Determination of Heavy Metal Concentrations in Household Dusts in Irbid and Mafraq Cities, Jordan

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Abstract: *The objective of this study was to measure the concentrations of selected heavy metals (Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn) in house dust collected during the summer and winter seasons from Mafraq and Irbid cities, Jordan. The average concentrations (±SD) of the metals were found to be 66.8 (±22.4), 10.8 (±3.75), 366 (±108), 81.6 (±43.9), 7586 (±4304), and 37.2 (±15.4) mg/kg, for Pb, Cd, Zn, Cu, Fe, and Cr, respectively, in the summer season. The average concentrations (±SD) of the metals were found to be 92.8 (±65.5), 5.10 (±4.75), 305 (±160), 144 (±163), 5385 (±3812), 27.1 (±15.1), 18.7 (±3.70), 42.2 (±15.1), and 139 (±69.2) mg/kg, for Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn, respectively, in the winter season. The influence of different heating systems on the concertation of heavy metal was examined by comparing the results obtained in both summer and winter seasons. The concentrations of the metals in this study were compared with those reported by other researchers around the world. This study shows that the significant accumulation of heavy metals in house dust should be considered a serious risk to the health of residents in Mafraq and Irbid cities.*

Keywords: *house dust; pollution; Irbid; Mafraq; Jordan*

■ INTRODUCTION

Air is the most important and essential part of environmental elements because it receives contaminants coming from different natural and anthropogenic sources. Good indoor air quality is very important for survival and for a healthy life, but it is negatively affected by outdoor and indoor air pollution [1-6]. Air is defined as polluted when it contains toxic chemicals or compounds that result in undesirable changes in its physical, chemical, or biological properties [7]. Air pollution can be indoor or outdoor and can cause adverse effects on human health including respiratory diseases, high blood pressure, neurological disorders, cardiovascular disease, asthma, kidney pathology, allergies, and lung cancer [3-4,8-14]. Additionally, air pollution has become a major environmental problem with a significant impact on climate change [1,15-16].

During the last years, the quality of indoor air has attracted much attention as a serious worldwide health and environmental issue [9,12-13,16-19]. This is because people, especially children, infants, and older adults, spend most of their time indoor (e.g., in homes, offices, or classrooms), and much of this time, which was estimated at about 80–90% of the daily life, is generally spent in contact with contaminated surfaces like floors, desks, windows, or furniture [1-2,11,13,18,20-21]. Children and infants are the most sensitive groups that are more susceptible to air pollution compared to adults due to their hand-to-mouth behavior, small body size, developing lunges and neurological system, and active digestion system [1,3,21-22].

Dust is described as a very small size fine solid particulate matter that is settled on the surface of objects and on the ground [2,7,11]. The rate of deposition of dust particles is directly related to their sizes, so smaller size particles have lower deposition rates than larger particles, and hence they can stay suspended in the air for a long time [23]. In urbanized and industrialized areas, house dust is a heterogeneous and complex mixture of organic and inorganic particles of various origins, shapes, sizes, and toxicity [3,17,23]. House dust may originate either from natural sources like bedrocks erosion or from anthropogenic sources like infiltration of outdoor emissions from vehicles, soil, refineries, building materials, wildfires, fossil fuel burning, and industries into the indoor environment [2,3,9,13,24-26]. In addition, house dust may originate from different indoor activities like smoking, incense burning, cooking, cleaning, fibers, hairs, furniture material, aerosols, and paint pigments [4,6,9,13,16,24-25]. Furthermore, it is reported that the type of heating system has a significant role in indoor air pollution [24].

A wide variety of inorganic and organic toxic pollutants like polycyclic aromatic hydrocarbons, heavy metals, or pesticides can be transferred with the air from the street into the indoor environment and attach to house dust particles [11,27-28]. Among these pollutants, heavy metals are chemical compounds that normally occur in nature, but different anthropogenic sources can also introduce them in significant amounts in different environmental elements (water, soil, and air) [28-29]. According to the International Agency for Research on Cancer (IARC), heavy metals are classified as toxic and carcinogenic substances, and different health organizations such as World Health Organization (WHO), Food and Agriculture Organization (FAO), or the United States Environmental Protection Agency (US-EPA) have established the maximum permissible limits for these metals as reported by the recent literatures [18,30-31]. Heavy metals like iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), or magnesium (Mg) are essential micronutrients for human life but are toxic at elevated levels [31-34]. On the other side, toxic heavy metals like cobalt (Co), cadmium (Cd), lead (Pb), Nickel (Ni), or arsenic (As) are the most hazardous environmental pollutants when permissible concentration limits are exceeded [28-29,34-36]. In urban environments, heavy metals originate from different anthropogenic sources such as vehicle emissions, disposal of municipal and industrial wastes, fossil fuel combustion, wear of brake lining materials, and use of large quantities of fertilizers and metal-based pesticides [28,31,35,37]. Heavy metals are generally toxic, even at very low concentrations, due to their non-biodegradable nature, persistence in the environment, thermostable, carcinogenic nature, and long biological half-lives [28,31,33,38-39]. Toxic heavy metals can cause many health problems when consumed excessively. For example, accumulation of Pb in the human body can cause significant health problems such as damage to the kidneys, headache, respiratory disorders, chronic cardiovascular impairments, increased blood pressure, neurological impairments, muscle weakness, and mental disorders [33,40]. The toxic symptoms caused by Cd include lung cancer, kidney disfunction, bone diseases, reproductive deficiencies, and cancer [30,41]. High levels of Ni in the body lead to skin sensitivity, asthma, diarrhea, heart attack, lung fibrosis, chronic cough, kidney and cardiovascular infections, and low blood pressure [40,42].

In recent years, contamination of house dust by heavy metals has been studied extensively, and several metals such as Pb, Co, Ni, Cd, Zn, Cr, and others have been estimated [2,13,18,22,43]. The sources of heavy metals in house dust are varied and depend on several factors, such as the geographic location of the house, indoor activities, and outdoor pollution sources [22]. Several studies have indicated that heavy traffic, industrial emissions, contaminated soil, and building renovation materials are the major sources of heavy metals in house dust [11,13,22]. House dusts act as a medium for heavy metals deposition in the urban environment [44]. Thus, they are a major pathway of human exposure to toxic heavy metals [2,9,44]. This implies that heavy metals in house dust will accumulate to higher levels in the human body via inhalation of tiny size dust particles, via ingestion of contaminated food and drinks due to hand-to-mouth contact, or via skin absorption [2,11,13,18]. In this context, it is reported that house dust contaminated with high concentrations of Pb are a major source of Pb exposure for urban children [45]. Moreover, several environmental studies have reported the impact of indoor pollutants on the academic achievement and mental stability of children [3,4,22].

