentration of Cu is attributed to green, Zn, and Pb to purple and Cd, Cu, Pb and Zn to yellow paint colors (Tashakor et al. 2022; Tong et al. 2000). It is thus inferred that deterioration and peeling of paints and their settling as indoor dust in old buildings can cause elemental concentrations (Tan et al., 2016). Opinions have remained divided about the relationship between the concentration of elements and the height of the buildings. According to Zhou et al., (2019), concentrations of heavy metals negatively change with vertical distance, whilst some studies found that higher floors lead to a regular increase in metal concentration (Zhou et al., 2019). In addition to the floor level, floor covers can control the content of heavy metals in dust particles. Plastic covers in indoor environments are believed to release higher levels of Cd, Cr, Cu, Ni, Pb, and Zn than ceramic tiles (Iwegbue et al., 2017). Carpets are thought to act as sinks for those heavy metals with a binding affinity with organic-rich particles (Rasmussen et al., 2018; Roberts et al. 2004). The influence of indoor activities such as the method of heating, cooking, and smoking on the amount of PM and its composition, particularly the enrichment of Pb, Zn, and Cd, in indoor dust has been pointed out by various scholars (Latif et al. 2009; Bohlandt et al., 2012).

Table 1. Tehran and global concentration of selected metal(loid)s ($\mu\text{g g}^{-1}$) in indoor dust

Location	As	Be	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sr	V	Zn	n	Ref.	
Tehran City Center	DL	0.03	0.01	0.02	0.02	0.03	4.65	0.02	0.31	0.07	0.05	0.20	0.16	0.02	3.28	31	This study
	minimum	7.45	0.34	0.55	7.00	35.9	71.4	0.04	547	1.02	27.0	61.5	228	47.1	309		
	maximum	39.0	1.07	5.65	21.3	121	555	3.62	733	6.22	90.3	413	649	65.7	2072		
	average	12.2	0.58	1.51	12.4	71.9	206	0.32	647	3.71	49.9	176	335	56.5	938		
	median	11.3	0.55	1.16	12.1	69.0	199	0.17	640	3.94	45.9	153	319	56.1	839		
	SD	5.18	0.17	1.08	2.71	21.6	83.5	0.64	43.7	1.24	13.6	69.8	75.6	5.08	423		
	skewness	4.89	1.03	2.62	0.87	0.53	2.41	4.93	0.10	-0.35	1.43	1.56	2.63	0.04	1.25		
	kurtosis	26.0	1.13	7.26	3.08	0.12	9.67	25.8	-0.14	-0.12	2.27	3.35	9.42	-0.85	1.29		
Istanbul, Turkey	n.a	n.a	0.80	5.00	55.0	156	n.a	136	n.a	263.00	28.00	n.a	n.a	832	31	Kurt-Karakus (2012)	
Giza and Cairo, Egypt	n.a	n.a	2.23	n.a	68.1	n.a	n.a	n.a	n.a	39.20	222	n.a	n.a	n.a	16	Hassan (2012)	
Ilorin, North Central Nigeria	0.08	n.a	0.12	3.35	1.92	0.4	n.a	6.3	n.a	1.35	5.55	n.a	n.a	4.08	10	Abdulraheem et al. (2022)	
Chengdu, China	n.a	n.a	2.37	n.a	82.7	161	n.a	n.a	n.a	52.6	123	n.a	n.a	675	90	Cheng et al. (2018)	
Selangor, Malaysia	n.a	n.a	0.23	n.a	11.9	n.a	n.a	n.a	n.a	830	253	n.a	n.a	145	31	Latif et al. (2014)	
Warsaw, Poland	n.a	n.a	n.a	n.a	90	109	n.a	n.a	n.a	30	124	n.a	n.a	1070	23	Lisiewicz et al. (2000)	
Birmingham and Plymouth, UK	n.a	n.a	1.3	n.a	n.a	339	n.a	578	n.a	56.5	181	n.a	n.a	666	32	Turner and Simmonds (2006)	
Toronto, Canada	n.a	n.a	1.7	n.a	42	136	n.a	58	n.a	23	36	n.a	n.a	386	67	Al Hejami, et al. (2020)	
Ottawa, Canada	4.1	0.53	4.3	8.8	69	157.3	1.6	266	1.7	52	222	249	22	633	48	Rasmussen, et al. (2001)	
Tokyo and Hiroshima, Japan	n.a	n.a	1.02	4.96	67.8	304	n.a	226	2.11	59.6	57.9	66.8	24.7	920	100	Yoshinaga, et al. (2014)	
Sydney, Australia	n.a	n.a	1.6	n.a	65	92.6	n.a	48.3	n.a	14.9	76	n.a	n.a	372	82	Chattopadhyay et al. (2003)	
Global Urban soil (300 cities)	15.9	3.3	0.9	14.1	80	39	0.88	729	2.4	33	54.5	458	105	158		Alekseenko and Alekseenko (2014)	

3.2 Comparison of metal distributions among different indoor uses

Elements levels in deposited dust samples taken from different indoor environments were compared by the Kruskal–Wallis H test regarding their category (residences, offices, shops, and storerooms). Almost all elements (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, and Zn) didn't show statistically significant ($p>0.05$) differences regarding indoor category (Table 2), however, significant differences were detected for Pb ($p=0.004$) and Zn ($p=0.012$) and the null hypothesis was rejected for these elements confirming that their concentrations significantly differ among different sampling site categories. The highest Pb level was associated with storerooms ($245 \mu\text{g g}^{-1}$) followed by commercial ($223 \mu\text{g g}^{-1}$) uses while Zn showed its highest mean concentration in dust collected from offices ($2232 \mu\text{g g}^{-1}$) and storerooms ($1541 \mu\text{g g}^{-1}$).

Table 2. The result of the Kruskal–Wallis H test for dust samples from various indoor uses in Tehran

	Kruskal-Wallis H	df	Asymp. Sig.
As	2.592	3	0.459
Cd	3.804	3	0.283
Co	2.851	3	0.415
Cr	6.526	3	0.089
Cu	3.009	3	0.39
Hg	3.66	3	0.301
Mn	6.252	3	0.1
Ni	6.675	3	0.083
Pb	13.271	3	0.004
Se	4.868	3	0.182
V	3.387	3	0.336
Zn	10.974	3	0.012

3.3 Comparison of metal concentration in Tehran indoor and outdoor dust

As it is mentioned, the stations for indoor dust sampling in this research correspond with those of street dusts studied by Dehghani et al. (2018). This proximity allows us to compare elemental compositions of indoor and outdoor dusts in the central districts of Tehran (Fig. 2). Dehghani et al. (2017, 2018) showed that the street dusts are significantly enriched in Cu, Pb, and Zn and moderately loaded by Cr, Mn, Mo and Ni. They have noted the following trend of mean enrichment factor for the Tehran street dusts: $\text{Cu} > \text{Zn} > \text{Pb} > \text{Mo} > \text{Ni} > \text{Mn} > \text{Cr}$. This result is similar to the chemical concentration of metals in indoor dusts in the current study and suggests that outdoor suspended particulates have contributed to the total content of dust in Tehran indoor environments. This finding has also been obtained in other research (Chen et al., 2016; Qiao et al., 2013) and stated by previous scholars such as Hassan (2012) who have identified entryway dust as an important source of household dusts.

