Assessing Pregnant Women's Exposure to Toxic Metals via Indoor Dust and Biological Monitoring in Urine

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Research Article

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Abstract

This cross-sectional study investigated heavy metal concentrations in the indoor dust of pregnant women's homes in Isfahan City, Iran. It aimed to explore the relationship between metal concentrations in indoor dust and urine, as well as their correlation with the Air Quality Index (AQI) and relevant factors. A total of 80 indoor dust samples were collected from vacuum cleaners in different locations of Isfahan City over a three-month period (January to March) in 2020-2021. Additionally, 80 urine samples were obtained. Metal concentrations, including Chromium (Cr), Lead (Pb), Mercury (Hg), and Nickel (Ni), were analyzed using ICP-OES. The AQI value was derived from the maximum 8-hour daily $PM_{2.5}$ levels provided by the Isfahan Department of Environment and calculated following EPA guidelines. Standard questionnaires captured information regarding residential location, house age, floor level, floor cover, smoking habits, distance living place and green spaces, use of air conditioner usage, type of window, window opening direction, and presence of houseplants. The mean concentrations of metals in indoor dust and urine samples were determined, with non-detectable levels of Hg. Significant differences in Pb concentration were observed across various living locations, house ages, and smoking habits (p-value < 0.05). Pb and Ni concentrations varied significantly based on floor levels and the direction of opening the window (p-value < 0.05). Differences were also noted in floor cover types and the presence of houseplants with respect to Cr and Pb concentrations in indoor dust (p-value < 0.05). Notably, a significant positive correlation existed between indoor dust Pb and AQI (r= 0.53, p <0.001). The high levels of Pb, Cr, and Ni in indoor dust highlight poor indoor air quality in the homes of the pregnant women studied. It is crucial to implement measures to raise awareness about the factors contributing to heavy metal pollution among communities.

Introduction

Individuals spend extensive time indoors such as in homes, schools, and offices, which is estimated over 80 percent of the day for adults and children (Cao et al. 2022). Indoor dust is a repository for environmental pollutants that may accumulate indoors from both external and internal sources over a long-term period (Yadav et al. 2019). Indoor dust may act as a sink for different pollutants, such as metals. For example, industrial activities, traffic, and fossil fuel combustion are the primary sources that increase heavy metal concentration. Heavy metals exist naturally as trace elements in soils and rock, although they are released into the environment due to human activities. In addition, activities carried out indoors, such as renovations or heating, and also domestic factors such as house age, floor level, floor cover, cigarette smoking, ventilation, energy usage, and cleanliness could play a significant role in the entry of metals into the home (Shi and Wang 2021). Air quality index (AQI) can be used to assess the general quality of the air in an area and to prompt classification of pollution levels — a higher level of AQI is associated with lower air quality. The AQI methodology consists of pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), and carbon monoxide (CO) that cause acute problems in health (Zhang et al. 2019). Heavy metals are of concern owing to their non-degradability, high toxicity, and adverse effects on humans. Many of these contaminants adsorb to particulate matter suspended in indoor air, which later settles as house dust. Heavy metals in dust can accumulate in human fatty tissues and internal organs via direct inhalation, ingestion, and dermal contact absorption, thereby posing risks to human health, especially for vulnerable groups (Hu et al. 2018; Reis et al. 2018). The elevated level of PM associated with trace metals was found in previous studies (Kumar et al. 2010; Maitre et al. 2006; Jayaraman 2007). Therefore, indoor dust is considered an important source of exposure to metals in individuals. Even though some studies documented heavy metal concentrations in indoor dust (Ali et al. 2012; Latif et al. 2009; Rashed 2008) in the world, to the best of our knowledge, there are limited studies, regarding heavy metal levels in indoor dust in Iran. This is the first study reporting heavy metal concentrations in indoor dust from homes in Isfahan City. In brief, the main aims of the current study were: a) to measure heavy metal concentrations in indoor dust, b) to investigate the relationship between urinary metals of pregnant women and important variables affecting their concentration, and c) investigating the correlation between AQI index and indoor dust metals concentration.

Material and methods

Study area

This cross-sectional study aimed to determine heavy metal concentrations in indoor dust and investigate the relationship between indoor dust metals with urinary metals and factors affecting their concentration, and correlation with the AQI index.

A number of 79 maternal attended healthcare centres in Isfahan City were randomly selected to take urine and dust samples. The distribution of participants' locations is demonstrated in Fig. 1. The individuals who participated in this research were completely informed about the purposes, procedure, and voluntary nature of the study. In addition, a signed consent form was taken from them. It is worth mentioning that the ethical issues related to this study have been approved by the ethics committees of Isfahan University of Medical Sciences.