Jordan has been facing air pollution issues during the last few years due to rapid and uncontrolled industrialization and urbanization, especially due to extensive refugee migration from neighboring countries to different cities in Jordan. As a result, different environmental elements (air, water, and soil) have been heavily affected, especially in urbanized areas. For example, Al-Madanat et al. [25] determined the concentrations of eight heavy metals (Mn, Ti, Cu, Pb, Cr, V, Ni, and As) in indoor and outdoor dust samples collected from residential and commercial areas in Al-Karak city, Jordan. The authors reported that the concentrations of Cu, Cr, Ni in residential areas and Ti, Cu and Pb in commercial areas were higher in indoor dust compared with outdoor dust. They reported that Ni, Cr and Cu were found at a higher concentration in the indoor dust samples than the outdoor dust samples due to many household products such as leaded paint, furniture, and appliances of the residential area. The authors concluded that traffic emissions are the major sources of heavy metal pollution in Al-Karak city [25]. In 2015, Al-Momani [24] studied the influence of different heating systems (kerosene, natural gas, wood/olive residue, and central heating) on the concentrations of heavy metals (Al, As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Sr, V, Ti and Zn) in house dust samples collected from Ajlune city, Jordan. The author concluded that the levels of the studied metals in the analyzed dust samples followed the order of wood/olive residue samples > kerosene samples > natural gas samples > central heating samples > reference samples [24].

Although a large number of environmental studies have been performed to investigate heavy metal pollution in house dust, street dust, roadside surface soils, air, food, and agriculture soils in Jordan [24-25,29-31,35-36,43,46-48], there is a lack of information, on the best knowledge of the author, regarding the concentrations of heavy metals in house dust in Irbid and Mafraq cities, Jordan. Therefore, this is the first study reporting heavy metal concentrations of house dust collected during the summer and winter seasons from Irbid and Mafraq cities in Jordan. These cities were selected for this study because they have been facing serious air pollution due to rapid industrial and population growth, which may also highly contribute to indoor air pollution in these cities. The main objectives of this study are (i) to estimate the concentrations of selected heavy metals (Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn) in house dust samples collected from different locations during the summer and winter seasons including industrial zone (Irbid), commercial zone (Irbid), residential zone (Irbid), Irbid-Mafraq highway, commercial zone (Mafraq), and residential zone (Mafraq), Jordan, (ii) to investigate the influence of different heating systems (kerosene, gas, central heating, or wood) on the concentrations of heavy metals in house dust samples, and (iii) to compare the results obtained in this study with similar studies performed in Jordan and in neighboring countries and other countries in the world.

■ EXPERIMENTAL SECTION

Materials

All chemicals and reagents used in this study were of analytical grade. A multi-element standard solution of 1000 mg/L of each tested metal (Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn) was obtained from Merck KGaA, Darmstadt, Germany. Nitric acid (HNO_3, 70% v/v, extra pure-trace analysis grade) was obtained from Carlo Erba Reagent, France. Hydrogen peroxide (H_2O_2, 35% w/w, extra pure) and hydrofluoric acid (HF, 40%) were obtained from Union LAR. Supplies. Ultrapure deionized water was used to prepare standard and sample solutions.

Instrumentation

The instrumentations used in this study were flame atomic absorption spectrometry (Varian Spectra AA-55B, Australia) equipped with a deuterium background correction was used for measuring the concentrations of Pb, Cd, Cu, Zn, Fe, Cr, Co, Ni, and Mn in the collected dust samples. Measurements were made using the specific hollow cathode lamp for each metal. The proper wavelength and the slit width were adjusted. Analysis using FAAS was carried out at the most sensitive wavelength of the examined metals.

Procedure

Study area

The study area is located on the northern side of Amman, the capital of Jordan. Mafraq city (142401 population, 26551 km^2 total area) is around 60 km north of Amman at the crossroads of Iraq to the east and Syria to the north. Mafraq has a hot and semi-arid climate in which most of the rainfall is in the winter season. The prevailing wind direction in Mafraq city is from west to east. During the last few years, Mafraq has witnessed significant commercial, industrial, and residential activities due to rapid industrialization and due to extensive migration of refugees from neighboring courtiers. New agricultural, plastic, concrete, food, fertilizers, and detergent factories represent the recent industrial development in this city. In addition, Mafraq city is surrounded by desert from all sides; thus, it is always subjected to dust storms throughout the year. During the last few years, dust storms have been added to Mafraq as an anthropogenic source of air pollution. Irbid city (951452 populations, 1572 km^2 total area) is around 80 km north of the capital of Jordan, Amman. Irbid is the second largest population, and it has the highest population density in Jordan. The Irbid city is a major ground transportation hub between Amman, Syria, to the north and Mafraq to the east. The climatic conditions in Irbid are characterized by long, hot, dry summers and short, cool, rainy winters. New plastic, cement, food, textile, steel, and detergent factories represent the recent industrial development in this city.

In the present study, dust samples from different houses were collected during the summer and winter seasons from six sampling sites, as shown in Fig. 1. The first sampling site is the industrial zone (Irbid). It is a highly crowded area located near the main industrial area in Irbid city. This sampling site is characterized by having a high traffic volume, garage repairs, wear of brake lining, shopping centers, and gas stations. The second sampling site is the commercial zone (Irbid). It is a highly crowded urban area close to the city center of Irbid city and witnessing a large commercial movement. This sampling site has a large number of shopping centers and high traffic intensity. The third sampling site is the residential zone (Irbid) which represents the Hawara area. It is one of the oldest and most densely populated areas in the Irbid city. The fourth sampling site represents the area along the Irbid-Mafraq highway. This sampling site is characterized by a high traffic volume of 24 h a day. The fifth sampling site is the commercial zone (Mafraq), which is a highly crowded area that represents the center of Mafraq city. This