Compared to the indoor dust, the mean concentrations of Mo ($6 \mu\text{g g}^{-1}$), Cu ($275 \mu\text{g g}^{-1}$), Pb ($213 \mu\text{g g}^{-1}$), and Ni ($57.7 \mu\text{g g}^{-1}$) in the street dusts were up to 1.6 times higher. In contrast, As, Cd, and Zn with the respective mean concentration of 5.4, 0.8 and $666 \mu\text{g g}^{-1}$ showed relatively lower values in the street dust than indoor samples. This indicates that domestic influences are at least partially responsible for the augmentation of these elements in indoor dusts. In other words, dust generated within the indoor environment can also be a critical source of exposure to certain metals (Rasmussen 2001). The interactions between the indoor-outdoor concentrations vary widely due to many factors including ventilation, local weather condition and wind pattern (Praveena et al., 2015) and a general rule cannot be considered for them. Cr was found in almost the same range of concentration ($49\text{-}128 \mu\text{g g}^{-1}$) in both external and internal dusts.

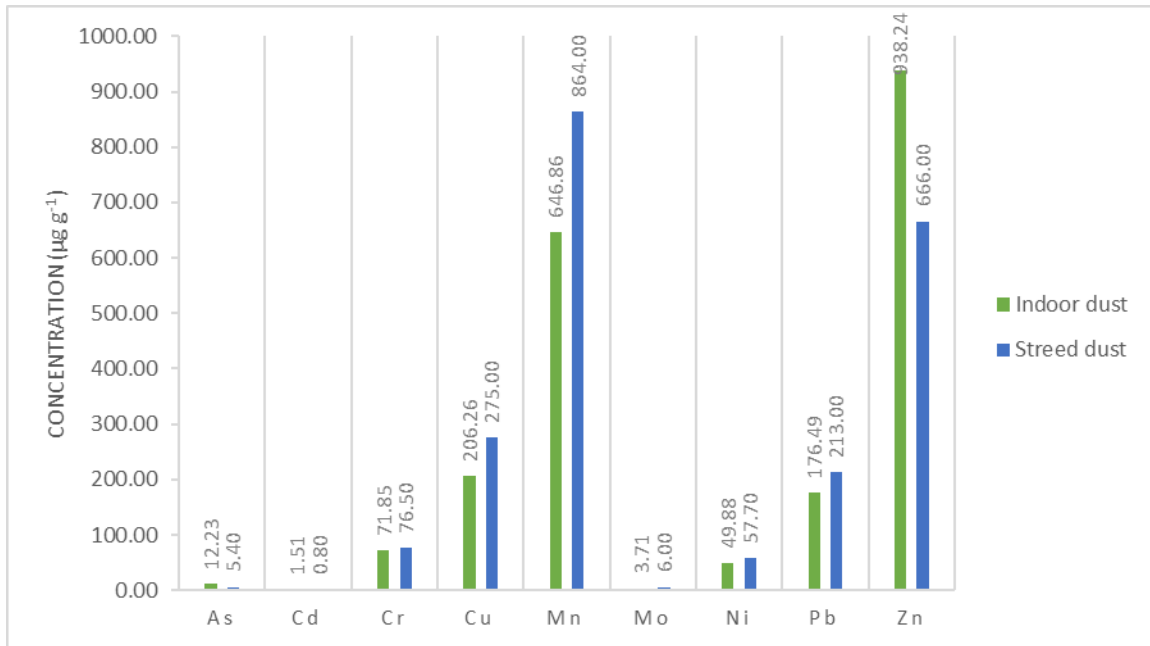


Fig. 2 Comparison of concentration of metals in Tehran indoor (present study) and outdoor (Dehghani et al. (2018)) dust.

3.4 Evaluation of the Degree of Indoor Dust Pollution

Comparing the concentration of a single element with its given references or global abundances despite providing a probable estimation of the extent of contamination, is an insufficient approach to have a reliable evaluation of the elemental contamination severity (Kowalska et al., 2018; Honggui et al., 2012). Individual and complex geochemical indices of contamination as effective computational tools are extensively used to assess the degree of soil and dust pollution by heavy metals (Timofeev et al., 2019). In the present study, two useful, more reliable, and universally accepted indices of contamination factor (CF) and pollution load index (PLI) was calculated for As, Be, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sr, V, and Zn in indoor dust of Tehran. The average concentration of elements in world soils after Taylor and McLennan (2001) were used for the geochemical background.

Values of CF for As and metals are depicted in Fig. 3. Mean CF values are presented following order from the highest to the lowest: Hg (94.3) > Zn (15.9) > Cd (15.4) > Pb (10.5) > Cu (8.25) > As (8.15) > Ni (1.02) > Cr (0.85) > Co (0.73) > V (0.51).

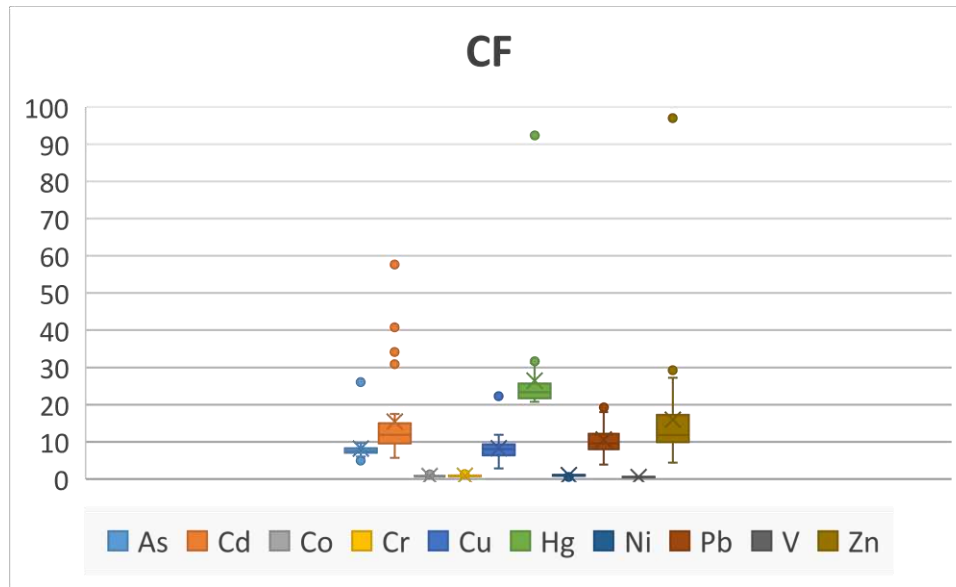


Fig. 3. Box plot of contamination factor (CF) for elements in indoor deposited dust of Tehran

According to the results obtained for Zn CF, except for one sample showing considerable contamination by Zn ($3 \leq CF < 6$), all of the analyzed dusts revealed very highly contamination ($CF > 6$) with minimum and maximum CF values of 4.36 and 97.0, respectively. The contamination factors for Pb and Cd show exactly the same classes as Zn in which except for one sample with considerable contamination, all other samples fall into the very highly contamination class (minimum and maximum values are 3.84 and 19.25 for Pb and 5.66 and 57.66 for Cd, respectively).

For Cu, considerable contamination was observed in two samples while all other samples fall in the category of very highly contamination displaying CF values between 2.86 and 22.21. With respect to Hg, all of the samples showed $CF > 6$. Co, Cr, Ni, Sr, and V in nearly all of the samples did not exceed the CF value of 3 (moderate contamination) and mostly did not surpass the CF value of 1 (low contamination).

The distribution of CF values for the most contaminant elements of As, Cd, Cu, Hg, Pb, and Zn, are plotted on the Tehran map using the Geographic Information System (GIS) (Fig. 4). As is apparent from the maps, the CF hotspots for Cd and Zn are more scattered throughout the study area which are different from those of Cu and Zn. Elevated levels of these elements were mainly distributed around urban centers which are characterized by a higher intensity of various municipal activities and older buildings. However, it seems that the distribution pattern of hotspots for Pb accords with the stations adjacent to the main highway routes, which separate municipal districts. The discontinuous Pb hotspots toward the connecting highways have also been recognized in other metropolitan cities (Tahmasbian et al., 2014). Concerning Zn, the highest levels of CFs are

distributed in districts 11, 12 and 6. Cu map also revealed the hotspots in these three districts in addition to certain remarkable spots in districts 15 and 16.