2. Sample collection and data analysis

2-1- Collection and analysis of urine samples

The urine samples were collected in borosilicate containers and then transferred to the laboratory to be kept at -20°C until future analysis. The frozen urine samples were completely thawed at room temperature and then homogenized. A total of 3.0 mL of urine was poured into a polypropylene tube containing 15 µL of 65% (v/v) HNO_3 and then stored in a refrigerator at 5°C. It should be mentioned that approximately 2 h before the preparation of samples, the urine samples were brought to room temperature. One milliliter of the sample was pipetted into a 10-mL polypropylene tube and filled up to 5.0 mL with 1.2% (v/v) HNO_3 (Moradnia, Attar, et al. 2021; Moradnia, Movahedian Attar, et al. 2021). Heavy metal concentrations were adjusted using creatinine amount to minimize the bias of the dilution difference between urine samples. The prepared urine samples were injected into the ICP-OES (Varian 720/730-ES) to determine the concentration of the metal.

2-2- Collection and analysis of dust samples

A number of 80 indoor dust samples were collected from vacuum cleaners of pregnant women's houses in different areas of Isfahan City including north, south, east, west, and center within 3 months (January, February, and March 2020–2021). The indoor dust samples were all taken by early morning sweeping of the houses using a vacuum cleaner. Samples collected daily during each week were pooled together to form a composite sample. At least 20 gr composite samples of indoor dust were collected from each location and transferred to a polyethylene bag. The dust samples collected were dried at 105°C for 24 h and weighed. About 10g of dried samples were pulverized to a uniform size. About 1.5g of pulverized sample was digested in a mixture of hot concentrated Pperchloric acid (4ml), nitric acid (25ml) and Sulphuric acid (2ml) (Juo 1978). Finally, the prepared solution was injected into the ICP-OES (Varian 720/730-ES) to measure the concentration of heavy metals.

Standard questionnaires were used to collect the information including living location (north, center, south, east, and west), house age (less than 5 y, 5–14 y, 15–29 y ,30–50 y), floor level (1, 2, 3, and > 3), floor cover (carpet, moquette, ceramic, parquet, granite, others), smoking at home (yes, no), distance between living place and green space (very close, close, normal, and away), use of air conditioner (no, yes; if yes how often: less than 1 per day, 1–3 per day, higher than 3 per day), type of window (single pane window, double pane window), direction of opening the window (toward street, opposite to street), houseplant (no, yes; if yes: high, moderate, low), How many times use vacuum cleaner (higher than once a week, once a week, less than once a week.

2-3- The Air Quality Index (AQI)

To calculate the air quality index, PM2.5 information during the studied period was collected from the Isfahan Department of Environment. The AQI calculation was carried out in two stages: first, according to the ambient air standard, the maximum amount of 8 hours of daily $PM_{2.5}$ extracted Isfahan Department of Environment and then we calculated the mean amount of $PM_{2.5}$ for separate months. In the second stage, the AQI was calculated as per the EPA guidelines, according to Formula 1 by use of Excel software. For accreditation, some of the AQI results were compared with the results of the EPA online application (Mintz 2006).

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{lo}) + I_{Lo} \, (1)$$

2-4- Statistical Analysis

Continuous variables are reported as mean (SD), maximum, and minimum whereas categorical variables are as percent (frequency). Q-Q plot and Kolmogorov–Smirnov test were used to determine the normality of continuous variables. The data that did not follow the normal distribution were normalized as much as possible by different methods (Box-Cox, logarithmization, etc.). An Independent t-test was used to compare two independent normal groups, and Mann-Whitney test was used to compare the average concentration of heavy metals in two non-normal groups. ANOVA test was used to compare more than two independent normal groups, and Kruskal-Wallis test was used to compare the average concentration of heavy metals in more than two non-normal groups. For normal parameters, the correlation coefficient was calculated using the Pearson method, and for non-normal parameters, the correlation coefficient was calculated using the Spearman method. All statistical analyses were done using SPSS software version 23 (IBM SPSS Inc., Chicago, IL). $P < 0.05$ was considered as statistically significant.

Results

The information obtained from the studied population is demonstrated in Table 1. Among the participants, 19%, %20.3, %13.9, %19, %27.8, respectively lived in the north, centre, south, east, and west of Isfahan City. Most of the participants (%93.6) lived in houses under 50 years old and %72 of them used air conditioners. About %37 of the individuals used an air conditioner 1 to 3 times a day while smoking at home was around 64%. Over %70 of the houses had double pane windows and %49.4 of them opened toward streets. About %34 of women dwelled on the third floor and 34.2% of the studied houses had ceramic as floor cover. All of the women declared that they had houseplants.

The results of mean concentrations of heavy metal in indoor dust and urine samples are presented in Table 2. The highest mean metal concentrations in indoor dust and urine samples were found for Pb with 765.25 μg/g in indoor dust and 41.48 μg/g for urine samples while the lowest mean metal concentrations were found for Ni in indoor dust and urine samples. In all samples of indoor dust and urine, the concentration of Hg was non-detectable.

Table 3 indicates the mean value of AQI in January, February, and March in the studied area. According to Table 3, the highest mean AQI is respectively related to the east, centre, west, north, and south regions of Isfahan City.

The distribution of Cr, Pb, and Ni concentrations in relation to influencing variables is presented in Table 3. Based on the results, the mean concentration of Pb in indoor dust showed significant differences in various living locations and houses with different ages ($p\text{-value} < 0.05$). In addition, the concentration of Pb indicated a significant difference with smoking at home.