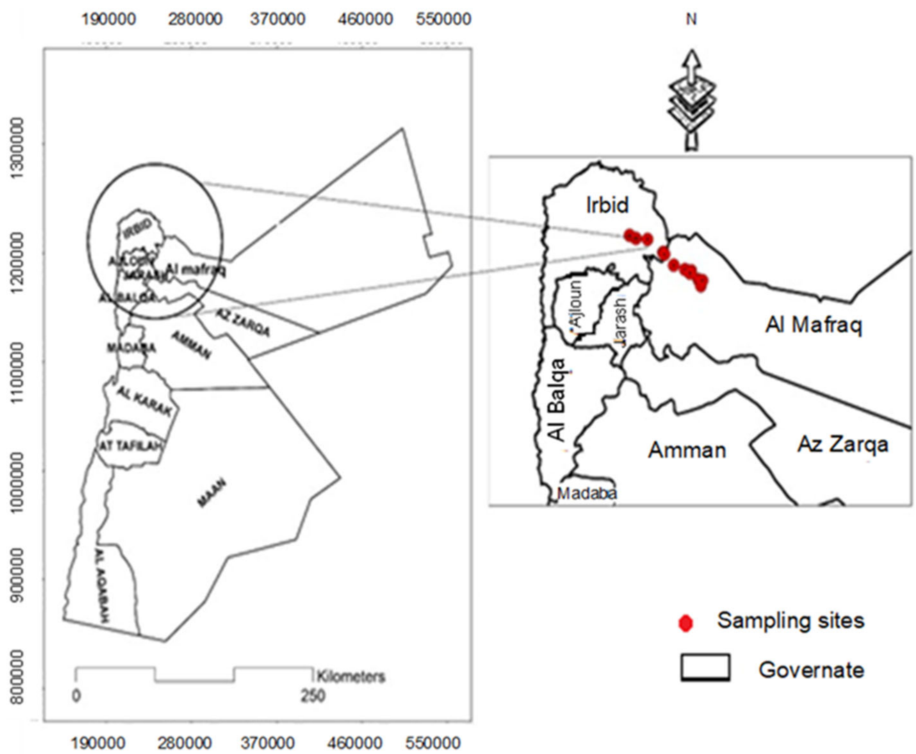

Fig 1. Irbid and Mafraq map shows the study area and sampling sites

sampling site has two main bus stations and a large number of shopping centers and gas stations. The sixth sampling site is the residential zone (Mafraq), which is composed of officers and the Al Hussein neighborhood. These sampling sites are the oldest areas in the city, with severe overcrowding and high population density.

Sample collection and pretreatment

In this study, a total of 88 dust samples were collected from six sampling sites during the summer season (June–August 2019) including the industrial zone (Irbid), commercial zone (Irbid), residential zone (Irbid), Irbid-Mafraq highway, commercial zone (Mafraq), and residential zone (Mafraq), Jordan. In addition, 30 dust samples were recollected from the same houses using different heating systems during the winter season. In order to make a comparison of the results based on the type of heating system, all dust samples were collected in the middle of the winter season (January 2020). This approach will reduce the influences of different anthropogenic sources (e.g., indoor human activities and traffic emissions) on the concentration of the studied metals in the collected dust samples.

In this study, dust samples were collected from all parts of the house (bedrooms, kitchen, living room, etc.) using vacuum cleaners. In order to increase the accuracy of the analysis method and reduce the risk of contamination, all required precautions were taken during sample collection and preparation as follows: (i) new vacuum cleaner bags were used for samples collection, and the vacuum cleaners were permanently cleaned before collecting the next dust sample; (ii) dust samples were collected from the inner bag of the vacuum cleaner, emptied into labeled polyethylene bags, and prepared in a clean laboratory; (iii) a trace element grade nitric acid HNO_3 (70% extra-pure HNO_3) was used for digestion and solution preparation; and (iv) all glassware apparatuses were effectively cleaned and previously soaked in 20% (v/v) HNO_3 for 24 h, then rinsed with deionized water and dried prior to use.

Sample preparation

All collected dust samples were sieved through a 2-mm plastic mesh to remove large impurities such as hair, plastic parts, cigarettes, or glasses. The sieved samples were dried at 85 °C for about 24 h to a constant weight. The dried dust samples were then homogenized with a mortar and pestle, stored in clean, and sealed polyethylene bags for subsequent analysis. A microwave digestion system (Anton Paar, Multiwave Eco.) was used to extract metal ions from the collected dust samples. A mass of 0.5 g of each sieved dust sample was accurately weighed and transferred into a labeled microwave Teflon vessel. To each vessel, 8 mL of HNO_3 (70% extra-pure HNO_3), 2 mL HF, and 2 mL H_2O_2 were then added. The mixture was allowed to stand in the vessel for 10 min prior to sealing. The microwave was operated at a power of 850 W, and the vessels were heated to 200 °C over 10 min and then held at 200 °C for 10 min. At the end of the digestion procedure, the solutions were filtered and quantitatively transferred into 50 mL volumetric flasks and brought to volume with deionized water. Each extract solution was analyzed by using FAAS.

Calibration

Working standard solutions of each studied metal were freshly prepared by diluting an appropriate aliquot of standard stock solution of 1000 mg/L using 1% (v/v) HNO_3. The method of linear least squares was used for the calculation of correlation coefficient (R^2), slope with standard error ($m\pm S_b$), and intercept with standard error ($a\pm S_a$). From the linear calibration curve, the limit of detection (LOD, mg/kg) and limit of quantitation (LOQ, mg/kg) were calculated using Eq. (1) and (2) [31,35]:

$$\mathrm{LOD} = \frac{3.3 \times S_a}{m} \tag{1}$$

$$\mathrm{LOQ} = \frac{10 \times S_a}{m} \tag{2}$$

where m is the slope of the calibration curve, and S_a is the standard error of the y-intercept of a regression line.

Quality control and assurance

In an analysis of real samples, analysis of blank is the most important way to detect and correct any contamination problem [24]. In this study, the results obtained for the dust samples were blank-corrected to obtain the exact concentration of each metal in the collected dust samples. With the aim to assess the accuracy and reproducibility of the instrumental method used for the analysis of the studied metals in the dust samples, a quality assurance program was employed, and standard reference materials for these metals were analyzed. In this context, three standard reference materials, SRM-1646a (Estuarine Sediment), SRM-1633b (Trace elements in coal fly ash), and SRM-2702 (Inorganics in marine sediment), were prepared in the same manner as for the original dust samples and analyzed along with dust samples. The results obtained in this study indicated that the measured values for the examined metals are in good agreement with their certified values provided by the National Institute of Standards and Technology (NIST) (Table 1). These results confirm the good accuracy, validity, and robustness of the FAAS analysis method used for the determination of heavy metal concentration in the investigated dust samples.

■ RESULTS AND DISCUSSION

Limit of Detection and Limit of Quantitation

The LOD and LOQ values obtained for each metal were summarized in Table 1. The calibration curves of the studied metals were linear with correlation coefficients $R^2 > 0.97$ (Table 1). The LOD values of the studied metals ranged between 0.0085 mg/kg for Cu and 0.2277 mg/kg for Fe, while LOQ ranged between 0.0284 and 0.7589 mg/kg for both metals, respectively (Table 1). The low LOD and LOQ demonstrate the sensitivity of the FAAS method used for the metal analysis in the dust samples.