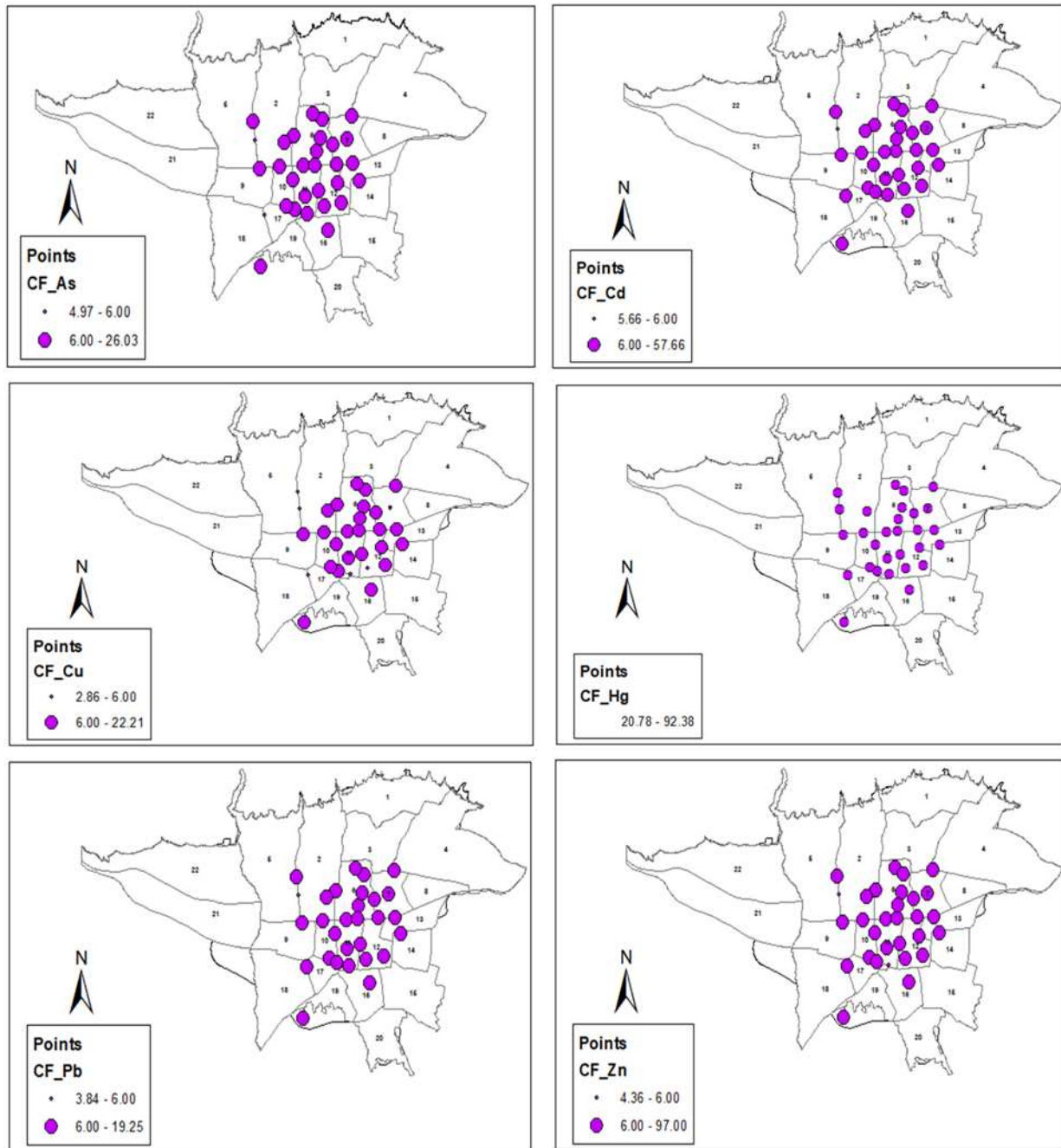


Fig. 4 Distribution maps of contamination factor (CF) for the most contaminant elements of As, Cd, Cu, Hg, Pb and Zn in the indoor dust of Tehran, the diameters of circles are proportional to the CF values of given elements

The results of the calculated PLI, as a cumulative index for the overall level of pollution at a given location, revealed values higher than 1 for all of the indoor dust samples. According to this finding, all of the studied sites are to some extent polluted by metals with the lowest and highest PLI values

of 2.07 and 6.66, respectively (mean 3.97). The most contaminated sites coincide with two commercial stations in District 12 of Tehran (samples T-05 and T-06, Fig. 5) which is one of the most densely populated districts and the historical and commercial core of the city. In addition, sample T-10 collected from the vicinity of Saeedi Highway displayed noteworthy contamination by the concerned elements. As is seen in the PLI distribution map in Fig. 5, the degree of pollution tends to be increasing toward the east and southeastern parts of the city which are in accordance with the dominant west-east wind direction. According to Dehghani et al. (2018), 54% of over 7000 industrial units are located in the southern parts of Tehran, which have a considerable role in intensifying the city's air pollution. Pb and Cu were recognized to have the largest contribution to the overall PLI values.