The concentration of Pb and Ni were significantly different in indoor dust of houses with different floor levels and with the direction of opening the window towards the street or opposite of it. Furthermore, significant statistical differences were observed in the houses with different types of floor cover as well as the use of different houseplants with Cr and Pb. There was a significant difference between Ni concentration in indoor dust and distances with green space.

The results of the mean concentration of indoor dust metals and the related AQI in different locations of this study are presented in Table 5. According to the results, the mean values of AQI values for different areas of Isfahan City were in the order of east > center > west > north > south.

Correlations between metals

The correlation matrix for heavy metal concentration in the studied sample is summarised in Table 6. Statistical analysis indicated a negative correlation between Pb with Ni (Pb-Ni: $r=-0.01$ and Pb-Cr: $r=-0.11$) and a positive correlation between Ni with Cr (Cr-Ni: $r = 0.31$) at 99% or higher confidence level. The result suggests that Ni and Cr originate from similar sources which may have derived from automobile emission, street dust and other related activities while Pb originate from different sources.

Table 7 shows the results of correlation between quantitative variables and heavy metals concentrations in indoor dust. According to the results, significant positive correlation was found between indoor dust Cr and urinary Cr ($r = 0.51$, p: <0.001), indoor dust Pb and urinary Pb ($r = 0.74$, p: <0.001), and indoor dust Ni and urinary Ni ($r = 0.38$, p: <0.001).

Regarding quantitative variables, significant negative correlations were found between Ni ($r= -0.23$, p: 0.03) and Cr ($r= -0.25$, p: 0.02) in indoor dust with the frequency of using air conditioners. In other words, by increasing the frequency of use of air conditioner, the concentration of Ni and Cr in indoor dust decrease. Furthermore, a significant positive correlation was found between indoor dust Pb and AQI while the correlation for Cr and Ni were not significant ($r = 0.53$, $p < 0.001$).

Discussion

Heavy metal contamination of indoor dust derived from the indoor activity and outdoor sources is known as a major environmental issue (Rasmussen 2004; Lin et al. 2015; Turner and Ip 2007). Therefore, the current study was conducted to measure Cr, Pb, Ni and Hg in the indoor dust of Isfahan City and to investigate the correlation between the content of metals in indoor dust with pregnant women's urinary metals. In addition, the relationship between the important influencing variables and AQI with indoor toxic metal concentration was investigated. According to the obtained results, the mean and maximum concentrations of Cr, Pb, and Ni were respectively found 34.74 µg/g and 332.3 µg/g, 111.1 and 765.25 µg/g, and 29.05 µg/g and 260.68 µg/g (Table 2).

Kurt-Karakus reported the mean concentration of 28 µg/g (the range: 3–230), 55 µg/g (the rang:2.8–190), and 268 µg/g (the rang:120–2600) respectively for Pb, Cr, and Ni in indoor dust in Istanbul city (Kurt-Karakus 2012). It can be concluded that the mean and maximum concentration of Pb and Cr in indoor dust of Iranian women's homes is higher than reported in Turkey but Ni content was lower than that. However, Rasmussen et al. detected higher mean concentrations of Pb (222 μg/g), Cr (69 μg/g), and Ni (59 μg/g) in Canadians' homes in comparison with our study (Rasmussen, Subramanian, and Jessiman 2001). In the study conducted in Khorramabad, Iran, the average concentration of Cr, Pb, and Ni in indoor dust were measured at 11.81 ± 5.29 mg/kg, 32.08 ± 20.60 mg/kg, and 60.19 ± 17.90 mg/kg, respectively that the mean contents of Cd and Ni, were higher than maximum permissible concentrations (Sabzevari and Sobhanardakani 2018). Our results indicated that the mean concentrations of Cr and Pb were much higher which were obtained in Khorramabad while Ni was lower.

Heavy metals embedded in indoor dust can enter the human body through oral ingestion, inhalation or skin contact. Pregnant women and infants are particularly at serious risk due to their sensitivity [1]. The concentration of heavy metals in dust samples strongly depends on the respective environmental conditions. The road traffic around a house is an important factor influencing the heavy metal concentrations in indoor dust (Lin et al. 2015). The burdens of Cd, Cu, Pb and Zn in areas with heavy traffic were reported significantly higher than those in other districts in Hong Kong, China (Tang et al. 2018).