Metal Concentrations in House Dust Samples

A total of 88 house dust samples were collected during the summer season, and 30 dust samples were re-collected from the same houses using different heating systems during the winter season. These samples were evaluated for determination of the concentrations of six heavy metals (Pb, Cd, Zn, Cu, Fe, and Cr) in the summer season, and nine heavy metals (Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn) in the winter season using FAAS. The average concentrations (mean ± SD) of the studied metals are summarized in Tables 2 and 3 (for detailed data about the concentration of the investigated metals in all sampling sites, see Tables S1 and S2). With the aim to show the influence of the heating system on the concentration of heavy metal in dust samples, the summer-to-winter ratio (average concentration of metal in the summer season/average concentration of metal in the winter season) was calculated for each metal and listed in Table 3. The average concentrations (±SD) of the studied metals found in the analyzed dust samples in the summer season were found to be 66.8 (±22.4), 10.8 (±3.75), 366 (±108), 81.6 (±43.9), 7586 (±4304), and 37.2 (±15.4) mg/kg for Pb, Cd, Zn, Cu, Fe, and Cr, respectively (Table S1). The average concentrations (±SD) of the investigated metals found in the analyzed dust samples in the winter season were found to be 92.8 (±65.5), 5.10 (±4.75), 305 (±160), 144 (±163), 5385 (±3812), 27.1 (±15.1), 18.7 (±3.7), 42.2 (±15.1), and 139 (±69.2) mg/kg, for Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn, respectively (Table S2). The average concentrations

Table 1. Limit of detection (LOD), limit of quantitation (LOQ), correlation coefficient (R^2), and percent recovery (based on the three standard reference materials) of each metal

Heavy metal	LOD (mg/kg)	LOQ (mg/kg)	R^2	SRM-1646a Recovery (%)	SRM-1633b Recovery (%)	SRM-2702 Recovery (%)
Cu	0.0085	0.0284	0.9994	93	97	96
Cd	0.0121	0.0303	0.9989	99	95	93
Zn	0.0195	0.0653	0.9894	98	94	94
Pb	0.1050	0.3504	0.9991	97	93	92
Fe	0.2277	0.7589	0.9911	97	95	93
Cr	0.0310	0.1030	0.9993	98	95	95
Co	0.0188	0.0627	0.9987	96	93	95
Ni	0.0289	0.0963	0.9996	95	93	97
Mn	0.0089	0.0299	0.9997	93	96	98

Table 2. Statistical heavy metal concentration (mg/kg) in different areas of Irbid and Mafraq cities, Jordan, during the summer season

Location	Pb	Cd	Zn	Cu	Fe	Cr
Industrial zone-Irbid (N = 15)						
Average	90.2	9.10	391	96.9	9216	44.5
(±SD)	(±27.0)	(±3.88)	(±148)	(±73.4)	(±6439)	(±20.0)
C.V (%)	30	43	40	76	70	45
Range	45–150	4–14	146–686	29–339	4553–31062	31–110
Commercial zone-Irbid (N = 15)						
Average	67.2	11.2	387	91.9	7069	37.5
(±SD)	(±12.1)	(±4.00)	(±82.4)	(±36.1)	(±2286)	(±12.8)
C.V (%)	18	36	21	39	32	34
Range	44–96	5–16	220–533	34–150	3907–11270	23–71
Residential zone-Irbid (N = 14)						
Average	49.1	12	362	82.6	5852	31.1
(±SD)	(±12.7)	(±3.50)	(±82.5)	(±32.6)	(±2565)	(±8.12)
C.V (%)	26	29	23	39	44	26
Range	32–81	4–17	159–493	40–162	1626–10142	18–46
Irbid-Mafraq Highway (N = 14)						
Average	70.6	11.1	288	65.4	10092	42.1
(±SD)	(±23.0)	(±3.97)	(±127)	(±39.0)	(±5989)	(±21.3)
C.V (%)	33	36	44	59	60	51
Range	46–120	5–17	123–582	29–164	3958–23649	22–86
Commercial zone-Mafraq (N = 15)						
Average	59.5	9.50	395	89.6	5981	30.6
(±SD)	(±22.3)	(±3.16)	(±78.7)	(±36.7)	(±2572)	(±11.0)
C.V (%)	37	33	20	41	43	36
Range	35–120	4–14	290–538	38–150	3022–13194	11–52
Residential zone-Mafraq (N = 15)						
Average	63.7	11.7	364	62.4	7357	37.3
(±SD)	(±10.5)	(±3.50)	(±86.7)	(±21.0)	(±2682)	(±11.7)
C.V (%)	16	30	24	34	36	31
Range	44–80	5–16	283–635	6–89	3876–12022	18–62

of the studied metals in the analyzed house dust samples followed the order of Fe > Zn > Cu > Pb > Cr > Cd in the summer season, while these values in the winter season followed the order of Fe > Zn > Cu > Mn > Pb > Ni > Cr > Co >Cd (Tables 2 and 3). As a general trend, it is observed that the standard deviations are high for most of the studied metals. The high standard deviation values are expected because of the large variability in the sampling sites and variations in the chemical nature of the sampling site. Currently, there are no standard values for the maximum permissible limits of heavy metals in dust. Therefore, the FAO/WHO, Dutch, Nigeria, and other guidelines for soil were used as references to estimate the contamination levels of the studied heavy metals in dust [49-53].

Lead (Pb)

According to the results presented in Tables 2 and 3, the average concentrations of Pb in the analyzed dust samples ranged from 49.1 to 90.2 mg/kg with a mean of 66.8 mg/kg in the summer season and from 68.0 to 121 mg/kg with a mean of 92.8 mg/kg in the winter season (for details refer to Tables S1 and S2). The maximum Pb concentration permitted in the soil is

Table 3. Mean (±SD) of heavy metals (mg/kg) and S/W ratio in house dust samples collected from all sampling sites during the winter season

Heavy metal	Mean (±SD) S/W					
	Industrial zone (Irbid)	Commercial zone (Irbid)	Residential zone (Irbid)	Irbid-Mafraq highway	Commercial zone (Mafraq)	Residential zone (Mafraq)
Pb	86 (±27) 1.1	108 (±63) 0.62	68 (±28) 0.72	121 (±141) 0.58	86 (±21) 0.69	84 (±23) 0.76
Cd	7.0 (±5.7) 1.3	2.7 (±0.6) 4.1	2.5 (±0.7) 4.8	6.8 (±6.8) 1.6	3.4 (±3.4) 2.8	4.4 (±5.3) 1.8
Zn	336 (±207) 1.2	259 (±157) 1.5	278 (±44.3) 1.3	304 (±149) 0.95	253 (±148) 1.6	363 (±208) 1.0
Cu	152 (±93.8) 0.64	162 (±136) 0.57	192 (±133) 0.43	58.0 (±19.3) 1.12	94.0 (±64.5) 0.95	215 (±261) 0.29
Fe	2487 (±2585) 3.7	4245 (±3327) 1.7	3442 (±1650) 1.7	5838 (±4265) 1.73	4328 (±2771) 1.4	7579 (±4553) 0.97
Cr	17 (±4.2) 2.6	33 (±18) 1.2	21 (±2.1) 1.5	27 (±15) 1.6	21 (±5.8) 1.4	34 (±21) 1.1
Co	19 (±1.8)	16.5 (±4.8)	16 (±2.4)	19 (±3.7)	20 (±3.8)	19 (±4.2)
Ni	41 (±10)	55 (±32)	38 (±17)	41 (±6.5)	45 (±16)	39 (±13)
Mn	79 (±17)	73 (±7.9)	108 (±10)	139 (±35)	166 (±108)	163 (±60)

S/W = Average concentration of metal in the summer season/average concentration of metal in the winter season