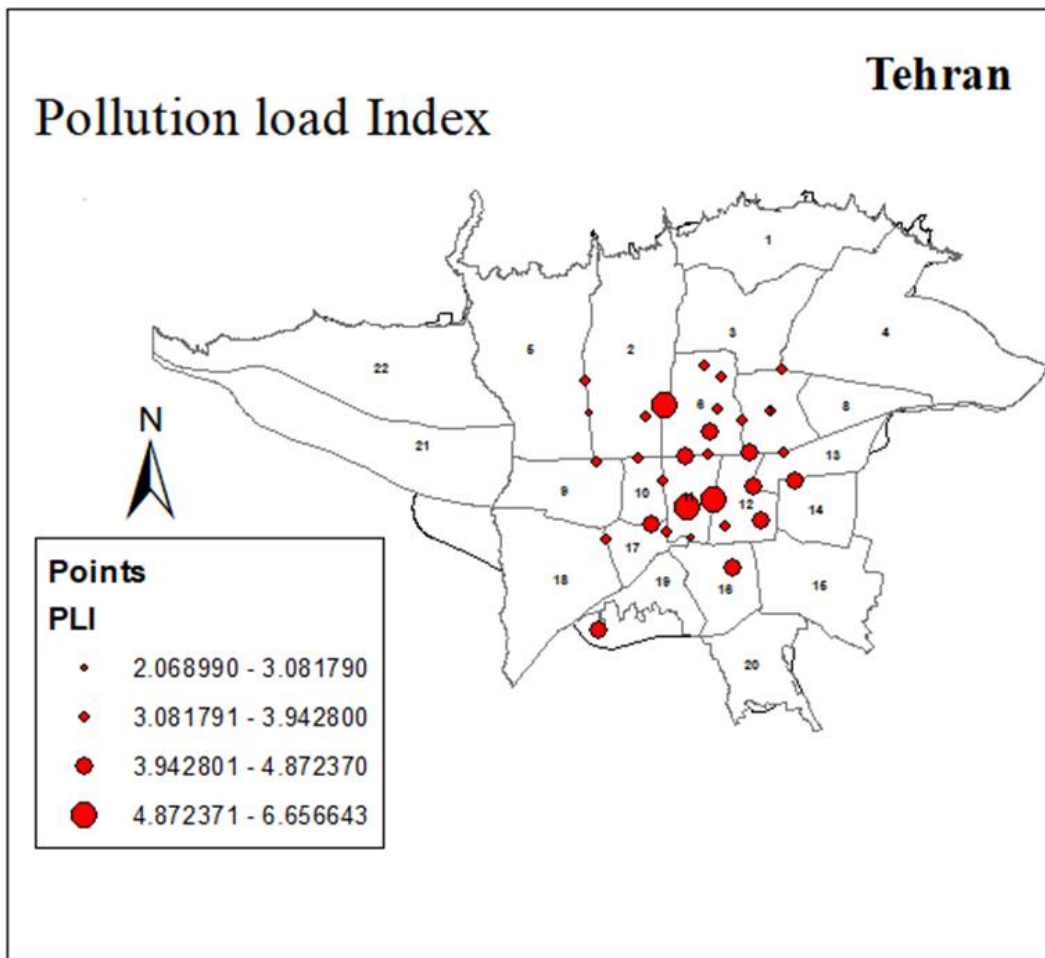


Fig. 5. Pollution Load Index (PLI) for indoor dust samples in the Tehran Greater City

4. Potential source identification

The multivariate statistics method of principal component analysis (PCA) was used to evaluate the possible source of heavy metals in Tehran's indoor-deposited dusts. The result of the Kaiser–

Meyer– Olkin test (KMO= 0.645) confirmed the adequacy of data for PCA. After applying the varimax rotation method, with eigenvalues greater than 1, three principal components accounting for 75 % of the cumulative variance were obtained (Table 3). Factor loadings greater than 0.6 are regarded as excellent, and those smaller than 0.32 are considered very poor.

Table 3. The rotated component matrix of PTEs in urban indoor dust from Tehran

	1	2	3
As	0.015	0.633	0.320
Co	0.321	0.542	-0.500
Cr	0.778	0.363	0.362
Cu	0.939	-0.144	0.044
Fe	0.856	0.053	0.403
Ni	0.861	0.071	-0.190
Pb	-0.098	0.888	0.038
V	0.122	0.794	-0.035
Zn	0.238	0.159	.0778

Extraction Method: Principal Component Analysis.
 Rotation Method: Varimax with Kaiser Normalization.
 Rotation converged in 6 iterations.

The first component (PC1) explains 35% of the total variance and exhibits a strong positive association between Cr, Cu, Fe, and Ni with factor loadings of 0.778, 0.939, 0.856, and 0.861, respectively. This result is in agreement with the correlation analysis of street dust samples (Dehghani, 2017) which displayed a significant inter-relationship between the elements of this group. Cr, Fe and Ni are generally attributed to geogenic origins and bedrock geochemistry (Argyraki and Kelepertzis, 2014; Ludden et al., 2015). All of these elements are found in abundant mafic-intermediate rocks surrounding Tehran and a geogenic source for these elements is plausible. Copper is also found in the volcanic rocks and an abandoned mine called Pas Ghal'eh occurs in the north Tehran volcanic materials.

The second component (PC2, 26% of total variance) is dominated by As (0.633) and Pb (0.888) and V (0.794). The probable source of these elements can be fossil fuel combustion and especially gasoline. The high concentration of Pb is specifically related to leaded gasoline and lubricants of vehicles. The Pb-bearing particulates remain in the urban atmosphere for a short time and they are deposited rapidly on urban soils, plant leaves and other surfaces where they remain for a long time of several years (Al-Chalabi, & Hawker, 1997; Cicchella et al., 2008; Lee et al., 2022). Lead was phased out of gasoline more than 25 years ago however its current accumulation in soils and dusts can be attributed to an older usage of leaded gasoline which was the case in other parts of the world (Chen et al., 2014; Wei et al., 2005). The presence of As and V in oil-prone areas have been reported frequently and they are among the common elements found in gasoline and other fossil fuels (Dahmardeh Behrooz et al., 2022).

Zn is the only element presented in PC3. This component is sourced from the non-exhaust traffic emissions, i.e tearing and wearing of vehicle tires which is the main source of Zn in the urban environment (Lin et al., 2021; Van Beers, and Graedel, 2007; Van Bohemen, and Van De Laak, 2003). In the study area, there is no zinc smelting and processing plant to be considered as an industrial source for this element.

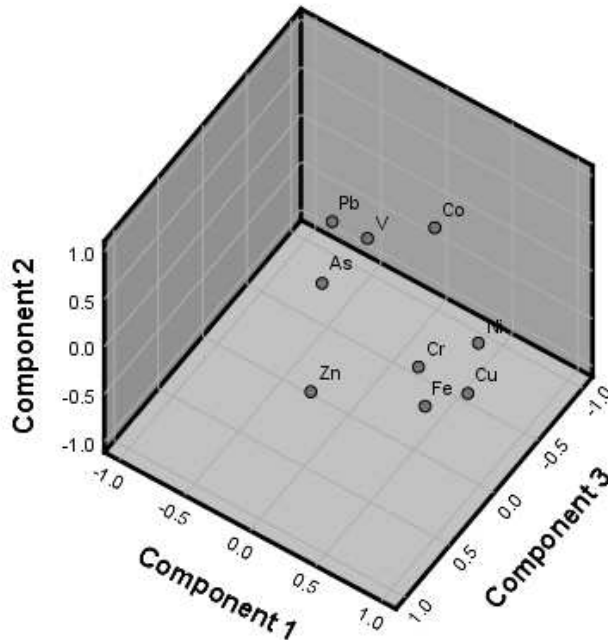


Fig 6. Principal component analysis results in the three-dimensional space: plot of loading of the first five factors

The sand and gravel mining is frequently considered as a source of particulate matter in Tehran however they are mostly located in the southwestern part of Tehran and could be transported to large distances just in unusual storms. Menhaj Bena et al. (2021) found high levels of Cu, Pb, Zn,

Mn and V in these quarries however they can be considered as local sources and limited to southwestern parts.

There are three fossil fuel power plants (Tarasht, Be'sat, and Rey) within and around the city and they are reported by non-scientific society as the main sources of air pollution especially in winter and inversion days. During the cold days of winter when the gas pressure is dropped in pipelines, they use gas oil as an alternative fuel and may contribute to the pollution burden however in most of the year they use gas as the fuel to produce electricity and their role is not as reported by news agencies.

Since the 1970s the establishment of large industries was banned in a radius of 120 km from the center of Tehran therefore only a few large industries like powerplants and a refinery are located around the city. Rey cement plant was closed in the 1980s and is used as an industrial museum however it may be contributed to some legacy pollution from 60 years of operation in the close vicinity of the city.

The sewage and greywater are collected in the wastewater collecting system and cannot be considered as a pollution source of contaminants in this study.

5. Future Perspectives

This research raises several questions that need further investigation. Considering that a large number of combined exterior and interior parameters can affect the content and chemical composition of indoor dusts, it is pivotal that future studies conduct a more detailed survey on the general attributes of each sampling site. Parameters including building age, floor level, floor cover, specific construction, decoration, and furnishing materials, land-use history of the neighborhood, energy uses, and heating and cooling systems as well as ventilation and humidification devices are needed to be considered. Participants should be asked about the number of residents and their living habits and domestic activities such as smoking habits, cleaning, and sweeping frequency. More work is recommended on source identification using non-traditional isotope studies. Shifting from fossil fuel toward clean energies or at least fuels of better quality will definitely improve the quality of life and environment in the Tehran Greater City.

5. Conclusion

Despite the widespread well-known air pollution in the metropolis of Tehran, no study has been conducted so far on the indoor environment of potentially toxic elements, and this research is the first study in this field that is conducted.