According to the results of other studies, the concentration of Pb decreases as the distance of houses from major roads increases in urban areas (Latif et al. 2009). The results obtained from this study showed that the mean concentration of Pb was significantly higher when windows were opened towards street (177.78μg/g) compared to when the windows were opened opposite to street (86.07μg/g) (Table 4). Previous studies have shown that houses that are located around industrial areas have the highest concentration of heavy metals. Industrial processes invariably generate dust during operation (Kim et al. 1998). The city of Isfahan has 15 regions including the north (regions 7, 12 and 14), south (regions 5, 6 and 13), east (regions of 15, 10 and 4), west (regions 9, 2 and 11) and center of Isfahan (regions of 3, 1 and 8). The city of Isfahan is one of the largest center of various industries in Iran. The results of the present study showed that the average concentration of Pb in indoor dust was significantly different among participants living different locations ($p\text{-value} < 0.05$) (Table 4). According to the results, the highest average concentrations of Pb found in the indoor dust samples belonged to the place of residence of women living in the eastern and northern areas of Isfahan City (Arvin 2019). The establishment of various industries mines and casting centers as well as automobile traffic are the main factors of air and soil pollution in big cities (Delang 2017; Meuser 2010). In recent years, the population, industries and vehicles in Isfahan city have dramatically increased, so that today, Isfahan is known as one of the most polluted cities in Iran. Heavy metals existing in street dust are one of the main pollutants of urban environments, which can emit from heavy traffic, industries, erosion of buildings, erosion of tires and parts used in cars, mining activities and combustion of fossil fuels. Combustion of fossil fuels produces amounts of heavy metals such as Ni, Cr, Pb and Mn (Jiries 2003). Street dust containing heavy metals can enter the body through inhalation and skin contact and even swallowing through hands and mouth (Jiries 2003; Dayan and Paine 2001).

The study of the distribution of air pollution in Isfahan City has shown that the center, north and east areas of Isfahan City have more pollution (Arvin 2019). This is due to the urban topography as the southern and western regions of Isfahan are higher due to the presence of Soffeh Mountain, so the pollution tends to subside due to the mass weight in the lower northern and eastern regions of Isfahan. Soffeh Mountain is situated just south of the city of Isfahan, southeast of Mount Donbeh and south of the Zayanderud River in Iran. On the other hand, due to the gentle flow of the prevailing wind, which is from the west, the intensity of pollution is concentrated in the eastern and center areas.

Air pollution caused by heavy metals can be one of the major and important ways of exposure of people to these pollutants (Arvin 2018). Han et al. showed that the concentration of heavy metals including lead, cadmium, nickel and selenium in the urine of pregnant women who were exposed to heavy metals in densely populated areas with high traffic is higher (Han et al. 2020). Soil is also a major contributor to house dust. Heavy metals exist in the environment naturally as trace elements in rocks and soils; however, they also are released into the environment because of human activities and soil erosion (Zheng et al. 2005). Studies have also shown that 45–50% of house dust originates from soil and street dust (Fergusson et al. 1986). Many heavy metals accumulate to higher concentrations in indoor dust and also have greater bio-accessibility in indoor dust compared with that in exterior soil (Argyraki 2014). The main reason for this is that the elevated organic matter content in indoor dust increases the binding capability of heavy metals, thereby transforming inorganic compounds into more soluble metal-organic compounds (Rasmussen et al. 2008). Investigating the distribution of heavy metals in the soil of different areas of northern Isfahan, the average concentration of Pb, Cd, Zn and Cu were 16.47 mg/kg, 26.2 mg/kg, 35.57 mg/kg and 31.22 mg/kg, respectively, in which Pb and Cd were higher than the global standard (Atabaki 2018). In general, in many studies, heavy metal pollution in soil has been attributed to industrial pollution. Dankoub et al (Dankoub, Khademi, and Ayoubi 2012) reported that the surface soil contamination in Isfahan city is attributed to heavy traffic and industrial activities in the study area. Therefore, it can be said that Isfahan soil contamination with heavy metals can be one of the sources of heavy metals in indoor air.

In addition to outdoor sources, domestic factors such as house age, floor level, floor cover, carpet and furnishing, cigarette smoking, ventilation, energy usage and cleanliness could explain the differences in house dust originating from indoors (Fergusson and Kim 1991). For instants, the enrichment of lead dust in this home may be linked to a long history of contamination from the former use of leaded paint, lead solder and lead pipe (Von Lindern et al. 2003).

House age only affects the accumulation of some heavy metals in indoor dust. According to Rasmussen et al. (Rasmussen et al. 2013), the relationships between house age and dust heavy metal concentrations were significant for Pb, Cd and Zn ($p < 0.001$). Higher Pb concentrations occurred in dust samples of older homes in Ottawa, Canada (Rasmussen, Subramanian, and Jessiman 2001). Similarly, the Pb levels in indoor dust in older houses were significantly higher than those in newer houses (Kim et al. 1998). Kelepertzis et al. (Kelepertzis et al. 2019) observed that only Pb displayed a trend of increasing concentration with house age. It was estimated that approximately 45% of the Pb was derived from paint in old houses (Fergusson and Schroeder, 1985). It has also been found that houses younger than 20 y constructed of concrete may not be considered old enough to highly impact the heavy metal concentrations in house dust (Shraim et al. 2016).