100 mg/kg according to FAO/WHO [49] and 85 mg/kg according to Dutch and Nigeria standards [50,52]. These findings indicate that the average concentrations of Pb in the analyzed dust samples were found to be within the permissible limits according to these guidelines. The highest Pb concentration was found in the industrial zone (Irbid) with a mean of 90.2 mg/kg followed by the Irbid-Mafraq highway during the summer season (Table 2). This is expected because of the proximity of the studied houses to the industrial zone and due to the high traffic density at the Irbid-Mafraq highway. The average concentrations of Pb in the analyzed dust samples followed the order of industrial zone (Irbid) > Irbid-Mafraq highway > commercial zone (Irbid) > residential zone (Mafraq) > commercial zone (Mafraq) > residential zone (Irbid) in the summer season (Table 2, Fig. 2). The elevated levels of Pb found in the analyzed dust samples could be due to the indoor sources like leaded paint, spills from batteries, cable cover, pigments, or furnishing, and due to infiltration of contaminated dust particles from the outdoor sources like combustion of leaded fuel, burning gas for heating, tires and brake abrasions, plating, gasoline additives, or engine wear [2,12,25-26,33,54-55]. The summer-to-winter ratio of Pb was found to be less than 1.0 in most sampling sites (Table 3). This means that the average concentration of Pb was higher in the winter season than in the summer season. These results indicate that there is a significant influence of different heating systems on the concentrations of Pb found in the analyzed dust samples. In addition, it is observed that there is an increase in the concentration of Pb in the dust samples collected from the houses using wood for heating compared to the houses using other heating systems. These results were in agreement with the conclusion reported by Al-Momani et al. [24]. The author reported in his study that the type of heating system (e.g., wood/olive residue, kerosene, natural gas, and central heating) has a significant impact on the concentrations of the studied metals found in the house dust samples collected from Ajlune city, Jordan [24]. Compared to other studies, the average concentration of Pb in this study was higher than those found in Malaysia [56], Kingdom of Saudi Arabia [57], Turkey [26], China [38], and Jordan, Al-Karak city [25], but lower than those

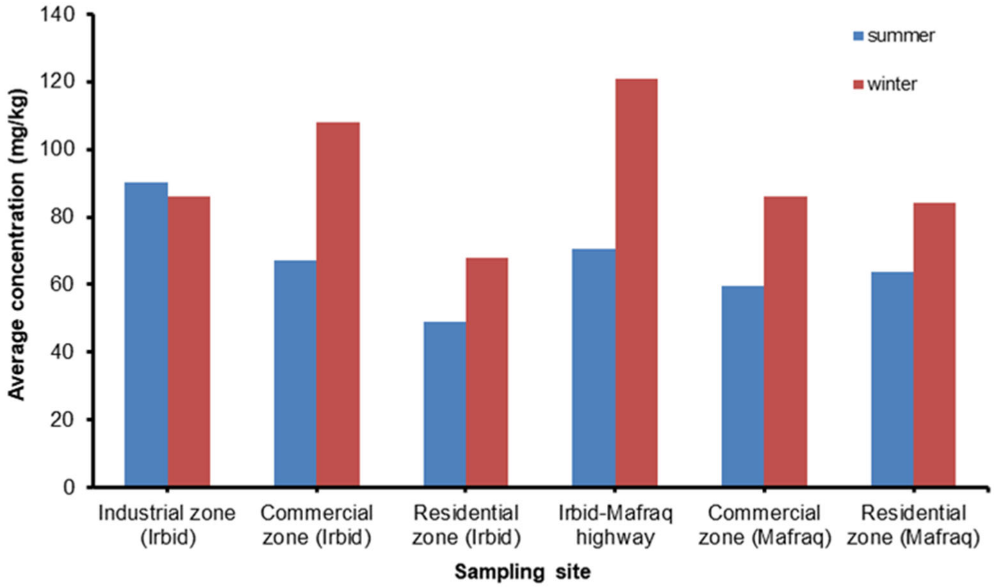

Fig 2. Average concentrations of Pb in the analyzed dust samples collected from the studied areas during the summer and winter seasons

found in Egypt [55], Australia [54], Canada [58], and Jordan, Amman city [43] as described in Table 4.

Cadmium (Cd)

Based on the results listed in Tables 2 and 3, the average concentrations of Cd in the analyzed dust samples ranged from 9.1 to 12 mg/kg with a mean of 10.8 mg/kg in the summer season and from 2.5 to 7.00 mg/kg with a mean of 5.10 mg/kg in the winter season (for details refer to Tables S1 and S2). The maximum Cd levels permitted in soil are 3.0 mg/kg according to WHO/FAO and EU [49,52] and 0.8 mg/kg according to Dutch and Nigeria standards [50-52]. These findings confirm that the average concentrations of Cd in the analyzed dust samples were found to be above the permissible limits set by these standards. The highest concentration of Cd was found in the residential zone (Irbid) with a mean of 12 mg/kg during the summer season (Table 2). The average concentrations of Cd in the analyzed dust samples followed the order of residential zone (Irbid) > residential zone (Mafraq) > commercial zone (Irbid) > Irbid-Mafraq highway > commercial zone (Mafraq) > industrial zone (Irbid) in the summer season (Table 2, Fig. 3). The elevated levels of Cd found in the analyzed dust samples could be due to the indoor sources such as

Table 4. Average concentrations of selected heavy metals (mg/kg) in house dust samples collected from Irbid and Mafraq cities, Jordan in the summer and winter seasons compared with other studies in different countries

Country	Pb	Cd	Zn	Cu	Fe	Cr	Co	Ni	Mn	Reference
Jordan, Amman city	206	4.50	3104	160	-	77.0	23.0	47.0	304	[43]
Jordan, Al-Karak city	52.3	-	-	74.0	-	62.1	-	40.0	251	[25]
Malaysia	31.2	-	149	30.2	4225	16.9	-	9.00	-	[56]
Kingdom of Saudi Arabia	23.0	-	141	52.8	17962	-	7.20	-	260	[57]
Australia	389	4.40	657	147	5850	83.6	-	27.2	76.1	[54]
Canada	406	6.50	717	206	14135	86.7	8.90	62.9	269	[58]
Egypt, Alexandria (March 2016)	260	0.77	771	141	-	29.2	3.20	25.1	237	[55]
Turkey, Ankara	27.5	0.35	263	65.7	-	23.8	2.25	32.3	65.9	[26]
China	40.7	2.29	166	16.9	-	19.8	-	-	-	[38]
Jordan (summer)	66.8	10.8	366	81.6	7586	37.2	-	-	-	This study
Jordan (winter)	92.8	5.10	305	144	5385	27.1	18.7	42.2	139	This study