In addition to the overcapacity population, the shortage of rainfall and blockage of the winds by high-stand buildings, the excessive movement of cars that exceeds the city's capacity, along with rapid and unplanned urbanization in recent years, as well as significant industrial development, have contributed to the low air quality, aggravating air pollution and the air inversion in most of the year. Also, the metropolis of Tehran is surrounded by the Alborz Mountain Range from the north and northeast, which acts as a barrier against air flow and the movement of dust particles.

The study analyzed the concentration and distribution of potentially toxic elements (As, Be, Cd, Co, Cr, Cu, Fe, Hg, Mn, Mo, Ni, Pb, Se, Sr, V, Zn) and some major elements in 31 indoor-deposited dust samples collected from different types of indoor environments in Tehran.

It is shown that the major elements have a similar distribution trend and abundance showing an almost uniform distribution in different parts of the city.

Mo, Se, Be, Co, V, Ni and Cr have a normal distribution, which is an indication of their low concentration and the absence of sources that can abnormally increase their concentration. While elements with positive skewness include Cu, Hg, As, Zn and Cd, all of which have abnormally high data and are a sign of the presence of pollution sources for them in Tehran.

The study found that the levels of some elements, such as Zn, Cu, and Pb, were higher than their mean values in the worldwide urban soils and upper continental crust. On the other hand, some elements, such as Cd, were higher than in most cities worldwide.

Comparing the concentration of elements in the city of Tehran with the average of the upper continental crust shows that As, Cd, Cu, Hg, Pb and Zn have exceeded at least 8 times, which indicates the enrichment of these elements in the indoor dust samples of the city of Tehran due to anthropogenic and geogenic factors, while Co, Cr, Mg, and Ni do not show any enrichment.

Multivariate statistical studies show Cr, Fe, Ni, and Cu in the first component, which indicates their geogenic origin. All these elements are found in mafic and intermediate igneous rocks and also an abandoned mine which are found in the north of Tehran city, the geological origin for this elemental association can be justified.

Pb, As and V are placed in the second component, whose probable origin is the combustion of fossil fuels, especially gasoline and diesel. Pb concentrations can be specifically attributed to fuel sources of leaded gasoline and vehicle oil. Pb has high resistance and can remain in the soil for a long time. Although lead has been phased out from gasoline more than 25 years ago, the current accumulation of this element could be the result of the legacy of an old pollution source. The presence of As and V has been widely reported in oil fields and they are common elements in gasoline and fossil fuels.

The third component contains only zinc, which is due to the erosion of car tire rubber. Comparing the concentration of elements in Tehran with other cities shows significant differences.

The Contamination Factor and Pollution load index revealed high pollution in Tehran, especially in commercial and historical districts highly impacted by traffic. Mean CF values are presented following order from the highest to the lowest: Hg (94.3) >Zn (15.9) >Cd (15.4) >Pb (10.5) >Cu (8.25) >As (8.15) >Ni (1.02) >Cr (0.85) >Co (0.73) >V (0.51).

The study recommends further investigations to consider various parameters that can affect the content and chemical composition of indoor dust and using non-traditional isotope studies for source identification.

Credit author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abdulraheem, M. O., Adeniran, J. A., Ameen, H. A., Odediran, E. T., Yusuf, M. N. O., & Abdulraheem, K. A. 2022. Source identification and health risk assessments of heavy metals in indoor dusts of Ilorin, North central Nigeria. *Journal of Environmental Health Science and Engineering*, 20(1), 315-330.

Adeniran, J. A., Araromi, D. O., Yusuf, R. O., Jimoda, L. A., Oke, E. O., and Sonibare, J. A., 2019., Analytical modeling of human exposure from short-term point source releases of aerosols from household spray products. *Science and Technology for the Built Environment*, 25(1), 83-90. <https://doi.org/10.1080/23744731.2018.1499383>

Aghadadashi, V., Neyestani, M. R., Mehdinia, A., Bakhtiari, A. R., Molaei, S., Farhangi, M., ... & Gerivani, H. 2019. Spatial distribution and vertical profile of heavy metals in marine sediments around Iran's special economic energy zone; Arsenic as an enriched contaminant. *Marine pollution bulletin*, 138, 437-450.

Ajmone-Marsan, F., & Biasioli, M. 2010. Trace elements in soils of urban areas. *Water, Air, & Soil Pollution*, 213, 121-143.

Al Hejami, A., Davis, M., Prete, D., Lu, J., & Wang, S. 2020. Heavy metals in indoor settled dusts in Toronto, Canada. *Science of the Total Environment*, 703, 134895.

Albanese, S., and Cicchella, D., 2012. Legacy problems in urban geochemistry. *Elements*, 8(6), 423-428. <https://doi.org/10.2113/gselements.8.6.423>

Al-Chalabi, A. S., & Hawker, D. 1997. Response of vehicular lead to the presence of street dust in the atmospheric environment of major roads. *Science of the Total Environment*, 206(2-3), 195-202.

Alekseenko, V., and Alekseenko, A., 2014. The abundances of chemical elements in urban soils. *Journal of Geochemical Exploration*, 147, 245-249. <https://doi.org/10.1016/j.gexplo.2014.08.003>

Ali-Taleshi, M. S., Feiznia, S., Shahbazi, R., & Squizzato, S. 2020. Characterization and source identification of heavy metals in atmospheric deposited dust of Tehran in 2018. *Health*, 6(1), 56-69.

Alloway, B.J., 2013. Sources of Heavy Metals and Metalloids in Soils. In: Alloway, B. (eds) *Heavy Metals in Soils*. Environmental Pollution, vol 22. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-4470-7_2

Alotaibi, M. O., Albedair, L. A., Alotaibi, N. M., Elobeid, M. M., Al-Swadi, H. A., Alasmay, Z., and Ahmad, M., 2022, Pollution indexing and health risk assessment of heavy-metals-laden indoor and outdoor dust in elementary school environments in Riyadh, Saudi Arabia. *Atmosphere*, 13(3), 464. <https://doi.org/10.3390/atmos13030464>

Argyaki, A., & Kelepertzis, E. 2014. Urban soil geochemistry in Athens, Greece: the importance of local geology in controlling the distribution of potentially harmful trace elements. *Science of the Total Environment*, 482, 366-377.

Ariapak, S., Jalalian, A., & Honarjoo, N. 2022. Source identification, seasonal and spatial variations of airborne dust trace elements pollution in Tehran, the capital of Iran. *Urban Climate*, 42, 101049.

Asvad, S. R., Esmaili-Sari, A., Bahramifar, N., Behrooz, R. D., Paschalidou, A. K., & Kaskaoutis, D. G. 2023. Heavy metals contamination status and health risk assessment of indoor and outdoor dust in Ahvaz and Zabol cities, Iran. *Atmospheric Pollution Research*, 101727.

Bohemen, H. V., & Janssen Van De Laak, W. H. 2003. The influence of road infrastructure and traffic on soil, water, and air quality. *Environmental management*, 31, 0050-0068.

Böhlandt, A., Schierl, R., Diemer, J., Koch, C., Bolte, G., Kiranoglu, M., ... & Nowak, D. 2012. High concentrations of cadmium, cerium and lanthanum in indoor air due to environmental tobacco smoke. *Science of the Total Environment*, 414, 738-741.