According to our findings (Table 4), the concentrations of Cr and Pb were significantly higher in older houses ($p < 0.001$). Thus, we can infer that the deterioration and peeling of paints on the walls of old buildings settle as indoor dust, thereby causing higher metal concentrations in indoor dust. Our results indicated that Pb concentration was significantly higher in smokers' homes ($p < 0.05$) (Table 4). Opinions remain divided about the influence of smoking on the amount of indoor dust pollutants. According to Latif et al., dust from households with smokers have high concentrations of Cd and Ni (Latif et al. 2009). Similarly, smoking is an important factor of heavy metal (Pb, Zn and Cd in particular) enrichment in household dust (Cheng et al. 2018). However, comparisons of non-smokers and smokers homes showed no difference ($0.15 \leq p \leq 0.97$) in dust heavy metals (As, Cd, Cr, Cu, Ni, Pb and Zn) concentrations in Canada (Rasmussen et al. 2013). The concentration of metals was not significantly different between the use of single panes or double-glazed windows ($p > 0.001$). According to our findings, ventilation through open windows especially when they open towards streets found to be a possible factor that contributes to Pb accumulation in indoor dust ($p < 0.001$). Homes that did not open their windows for ventilation had a lower level of Pb in house dust. Our results were in parallel with the study conducted by Tong and Lam (Tong and Lam 2000).

Praveena et al. also reported a higher amount of metal accumulation on windows, floors and fans (Praveena, Abdul Mutalib, and Aris 2015).

Improper ventilation increases indoor air humidity (Lee and Chang 2000). Meyer showed increased levels of As, Cd and Pb in damp households compared with those in dry households. It may be possible that a higher indoor humidity promotes particle coagulation and condensation, and thus increases the deposition velocities of metal-containing particles (Meyer, Heinrich, and Lippold 1999). The inadequate exchange between indoor air and outdoor air can result in an increased indoor fungal concentration (Garrett et al. 1998). Fungi and other lower plants are capable of accumulating high concentrations of metals (Kamal, Prasad, and Varma 2010).

There are different documents indicating the role of houseplants in absorbing toxicants, such as heavy metals into plant tissues (Kulkarni and Zambare 2018; Deng and Deng 2018). Our results also indicated that the amount of Cr and Pb in indoor dust of homes which had a lot of houseplants significantly were lower than those that had moderate and lower numbers of houseplants (Table 4).

According to the findings (Table 4), the concentration of Ni and Pb in the dust of lower floors was low compared to the higher floors. Taoran Shi, Yuheng Wang in their study indicated that The average heavy metal concentrations of Pb, Cu, and Cd were higher in the dust on windows than that on floors (Shi and Wang 2021). Furthermore, Cheng et al. revealed a negative correlation between the concentrations of toxic metals (Cr, Cd, Cu, Ni, Pb and Zn) and floor level (Cheng et al. 2018). Zhou et al. also showed that the concentrations of Cr, Cd, Pb and Ni on the higher floors were significantly lower than on lower floors (Zhou et al. 2019). Higher floors may lead to changes in the heavy metal pollution patterns of indoor dust.

In addition, in our study, the concentration of Cr and Pb metals in the houses that used carpets and moquette for floor covering was higher than that of ceramic and parquet (Table 2). Rasmussen et al. indicated that carpets, rugs and moquette provide a reservoir where toxic metals that have an affinity for organic-rich particles may become more concentrated as the dust ages. In their study, The concentrations of As, Cd, Cr, Cu, Ni and Zn were approximately 1.4–2.1 times higher in the dust from carpeted homes than in dust from non-carpeted homes (Rasmussen et al. 2018). Iwegbue et al. revealed that homes floored with moquette and carpets had higher amounts of toxic metals such as Cd, Cr, Cu, Ni, Pb and Zn than those with ceramic tiles (Iwegbue, Oliseyenum, and Martincigh 2017).

The correlation results also indicated that the concentration of Pb ($r=-0.48$, $p < 0.001$) and Ni ($r=-0.47$, $p < 0.001$) was lower when the frequency of use of the air conditioner increased (Table 7). Although the frequency of cleaning was not correlated with the concentration of metals in indoor dust.

However, the urinary metals concentration was found higher than those reported in Spain (Fort et al. 2014), Tokyo (Shirai et al. 2010), and Suadi Arabia (Al-Saleh et al. 2011). Our results indicated that there was no significant correlation between indoor dust metals and urinary. Thereby indicating that indoor dust might not be the only source of heavy metals in the urine of pregnant women. Although the small number of samples can also be effective in the results. The results of the previous study showed that the concentration of urinary Pb and Cr were significantly associated with being second-hand smokers, use of damaged cookware and use of cosmetic products. Our previous studies indicated that lifestyle variables were the important predictors for the higher level of metals in the urine (Moradnia, Attar, et al. 2021; Moradnia, Movahedian Attar, et al. 2021).

In addition, our results indicated a positive correlation between Ni with Pb Pb-Ni: $r = 0.36$) and Ni-Cr: $r = 0.31$ at 99% or higher confidence level (Table 6). However, there were no significant correlations between Cr and Pb. The result suggests that the metals originate from similar sources which may have derived from related activities.