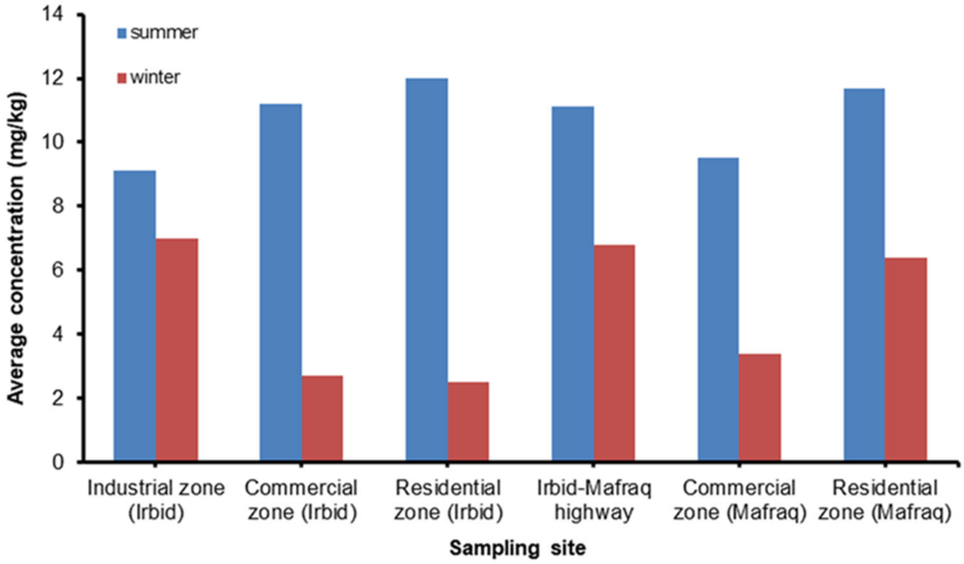

Fig 3. Average concentrations of Cd in the analyzed dust samples collected from the studied areas during the summer and winter seasons

smoking, spills from batteries, or building painting, and due to the infiltration of contaminated dust particles from the outdoor sources like combustion of leaded gasoline, Ni-Cd batteries, corrosion of brake linings, or old car tires [2,8-9,38,41,59]. The summer-to-winter ratio of Cd was found to be greater than 1.0 in all sampling sites (Table 3). This means that the average concentration of Cd was higher in the summer season than in the winter season, which confirms that there is no strong influence of different heating systems on the concentrations of Cd detected in the analyzed dust samples. Compared to other studies, the average concentration of Cd determined in this study was much higher than those reported by other researchers, as shown in Table 4.

Zinc (Zn)

The results in Tables 2 and 3 show that the average concentrations of Zn in the analyzed house dust samples ranged from 288 to 395 mg/kg with a mean of 366 mg/kg in the summer season and from 253 to 363 mg/kg with a mean of 305 mg/kg in the winter season (for details refer to Tables S1 and S2). The maximum permissible Zn limit in soil recommended by WHO/FAO is 300 mg/kg [49], while Dutch and Nigeria standards set this level at 140 mg/kg [50,52]. This implies that the average concentrations of Zn in the analyzed dust samples were found to be above the permissible limits set by these health organizations. The highest concentration of Zn was found in the commercial zone (Mafraq) with a mean of 395 mg/kg followed by the industrial zone (Irbid) during the summer season. This is because of the proximity of the studied houses to the pollution sources at these sampling sites (Table 2). The average concentrations of Zn in the analyzed dust samples followed the order of commercial zone (Mafraq) > Industrial zone (Irbid) > commercial zone (Irbid) > residential zone (Mafraq) > residential zone (Irbid) > Irbid-Mafraq highway in the summer season (Table 2, Fig. 4). The elevated levels of Zn in the analyzed dust samples might be due to the indoor human activities such as alloys, building materials, rubber, paints, or wood preservatives, and due to the infiltration of contaminated dust particles from the outdoor sources like wear and tear of automobile tires, traffic emission, brake linings, corrosion of galvanized vehicular parts, or waste combustion [7,51,60-61]. With the exception of the dust samples collected from the Irbid-Mafraq highway, the results showed that the summer-to-winter ratio of Zn was found to be greater than 1.0 in all sampling sites (Table 3). These findings reveal that there is no strong influence of different heating systems on the concentrations of Zn found in the analyzed dust samples. The average concentration of Zn obtained in

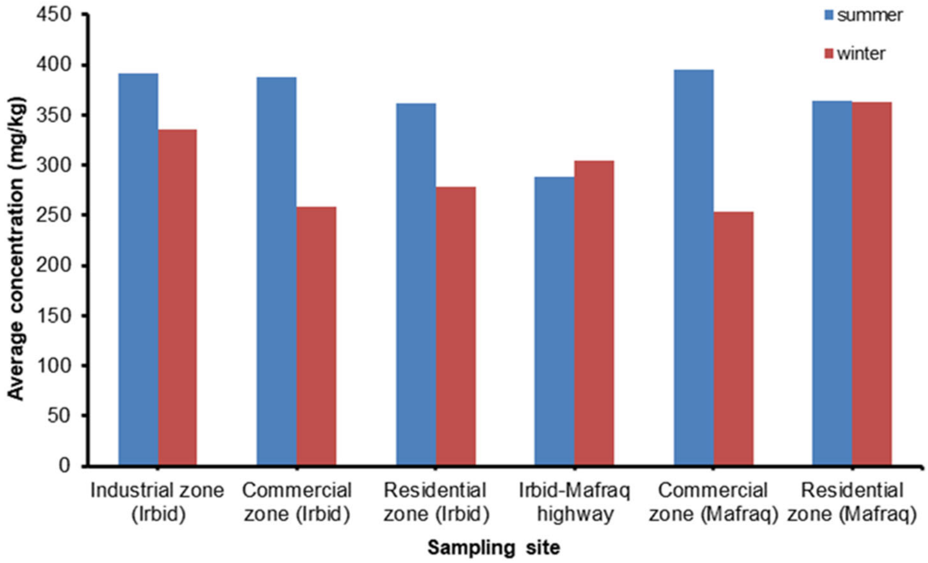

Fig 4. Average concentrations of Zn in the analyzed dust samples collected from the studied areas during the summer and winter seasons

this study was higher than those found in the Kingdom of Saudi Arabia [57], China [38], Turkey [26], and Malaysia [56], but lower than those found in Australia [54], Egypt [55], Canada [58], and Jordan, Amman city [43] as shown in Table 4.