Cao, S., Chen, X., Zhang, L., Xing, X., Wen, D., Wang, B., ... and Duan, X., 2020. Quantificational exposure, sources, and health risks posed by heavy metals in indoor and outdoor household dust in a typical smelting area in China. *Indoor Air*, 30(5), 872-884. <https://doi.org/10.1111/ina.12683>

Cao, S., Wen, D., Chen, X., Duan, X., Zhang, L., Wang, B., ... and Wei, F., 2022. Source identification of pollution and health risks to metals in household indoor and outdoor dust: A cross-sectional study in a typical mining town, China. *Environmental Pollution*, 293, 118551. <https://doi.org/10.1016/j.envpol.2021.118551>

Chattopadhyay, G., Lin, K. C. P., & Feitz, A. J. 2003. Household dust metal levels in the Sydney metropolitan area. *Environmental Research*, 93(3), 301-307.

Chen, M., Pi, L., Luo, Y., Geng, M., Hu, W., Li, Z., ... & Ding, S. 2016. Grain size distribution and health risk assessment of metals in outdoor dust in Chengdu, Southwestern China. *Archives of environmental contamination and toxicology*, 70, 534-543.

Cheng, X., Huang, Y., Zhang, S. P., Ni, S. J., & Long, Z. J. 2018. Characteristics, sources, and health risk assessment of trace elements in PM10 at an urban site in Chengdu, Southwest China. *Aerosol and Air Quality Research*, 18(2), 357-370.

Cicchella, D., De Vivo, B., Lima, A., Albanese, S., McGill, R. A. R., & Parrish, R. R. 2008. Heavy metal pollution and Pb isotopes in urban soils of Napoli, Italy. *Geochemistry: Exploration, Environment, Analysis*, 8(1), 103-112.

Cicchella, D., Zuzolo, D., Albanese, S., Fedele, L., Di Tota, I., Guagliardi, I., ... and Lima, A., 2020. Urban soil contamination in Salerno (Italy): Concentrations and patterns of major, minor, trace and ultra-trace elements in soils. *Journal of Geochemical Exploration*, 213, 106519. <https://doi.org/10.1016/j.gexplo.2020.106519>

Cowan, N., Blair, D., Malcolm, H., & Graham, M. 2021. A survey of heavy metal contents of rural and urban roadside dusts: comparisons at low, medium and high traffic sites in Central Scotland. *Environmental Science and Pollution Research*, 28, 7365-7378.

Dahiru, T. 2008. P-value, a true test of statistical significance? A cautionary note. *Annals of Ibadan postgraduate medicine*, 6(1), 21-26.

Dehghani, S., 2017. Environmental Geochemistry, Speciation and Health Risk Assessment of Selected Potentially Toxic Metals in Street Dust of Heavy Traffic Restricted Areas of Tehran Metropolis. PhD. Dissertation, Shiraz University, Iran. 300p.

- Dehghani, S., Moore, F., Keshavarzi, B., and Beverley, A. H., 2017. Health risk implications of potentially toxic metals in street dust and surface soil of Tehran, Iran. *Ecotoxicology and environmental safety*, 136, 92-103. <https://doi.org/10.1016/j.ecoenv.2016.10.037>
- Dehghani, S., Moore, F., Vasiluk, L., and Hale, B. A., 2018. The geochemical fingerprinting of geogenic particles in road deposited dust from Tehran metropolis, Iran: Implications for provenance tracking. *Journal of Geochemical Exploration*, 190, 411-423. <https://doi.org/10.1016/j.gexplo.2018.04.011>
- Del Rio-Salas, R., Ruiz, J., De la O-Villanueva, M., Valencia-Moreno, M., Moreno-Rodríguez, V., Gómez-Alvarez, A., ... & Meza-Figueroa, D. 2012. Tracing geogenic and anthropogenic sources in urban dusts: Insights from lead isotopes. *Atmospheric Environment*, 60, 202-210.
- Doyi, I. N., Isley, C. F., Soltani, N. S., and Taylor, M. P., 2019. Human exposure and risk associated with trace element concentrations in indoor dust from Australian homes. *Environment international*, 133, 105125. <https://doi.org/10.1016/j.envint.2019.105125>
- Du, Y., Gao, B., Zhou, H., Ju, X., Hao, H., & Yin, S. 2013. Health risk assessment of heavy metals in road dusts in urban parks of Beijing, China. *Procedia environmental sciences*, 18, 299-309.
- El-Desoky, G. E., Aboul-Soud, M. A., Al-Othman, Z. A., Habila, M., & Giesy, J. P. 2014. Seasonal concentrations of lead in outdoor and indoor dust and blood of children in Riyadh, Saudi Arabia. *Environmental geochemistry and health*, 36, 583-593.
- Esplugas, R., Rovira, J., Mari, M., Fernández-Arribas, J., Eljarrat, E., Domingo, J.L., Schuhmacher, M., 2022. Emerging and legacy flame retardants in indoor air and dust samples of Tarragona Province (Catalonia, Spain). *Science of the Total Environment*, 806, 150494. <https://doi.org/10.1016/j.scitotenv.2021.150494>
- Ezani, E., Brimblecombe, P., Asha'ari, Z. H., Fazil, A. A., Ismail, S. N. S., Ramly, Z. T. A., & Khan, M. F. 2021. Indoor and outdoor exposure to PM_{2.5} during COVID-19 lockdown in suburban Malaysia. *Aerosol and Air Quality Research*, 21(3), 200476.
- Farahani, V. J., & Arhami, M. 2020. Contribution of Iraqi and Syrian dust storms on particulate matter concentration during a dust storm episode in receptor cities: Case study of Tehran. *Atmospheric Environment*, 222, 117163.
- Gad, A., Saleh, A., Farhat, H. I., Dawood, Y. H., and Abd El Bakey, S. M., 2022. Spatial Distribution, Contamination Levels, and Health Risk Assessment of Potentially Toxic Elements in Household Dust in Cairo City, Egypt. *Toxics*, 10(8), 466. <https://doi.org/10.3390/toxics10080466>
- Gunawardana, C., Goonetilleke, A., Egodawatta, P., Dawes, L., & Kokot, S. 2012. Source characterisation of road dust based on chemical and mineralogical composition. *Chemosphere*, 87(2), 163-170.
- Gustafsson, Å., Kraus, A. M., Gorzsás, A., Lundh, T., and Gerde, P., 2018. Isolation and characterization of a respirable particle fraction from residential house-dust. *Environmental research*, 161, 284-290. <https://doi.org/10.1016/j.envres.2017.10.049>
- Hakanson, L., 1980. An ecological risk index for aquatic pollution control. A sedimentological approach. *Water research*, 14(8), 975-1001. [https://doi.org/10.1016/0043-1354\(80\)90143-8](https://doi.org/10.1016/0043-1354(80)90143-8)
- Hassan, S. K. M. 2012. Metal concentrations and distribution in the household, stairs and entryway dust of some Egyptian homes. *Atmospheric Environment*, 54, 207-215.
- He, C. T., Zheng, X. B., Yan, X., Zheng, J., Wang, M. H., Tan, X., ... & Mai, B. X. (2017). Organic contaminants and heavy metals in indoor dust from e-waste recycling, rural, and urban areas in South China: spatial characteristics and implications for human exposure. *Ecotoxicology and Environmental Safety*, 140, 109-115.

Hodas, N., Loh, M., Shin, H. M., Li, D., Bennett, D., McKone, T. E., ... and Fantke, P., 2016. Indoor inhalation intake fractions of fine particulate matter: review of influencing factors. *Indoor Air*, 26(6), 836-856. <https://doi.org/10.1111/ina.12268>

Honggui, D., Teng-feng, G., Ming-Hui, L., & Xu, D. 2012. Comprehensive assessment model on heavy metal pollution in soil. *Int J Electrochem Sci*, 7(6), 5286-5296.