According to the presented results in Table 6, a negative correlation between Pb with Ni (Pb-Ni: r=-0.01 and Pb-Cr: r=-0.11) and a positive correlation between Ni with Cr (Cr-Ni: r = 0.31) at 99% or higher confidence level. The result suggests that Ni and Cr originate from similar sources which may have derived from automobile emission, street dust and other related activities while Pb originate from different sources. Furthermore, there was no significant correlation between indoor dust Cr and Ni with AQI while Pb showed a significant association with AQI suggesting their inter-dependence (Table 7). The primary sources of Pb are fossil fuel or wood combustion and vehicular traffic emissions. Particle matter less than 2.5 micrometre sometimes known as "black carbon", are one of the most important causes of air pollution in large cities, including Isfahan in recent years; The presence of these substances in urban areas is the cause of may respiratory diseases. Scientific research has shown that from the point of view of public health and health risks, airborne particles are among the main pollutants. The total percentage of annual death in Isfahan is caused by cardiovascular diseases and %95.5 of it is related to respiratory diseases caused by particulate matter (Abdolahnejad et al. 2017). Heavy metals such as Pb, Cd, Hg and other heavy metals in suspended particles are also considered important air pollutants due to their carcinogenic and mutagenic properties. In research that was conducted in Isfahan city to investigate the effect of urban, agricultural and industrial land use on the concentration of Zn (zinc), Cd (cadmium), Ni (nickel), Pb (lead), Cu (copper), it showed that the distribution of these elements in industrial areas due to the activity of metal smelting industries in industries and waste depots and scrap iron. In a research that was conducted in Isfahan city to investigate the effect of urban, agricultural and industrial land use on the concentration of Zn (zinc), Cd (cadmium), Ni (nickel), Pb (lead), and Cu (copper). Various heavy metals such as Hg, Fe, Cu, Cr, Co, Cd, As, Ni, Ti and Zn have been observed around coal-fired power plants, especially fuel oil and mazut (Ghadimi et al. 2019). Therefore, it can be concluded that the mentioned industries, burial sites, and use of mazut and fossil fuels are potential sources for the release of heavy metals in the city of Isfahan.

In parallel with our study, Kulshreshtha and Kumar revealed a strong positive and significant correlation between PM_{10} and Pb in ambient air pollution (significant at $p < 0.01$) (Kulshreshtha, Kumar, and Vaishya 2021). They attributed the correlation between PM10 and Pb in ambient air pollution caused by fossil fuel or wood combustion and vehicular traffic emissions. Therefore, it can be concluded that pollution from the external environment can be the direct cause of internal pollution, and if there is no proper ventilation, the risks related to their health, especially for sensitive groups such as pregnant women, are very high.

Conclusion

According to the results, the concentration of Pb, Cr and Ni metals was high in the indoor air of the homes of the studied pregnant women in the study. Various factors causing the high concentration of metals, especially Cr and Pb were identified in this study, including the place of residence, the type of floor covering, the age of the building and the level of the floor, the type of windows, the amount of use of houseplants, the use of air conditioning, and smoking. In addition, the results of this study showed that the high AQI and the amount of Pb metal in the indoor air of the house were related, which shows that the source of Pb in indoor dust can be affected by the amount of Pb in the ambient air. Pb, Cr and Ni metals were found to be high in the indoor dust indicating the low quality of the indoor air in the homes of the pregnant women in this study. Therefore, since pregnancy is a very sensitive period for the mother and the baby, necessary measures should be taken to warn the communities about the health hazard of house dust and to control the indoor and outdoor sources of heavy metal emissions.

Declarations

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Ethical Approval

This study was approved by the Ethics Committee, Isfahan University of Medical Sciences with the ethical code: IR.MUI.RESEARCH.REC.1399.065).

Consent to Participate: Given the nature of this study, "Consent to Participate" was not required.

Consent to Publish

All authors provide their consent for its publication in Environmental Science and Pollution Research

Authors Contributions

M. Moradnia and Mohammad Darvishmotevalli were responsible for designing and conducting the dust sampling and analysis. H. Movahedian Attar provided valuable input for the manuscript. Yaghoub Hajizadeh as supervisor conducted the critical revision of the manuscript. All authors have made significant contributions to the study, and all authors have reviewed and approved the final manuscript.

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Competing Interests

The authors declare that they have no competing interests related to this study.

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Tables

Table 1. The information obtained from the studied population

Variables	Categories		n (%)
Living location in the city	North		15(19)
	Center		16(20.3)
	South		11(13.9)
	East		15(19)
	West		22(27.8)
House age (years)	Less than 5		15(19)
	5-14		22(27.8)
	15-29		19(24.1)
	30-50		14(17.7)
	Higher than 50		9(11.4)
Smoking at home	Yes		50(63.3)
	No		29(36.7)
Floor level	1		17(21.5)
	2		19(24.1)
	3		27(34.2)
	>3		16(20.3)
	Carpet		22 (27.8)
	moquette		16(20.3)
	Ceramic		27(34.2)
	Parquet		12(5.1)
	Granite		2(2.5)
Distance between living place and green space	Very close		10(12.7)
	Close		12(15.2)
	Normal		30(38)
	Away		26(32.9)
Houseplant	No		0(0)
	Yes	High	19(24.1)
		Moderate	41(51.9)
		Low	19(24.1)
Use of air conditioner	Yes		56(71.8)
	No		22(28.2)