Copper (Cu)

According to the results presented in Tables 2 and 3, the average concentrations of Cu found in the analyzed house dust samples ranged from 62.4 to 96.9 mg/kg with a mean of 81.6 mg/kg in the summer season and from 58.0 to 215 mg/kg with a mean of 144 mg/kg in the winter season (for details refer to Tables S1 and S2). The maximum Cu concentration permitted in the soil is 100 mg/kg according to WHO/FAO [49] and 36 mg/kg according to Dutch and Nigeria standards [50,52]. These findings reveal that the average concentrations of Cu detected in the dust samples in the summer season were found to be within the permissible limits set by WHO/FAO, but higher than those set by Dutch and Nigeria standards. Additionally, the average concentrations of Cu found in the dust samples during the winter season exceeded the permissible limits set by these health organizations. The highest concentration of Cu was found in the industrial zone (Irbid), where Pb and Cr were also at the maximum during the summer season (Table 2). This is expected because Cu is mostly derived from the car components, tire abrasion, lubricants corrosion of cars, and engine wear [25,35,59,61]. In addition, it is reported that power wires made from copper are considered major sources of Cu in residential areas [25,35]. The average concentrations of Cu in the analyzed house dust samples followed the order of Industrial zone (Irbid) > commercial zone (Irbid) > commercial zone (Mafraq) > residential zone (Irbid) > Irbid-Mafraq highway > residential zone (Mafraq) in the summer season (Table 2, Fig. 5). The elevated levels of Cu found in the analyzed dust samples could be due to the indoor sources like interior paint, metal objects, or building materials, and due to the infiltration of dust particles from the outdoor sources like tire wear, car lubricant wear, brush, or brake dust [12,56,61]. With the exception of the dust samples collected from the Irbid-Mafraq highway, the summer-to-winter ratio of Cu was found to be less than 1.0 in all sampling sites (Table 3). These results confirm that there is a significant influence of different heating systems on the concentrations of Cu found in the analyzed dust samples. In addition, it is observed that there is an increase in the concentration of Cu in the dust samples collected from the houses using wood for heating compared to the houses using other different heating systems. Compared to other studies, the average concentration of Cu obtained in this study

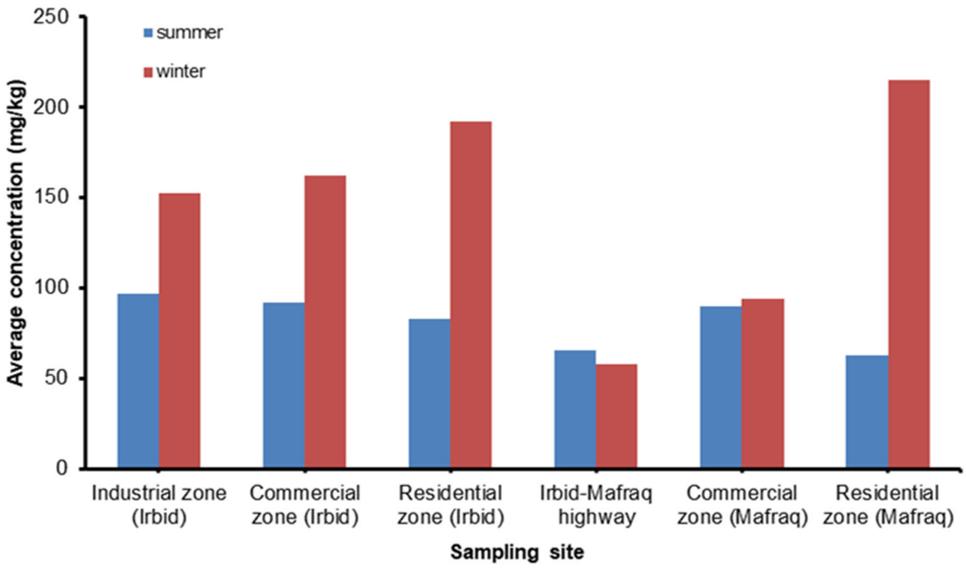

Fig 5. Average concentrations of Cu in the analyzed dust samples collected from the studied areas during the summer and winter seasons

was higher than those found in the Kingdom of Saudi Arabia [57], China [38], Turkey [26], Malaysia [56], and Jordan, Karak city [25], but lower than those found in Egypt [55], Australia [54], Canada [58], and Jordan, Amman city [43] as described in Table 4.

Chrome (Cr)

For the concentrations of Cr in the analyzed house dust samples, the results in Tables 2 and 3 show that the average concentrations of Cr ranged from 30.6 to 44.5 mg/kg with a mean of 37.2 mg/kg in the summer season and from 17.0 to 34.0 mg/kg with a mean of 27.1 mg/kg in the winter season (for details refer to Tables S1 and S2). The maximum concentration of Cr permitted in the soil is 100 mg/kg according to WHO/FAO, Dutch, and Nigeria standards [49-50,52]. These results indicate that the average concentrations of Cr found in the analyzed dust samples were found to be within the permissible limits set by these health organizations. The highest Cr concentration was found at the industrial zone (Irbid) with a mean of 44.5 mg/kg followed by the Irbid-Mafraq highway during the summer season (Table 2, Fig. 6). As reported in the literature, the elevated levels of Cr in house dust samples might be attributed to chrome steel manufacturing, tire abrasion, engine wear, using metal-based pesticides, combustion of fossils fuels, or coal burning [2,12,35]. The average concentrations of Cr found in the analyzed dust samples followed the order of Industrial zone (Irbid) > Irbid-Mafraq highway > commercial zone (Irbid) > residential zone (Mafraq) > residential zone (Irbid) > commercial zone (Mafraq) in the summer season (Table 2, Fig. 6). The elevated levels of Cr found in the analyzed dust samples could be due to the indoor activities such as interior paint, metallic objects, building materials, corrosion of appliances, or using of chrome-plated household products, and due to the infiltration of dust particles from the outdoor sources like vehicle emissions, vehicle lubricant wear, engine wear, or brake dust [2,13]. The results show that the summer-to-winter ratio of Cr was found to be greater than 1.0 in all sampling sites, indicating that there is no strong influence of different heating systems on the concentrations of Cr found in the analyzed house dust samples (Table 3). Compared to other studies, the average concentration of Cr in this study was higher than those found in Malaysia [56], China [38], Turkey [26], and Egypt [55] but lower than those found in Canada [58], Australia [54], Jordan, Amman city [43], and Jordan, Al-Karak city [25] as shown in Table 4.

Iron (Fe)

The results in Tables 2 and 3 show that the average concentrations of Fe determined in the analyzed dust samples ranged from 5852 to 10092 mg/kg with a mean

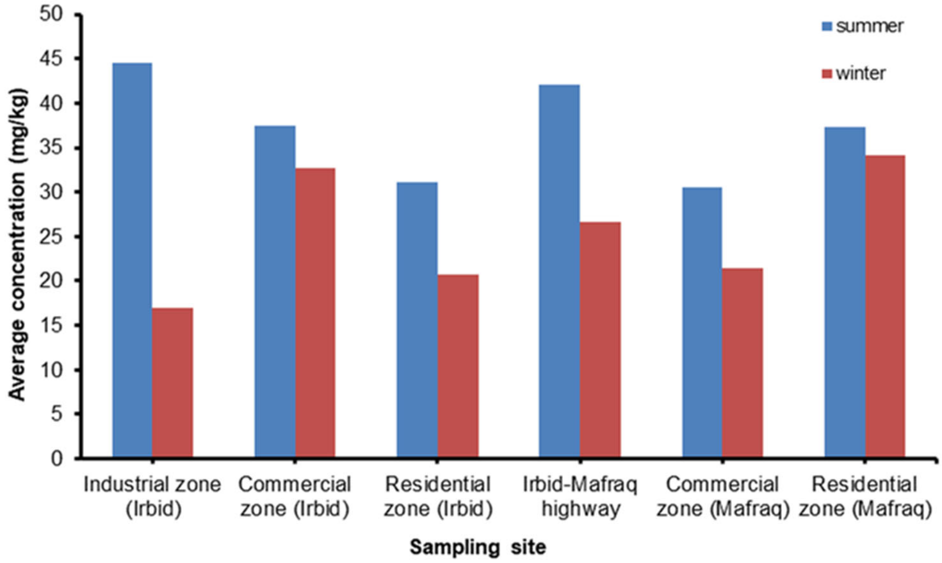

Fig 6. Average concentrations of Cr in the analyzed dust samples collected from the studied areas during the summer and winter seasons