Iwegbue, C. M., Nwose, N., Egbueze, F. E., Odali, E. W., Tesi, G. O., Nwajei, G. E., & Martincigh, B. S. 2020. Risk assessment of human exposure to potentially toxic metals in indoor dust from some small and medium scale enterprise workplace environments in southern Nigeria. *Indoor and Built Environment*, 29(8), 1137-1154.

Jafari, A. J., Kermani, M., Kalantary, R. R., & Arfaeinia, H. 2018. The effect of traffic on levels, distribution and chemical partitioning of harmful metals in the street dust and surface soil from urban areas of Tehran, Iran. *Environmental Earth Sciences*, 77(2), 38.

Johnson, C. C., Demetriades, A., Locutura, J., & Ottesen, R. T. 2011. Mapping the chemical environment of urban areas. Wiley.

Jose, J., & Srimuruganandam, B. 2020. Investigation of road dust characteristics and its associated health risks from an urban environment. *Environmental Geochemistry and Health*, 42, 2819-2840.

Kabata-Pendias, A., 2011. Trace elements in soils and plants (4th ed.). Boca Raton: CRC press, Taylor and Francis Group. <https://doi.org/10.1201/b10158>

Kelepertzis, E., Argyraki, A., Botsou, F., Aidona, E., Szabó, Á., & Szabó, C. .2019. Tracking the occurrence of anthropogenic magnetic particles and potentially toxic elements (PTEs) in house dust using magnetic and geochemical analyses. *Environmental Pollution*, 245, 909-920.

Kitagawa, Y. K. L., Pedruzzi, R., Galvão, E. S., de Araújo, I. B., de Almeida Albuquerque, T. T., Kumar, P., ... & Moreira, D. M. 2021. Source apportionment modelling of PM_{2.5} using CMAQ-ISAM over a tropical coastal-urban area. *Atmospheric Pollution Research*, 12(12), 101250.

Koehler, K., Good, N., Wilson, A., Mölter, A., Moore, B. F., Carpenter, T., ... and Volckens, J., 2019. The Fort Collins commuter study: Variability in personal exposure to air pollutants by microenvironment. *Indoor air*, 29(2), 231-241. <https://doi.org/10.1111/ina.12533>

Kowalska, J. B., Mazurek, R., Gąsiorek, M., and Zaleski, T., 2018. Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination—A review. *Environmental geochemistry and health*, 40(6), 2395-2420. <https://doi.org/10.1007/s10653-018-0106-z>

Kurt-Karakus, P. B. 2012. Determination of heavy metals in indoor dust from Istanbul, Turkey: estimation of the health risk. *Environment international*, 50, 47-55.

Latif, M. T., Othman, M. R., Kim, C. L., Murayadi, S. A., & Sahaimi, K. N. A. 2009. Composition of household dust in semi-urban areas in Malaysia. *Indoor and Built Environment*, 18(2), 155-161.

Latif, M. T., Yong, S. M., Saad, A., Mohamad, N., Baharudin, N. H., Mokhtar, M. B., & Tahir, N. M. 2014. Composition of heavy metals in indoor dust and their possible exposure: a case study of preschool children in Malaysia. *Air Quality, Atmosphere & Health*, 7, 181-193.

Lee, S., Han, C., Ahn, J., Han, Y., Lee, A. H., Ro, S., & Hong, S. 2022. Characterization of trace elements and Pb isotopes in PM_{2.5} and isotopic source identification during haze episodes in Seoul, Korea. *Atmospheric Pollution Research*, 13(6), 101442.

Lei, W., Zhang, L., Xu, J., Liu, Z., Xin, J., Li, X., & Zhao, W. 2021. Spatiotemporal variations and source apportionment of metals in atmospheric particulate matter in Beijing and its surrounding areas. *Atmospheric Pollution Research*, 12(11), 101213.

- Liang, L., Han, Z., Li, J., & Liang, M. 2022. Investigation of the influence of mineral dust on airborne particulate matter during the COVID-19 epidemic in spring 2020 over China. *Atmospheric pollution research*, 13(6), 101424.
- Lin, Y., Wu, M., Fang, F., Wu, J., & Ma, K. 2021. Characteristics and influencing factors of heavy metal pollution in surface dust from driving schools of Wuhu, China. *Atmospheric Pollution Research*, 12(2), 305-315.
- Lisiewicz, M., Heimbürger, R., & Golimowski, J. 2000. Granulometry and the content of toxic and potentially toxic elements in vacuum-cleaner collected, indoor dusts of the city of Warsaw. *Science of the Total Environment*, 263(1-3), 69-78.
- Ludden, J., Peach, D., & Flight, D. 2015. Geochemically based solutions for urban society: London, a case study. *Elements*, 11(4), 253-258.
- Maertens, R. M., Bailey, J., & White, P. A. 2004. The mutagenic hazards of settled house dust: a review. *Mutation Research/Reviews in Mutation Research*, 567(2-3), 401-425.
- Mari, M., Rovira, J., Sánchez-Soberón, F., Nadal, M., Schuhmacher, M., Domingo, J.L., 2018. Partial replacement of fossil fuels in a cement plant: Assessment of human health risks by metals, metalloids and PCDD/Fs. *Environmental Research*, 167, 191-197. <https://doi.org/10.1016/j.envres.2018.07.014>
- Melymuk, L., Demirtepe, H., and Jílková, S. R., 2020. Indoor dust and associated chemical exposures. *Current Opinion in Environmental Science and Health*, 15, 1-6. <https://doi.org/10.1016/j.coesh.2020.01.005>
- Menhaje-Bena, R., Koohi, M. K., Modabberi, S., Khansari, M. G., & Bakand, S. 2021. Investigation of Geological and Environmental Factors of Airborne Suspended Particles from Sand and Gravel Quarries in The West of Tehran, Iran. *Journal of Health and Safety at Work*, 11(1), 117-135.
- Mihankhah, T., Saeedi, M., & Karbassi, A. 2020. A comparative study of elemental pollution and health risk assessment in urban dust of different land-uses in Tehran's urban area. *Chemosphere*, 241, 124984.
- Odediran, E. T., Adeniran, J. A., Yusuf, R. O., Abdurraheem, K. A., Adesina, O. A., Sonibare, J. A., and Du, M., 2021. Contamination Levels, Health Risks and Source Apportionment of Potentially Toxic Elements in Road Dusts of a Densely Populated African City. *Environmental Nanotechnology, Monitoring and Management*, 100445. doi:<https://doi.org/10.1016/j.enmm.2021.100445>.
- Olujimi, O., Steiner, O., & Goessler, W. 2015. Pollution indexing and health risk assessments of trace elements in indoor dusts from classrooms, living rooms and offices in Ogun State, Nigeria. *Journal of African Earth Sciences*, 101, 396-404.
- Pan, H., Lu, X., & Lei, K. 2017. A comprehensive analysis of heavy metals in urban road dust of Xi'an, China: contamination, source apportionment and spatial distribution. *Science of the Total Environment*, 609, 1361-1369.
- Patino, E. D. L., & Siegel, J. A. 2018. Indoor environmental quality in social housing: A literature review. *Building and Environment*, 131, 231-241.
- Qiao, X., Schmidt, A. H., Tang, Y., Xu, Y., & Zhang, C. 2014. Demonstrating urban pollution using toxic metals of road dust and roadside soil in Chengdu, southwestern China. *Stochastic environmental research and risk assessment*, 28, 911-919.
- Rasmussen, P. E. 2004. Can metal concentrations in indoor dust be predicted from soil geochemistry?. *Canadian journal of analytical sciences and spectroscopy*, 49(3), 166-174.
- Rasmussen, P. E., Levesque, C., Chénier, M., & Gardner, H. D. 2018. Contribution of metals in resuspended dust to indoor and personal inhalation exposures: Relationships between PM10 and settled dust. *Building and Environment*, 143, 513-522.