How often use air conditioner (per day)	Less than	36(45.6)
	1-3	36(45.6)
	Higher than 3	7(8.9)
Type of window	Single pane window	23(29.1)
	Double pane window	56(70.9)
Windows opened	Toward street	36(49.4)
	opposite to street	40(50.6)
How many times use vacuum cleaner	Higher than once a week	15(19)
	Once a week	25(31.6)
	less than once a week	39(49.4)

Table 2 Mean concentration of heavy metals (μg/g) in indoor dust and urine samples of pregnant women (μg/g creatinine) in Isfahan City

Metals (μg/g)		LOD (μg/L)	% > LOD*	Min	Max	Mean (SD)
Cr	indoor dust	0.15	100	1.72	332.3	34.74(40.3)
	urine		100	1.86	33.2	11.63(7.45)
Pb	indoor dust	0.8	100	4.74	765.25	138 (140.83)
	urine		100	1.09	43.04	17.73(11.29)
Ni	indoor dust	0.3	100	2.49	260.68	29.05(37.73)
	urine		100	0.56	43.03	9.64(8.94)
Hg	indoor dust	0.8	0	ND	ND	ND
	urine		0	ND	ND	ND

Table 3. Mean AQI index in different parts of the studied location

	Center	North	South	East	West
January	148	132	127	147	134
February	124	118	110	128	117
March	86	93	72	100	98
Mean	119.33	114.33	103	125	116.33

Table 4. The mean concentration of heavy metals in indoor dust (μg/g) across categories of the studied variables

		Cr		Pb		Ni	
		Mean (SD)	p-value	Mean (SD)	p-value	Mean (SD)	p-value
Living location	North	32.26 (20.94)	0.45	176.3(90.08)	**0.006**	17.94(11.69)	0.53
	Center	30.23(17.84)		105.56(122.43)		24.28(9.94)	
	South	37.96(30.10)		83.07(104.32)		56.47(78.77)	
	East	57.17(80.89)		229.29(237.82)		29.03(23.97)	
	West	22.80(10.30)		100.68(61.86)		26.39(35.81)	
Floor Level	1	23.97(21.41)	0.08	202.27(172.48)	**0.003**	22.85(16.91)	**0.005**
	2	30.67(18.64)		160.41(121.38)		18.15(7.85)	
	3	42.16(64.19)		75.12(49.54)		20.81(15.03)	
	>3	41.55(30.55)		124.85(175.92)		59.95(70.20)	
Floor cover	Carpet	61.37(66.78)	**0.001**	85.55(60.72)	**0.04**	39.76(59.01)	0.5
	Moquette	30.76(19.77)		137.01(165.01)		33.24(40.61)	
	Ceramic	23.39(9)		203(173.55)		22.17(16.24)	
	Parquet	17.59(8.79)		62.44(18.02)		19.87(9.47)	
	Granite	23.62(2.69)		165.38(20.18)		25.63(0.33)	
Distance between living place and green space	Very close	45.72(34.64)	0.13	229.15(236.28)	0.26	75.09(77.86)	**0.001**
	close	41.62(28.27)		193.22(187.61)		28.86(12.35)	
	normal	25.66(11.51)		104.93(79.83)		28.34(29.74)	
	away	37.77(62.32)		114.53(110.46)		13.31(7.59)	
Houseplant	High	24.49(15.64)	**0.04**	71.91(57.9)	**0.001**	21.25(16.83)	0.36
	Moderate	40.74(50.97)		94.81(59.24)		26.1(24.52)	
	Low	42.04(26.69)		297.28(197.88)		43.21(65.22)	
House age (years)	Less than 5	34.87(27.76)	0.93	28.91(11.92)	**0.001**	33.58(38.16)	0.52
	5-14	31.66(16.72)		108.64(101.47)		38.40(61.01)	
	15-29	41.11(17.11)		105.33(56.51)		22.65(8.63)	
	30-50	35.25(28.94)		251.73(168.35)		26.67(19.53)	
	Higher than 50	27.76(25.04)		284.73(197.68)		15.85(13.82)	
Smoking at home	Yes	35.33(25.15)	0.15	177.24(160.48)	**0.001**	34.72(46.27)	0.15
	No	33.71(53.93)		70.34(51.88)		19.26(7.93)	

Type of window	1 layer	34.36 (26.58)	0.90	123.27(70.36)	0.69	29.52 (31.5)	0.65
	2 layers	34.89 (44.61)		144.04(161.31)		28.86 (40.27)	
Direction of opening the window	Toward a street	35.03(25.37)	0.39	177.78(172.91)	**0.04**	39.25(51.28)	**0.04**
	opposite to street	34.43(50.77)		86.07 (9.20)		19.1(8.92)	

Table 5. The mean concentration of indoor dust metals and the related AQI in different locations of this study

Living location	**Mean Indoor dust (μg/g)**			
	Cr	**Ni**	**Pb**	**AQI**
West	23.71	21.8	53.83	116.33
East	25.01	20.38	64.47	125
Center	20.60	20.77	76.95	119.33
South	25.07	21.87	52.61	103
North	27.04	24.80	75.76	114.33

Table 6. Correlation matrix for the concentration of heavy metal

	Cr	Pb	Ni
Cr	1		
Pb	-0.11	1	
Ni	0.31**	-0.01**	1
** Indicates statistical difference, $p< 0.01$.			

Table 7 Correlation between heavy metals concentrations with the quantitative variables

Variables	**Cr**		**Pb**		**Ni**	
	r	**p-value**	**r**	**p-value**	**r**	**p-value**
Urinary Cr	0.51	**<0.001****	-0.61	0.57	0.09	0.38
Urinary Pb	-0.06	0.59	0.74	**<0.001****	-0.11	0.34
Urinary Ni	0.19	0.09	-0.11	0.31	0.38	**<0.001****
AQI	-0.14	0.22	0.53	**<0.001****	0.14	0.21
How often use the air conditioner (per day)	-0.25	**0.02***	-0.84	0.47	-0.23	**0.03***
How many times use a vacuum cleaner	0.01	0.97	0.18	0.11	-0.05	0.64

r: Correlation coefficient

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed).

Figures

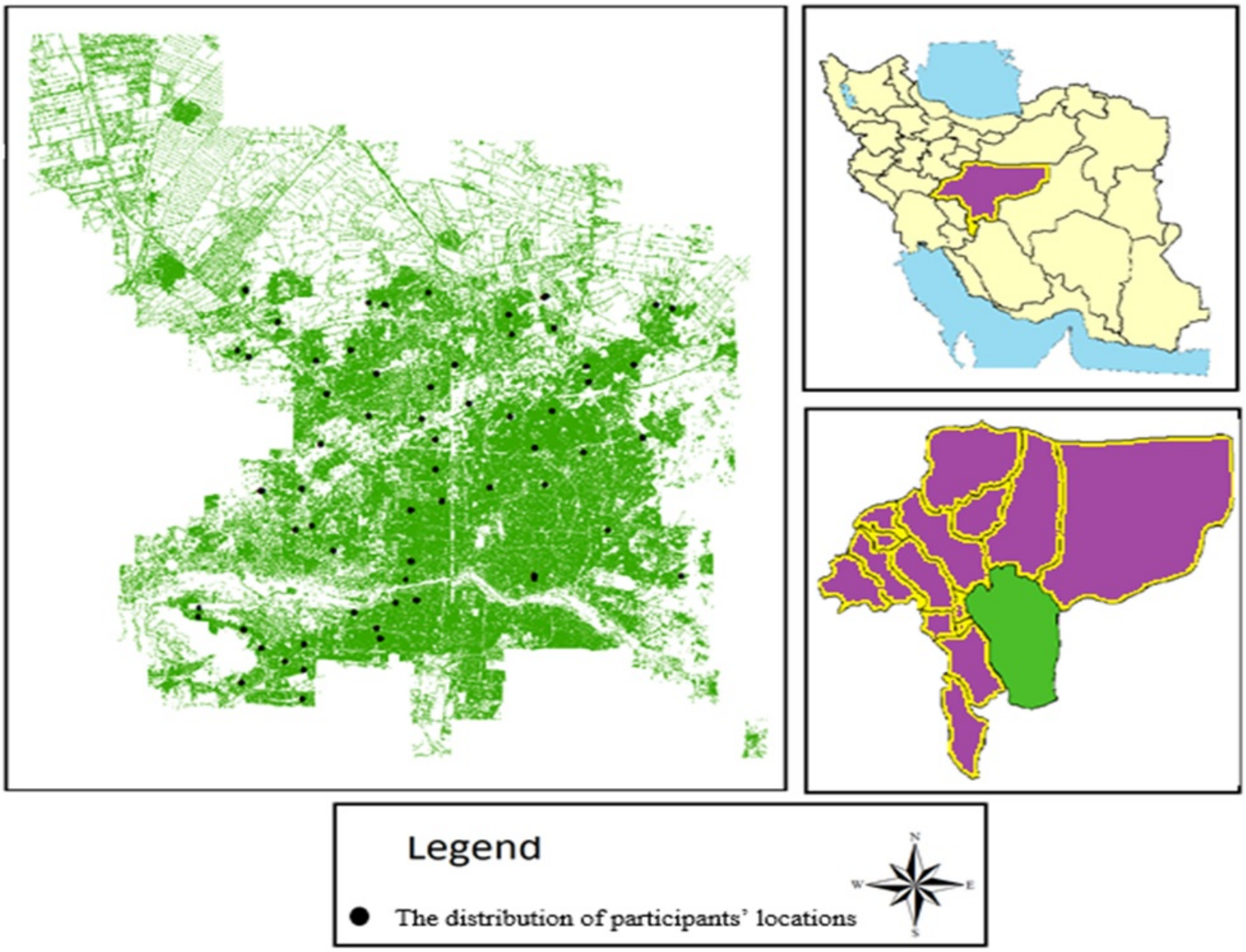

Figure 1

The distribution of participants' locations in this study