- Rasmussen, P. E., Subramanian, K. S., & Jessiman, B. J. 2001. A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. *Science of the total environment*, 267(1-3), 125-140.
- Rehman, A., Liu, G., Yousaf, B., Zia-ur-Rehman, M., Ali, M. U., Rashid, M. S., ... and Javed, Z., 2020. Characterizing pollution indices and children health risk assessment of potentially toxic metal(oid)s in school dust of Lahore, Pakistan. *Ecotoxicology and Environmental Safety*, 190, 110059. <https://doi.org/10.1016/j.ecoenv.2019.110059>
- Rezayani, N., Mirmohammadi, M., & Mehrdadi, N. 2021. Origin and risk assessment, and evaluation of heavy metal pollution in the soil of Tehran, Iran. *Iranian Journal of Chemistry and Chemical Engineering*.
- Roberts, J. W., Glass, G., & Mickelson, L. 2004. A pilot study of the measurement and control of deep dust, surface dust, and lead in 10 old carpets using the 3-spot test while vacuuming. *Archives of environmental contamination and toxicology*, 48, 16-23.
- Rovira, J., Nadal, M., Schuhmacher, M., Domingo, J.L. 2018. Concentrations of trace elements and PCDD/Fs around a municipal solid waste incinerator in Girona (Catalonia, Spain). Human health risks for the population living in the neighborhood. *Science of the Total Environment*, 630, 34-45. <https://doi.org/10.1016/j.scitotenv.2018.02.175>
- Salmanzadeh, M., Saeedi, M., Li, L. Y., & Nabi-Bidhendi, G. 2015. Characterization and metals fractionation of street dust samples from Tehran, Iran. *International Journal of Environmental Research*, 9(1), 213-224.
- Sánchez-Soberón, F., Mari, M., Kumar, V., Rovira, J., Nadal, M., Schuhmacher, M. 2015. An approach to assess the particulate matter exposure for the population living around a cement plant: Modelling indoor air and particle deposition in the respiratory tract. *Environmental Research*, 143, pp. 10-18. <https://doi.org/10.1016/j.envres.2015.09.008>
- Sánchez-Soberón, F., Rovira, J., Sierra, J., Mari, M., Domingo, J.L., Schuhmacher, M., 2019. Seasonal characterization and dosimetry-assisted risk assessment of indoor particulate matter (PM_{10-2.5}, PM_{2.5-0.25}, and PM_{0.25}) collected in different schools. *Environmental Research*, 175, 287-296. <https://doi.org/10.1016/j.envres.2019.05.035>
- Shi, L., Zhang, J., Yao, F., Zhang, D., & Guo, H. 2020. Temporal variation of dust emissions in dust sources over Central Asia in recent decades and the climate linkages. *Atmospheric Environment*, 222, 117176.
- Soleimani, E., Taghvaei, S., Mousavi, A., Sowlat, M. H., Hassanvand, M. S., Yunesian, M., ... & Sioutas, C. 2019. Sources and temporal variations of coarse particulate matter (PM) in Central Tehran, Iran. *Atmosphere*, 10(5), 291.
- Tahmasbian, I., Nasrazadani, A., Shoja, H., & Safari Sinigani, A. A. 2014. The effects of human activities and different land-use on trace element pollution in urban topsoil of Isfahan (Iran). *Environmental earth sciences*, 71, 1551-1560.
- Tan, S. Y., Praveena, S. M., Abidin, E. Z., & Cheema, M. S. 2016. A review of heavy metals in indoor dust and its human health-risk implications. *Reviews on environmental health*, 31(4), 447-456.
- Tashakor, M., and Modabberi, S., 2021. Human Health Risks Associated with Potentially Harmful Elements from Urban Soils of Hamedan City, Iran. *Pollution*, 7(3), 709-722. <https://doi.org/10.22059/poll.2021.318496.1015>
- Tashakor, M., Behrooz, R. D., Asvad, S. R., and Kaskaoutis, D. G., 2022. Tracing of Heavy Metals Embedded in Indoor Dust Particles from the Industrial City of Asaluyeh, South of Iran. *International Journal of Environmental Research and Public Health*, 19(13), 7905. <https://doi.org/10.3390/ijerph19137905>
- Tashakor, M., Modabberi, S., & Argyraki, A. 2022. Assessing the contamination level, sources and risk of potentially toxic elements in urban soil and dust of Iranian cities using secondary data of published literature. *Environmental Geochemistry and Health*, 44(3), 645-675.
- Taylor, S. R., & McLennan, S. M. 2001. Chemical composition and element distribution in the Earth's crust. *Encyclopedia of physical science and technology*, 312, 697-719.

- Timofeev, I., Kosheleva, N., & Kasimov, N. 2019. Health risk assessment based on the contents of potentially toxic elements in urban soils of Darkhan, Mongolia. *Journal of Environmental Management*, 242, 279-289.
- Tomlinson, D. L., Wilson, J. G., Harris, C. R., and Jeffrey, D. W., 1980. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer meeres untersuchungen*, 33(1), 566-575. <https://doi.org/10.1007/BF02414780>
- Tong, S. T., & Lam, K. C. 2000. Home sweet home? A case study of household dust contamination in Hong Kong. *Science of the total environment*, 256(2-3), 115-123.
- Turner, A., & Simmonds, L. 2006. Elemental concentrations and metal bioaccessibility in UK household dust. *Science of the Total Environment*, 371(1-3), 74-81.
- Van Beers, D., & Graedel, T. E. 2007. Spatial characterisation of multi-level in-use copper and zinc stocks in Australia. *Journal of Cleaner Production*, 15(8-9), 849-861.
- Wang, J., Li, S., Cui, X., Li, H., Qian, X., Wang, C., & Sun, Y. 2016. Bioaccessibility, sources and health risk assessment of trace metals in urban park dust in Nanjing, Southeast China. *Ecotoxicology and Environmental Safety*, 128, 161-170.
- Wong, C. S., Li, X., and Thornton, I., 2006. Urban environmental geochemistry of trace metals. *Environmental pollution*, 142(1), 1-16. <https://doi.org/10.1016/j.envpol.2005.09.004>
- Yang, Y., Liu, L., Xiong, Y., Zhang, G., Wen, H., Lei, J., ... & Lyu, Y. 2016. A comparative study on physicochemical characteristics of household dust from a metropolitan city and a remote village in China. *Atmospheric Pollution Research*, 7(6), 1090-1100.
- Yoshinaga, J., Yamasaki, K., Yonemura, A., Ishibashi, Y., Kaido, T., Mizuno, K., ... & Tanaka, A. 2014. Lead and other elements in house dust of Japanese residences—Source of lead and health risks due to metal exposure. *Environmental Pollution*, 189, 223-228.
- Zhou, L., Liu, G., Shen, M., and Liu, Y., 2022. Potential ecological and health risks of heavy metals for indoor and corresponding outdoor dust in Hefei, Central China. *Chemosphere*, 302, 134864. <https://doi.org/10.1016/j.chemosphere.2022.134864>
- Zhou, L., Liu, G., Shen, M., Hu, R., Sun, M., & Liu, Y. 2019. Characteristics and health risk assessment of heavy metals in indoor dust from different functional areas in Hefei, China. *Environmental Pollution*, 251, 839-849.
- Zhou, L., Liu, G., Shen, M., Liu, Y., and Lam, P. K., 2021. Characteristics of Indoor Dust in an Industrial City: Comparison with Outdoor Dust and Atmospheric Particulates. *Chemosphere*, 129952. <https://doi.org/10.1016/j.chemosphere.2021.129952>