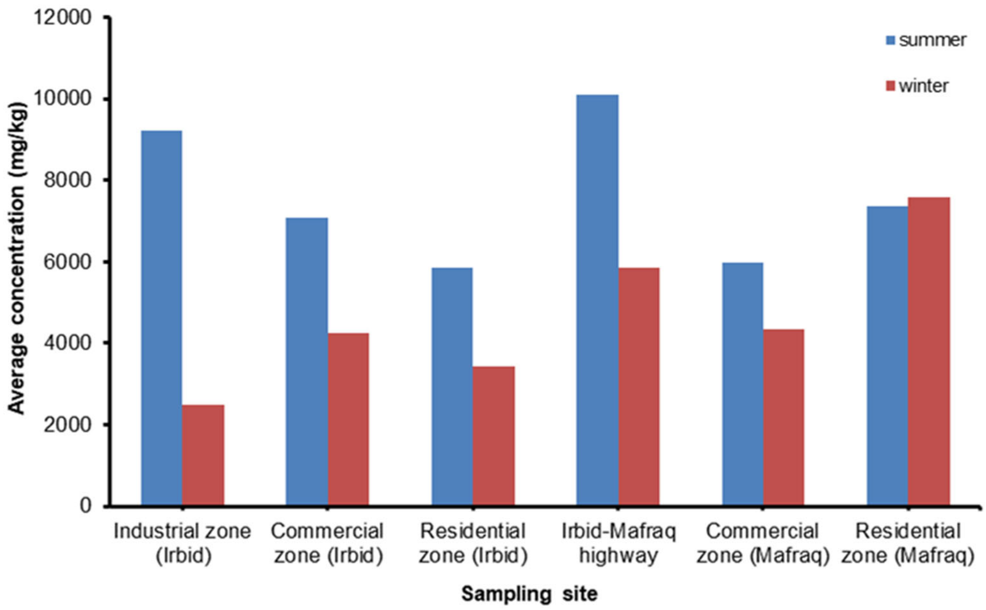

Fig 7. Average concentrations of Fe in the analyzed dust samples collected from the studied areas during the summer and winter seasons

of 7586 mg/kg in the summer season and from 2487 to 7579 mg/kg with a mean of 5385 mg/kg in the winter season (for details refer to Tables S1 and S2). The highest Fe concentration was found at the Irbid-Mafraq highway with a mean of 10092 mg/kg during the summer season, which might be attributed to the presence of the steel factory in Irbid city. The average concentrations of Fe in the analyzed dust samples followed the order of Irbid-Mafraq highway > industrial zone (Irbid) > residential zone (Mafraq) > commercial zone (Irbid) > commercial zone (Mafraq) > residential zone (Irbid) in the summer season (Table 2, Fig. 7). In this study, there are several anthropogenic sources that increase the concentration of Fe in the analyzed dust samples such as the presence of the steel factory (Howara city, Irbid), brake linings, and vehicle wear [57]. The summer-to-winter ratio of Fe was found to be greater than 1.0 in most sampling sites, which confirms that there is no significant influence of different heating systems on the concentrations of Fe found in the analyzed dust samples. The average concentration of Fe determined in this study was higher than those found in Malaysia [56] and Australia [54] but lower than those found in the Kingdom of Saudi Arabia [57] and Canada [58], as shown in Table 4.

Cobalt (Co)

According to the results presented in Table 3, the average concentrations of Co found in the analyzed house dust samples ranged from 16.0 to 20.0 mg/kg with a mean of 18.7 mg/kg in the winter season (for details refer to Table S2). According to the Dutch and Nigeria standards, the maximum Co levels permitted in soil are 9.0 and 20 mg/kg, respectively [50,52]. These results indicate that the average concentrations of Co in the dust samples were found to be within the permissible limit set by Nigeria standards but exceeded the permissible limit set by Dutch standards. The elevated levels of Co found in the analyzed dust samples might be due to indoor sources such as building materials, cigarette ash, combustion devices, or paints, and due to the infiltration of contaminated dust particles from outdoor sources like combustion of leaded fuel, wearing out of car tires, burning coal, oil leakage, or vehicle emissions [12,26,57]. As shown in Table 3, there was no significant difference between the average concentrations of Co detected in the different sampling sites. However, the highest concentration of Co was found in the commercial zone (Mafraq), where Mn is also at its maximum during the winter season (Table 3). This is expected because Co is mainly derived from the combustion of leaded gasoline, oil leakage, wearing out of car tires, and corrosion of batteries [35]. Compared to other studies, the average concentration of Co in this study was higher than those found in Canada [58], Turkey [26], Egypt [55], and the Kingdom of Saudi Arabia [57] but lower than those found in Jordan, Amman city [43] as described in Table 4.

Nickel (Ni)

According to the results presented in Table 3, the average concentrations of Ni found in the analyzed house dust samples ranged from 38 to 55 mg/kg with a mean of 42.2 mg/kg in the winter season (for details refer to Table S2). The maximum Ni concentrations permitted in soil are 50 mg/kg according to WHO/FAO [49] and 35 mg/kg according to Dutch and Nigeria standards [50,52]. These results reveal that the average concentrations of Ni in the dust samples were found to be within the permissible limits set by WHO/FAO standards but exceeded the permissible limits set by Dutch and Nigeria standards. It is reported that the presence of Ni in house dust samples could be due to lubricant corrosion of cars, use of Ni-plated household products, nickel plating, vehicle alloys containing nickel, erosion of metallic surfaces, tire abrasion, engine wear, heavy oil combustion, and brake dust [2,35,56]. The average concentrations of Ni in the analyzed house dust samples followed the order of commercial zone (Irbid) > commercial zone (Mafraq) > industrial zone (Irbid) > Irbid-Mafraq highway > residential zone (Mafraq) > residential zone (Irbid) in the winter season (Table 3). Compared to other studies, the average concentration of Ni found in this study was higher than those found in Turkey [26], Egypt [55], Australia [54], Malaysia [56], and Jordan, Al-Karak city [25], but lower than those found in Canada [58], and Jordan, Amman city [43] as described in Table 4.

Manganese (Mn)

For the concentrations of Mn in the analyzed house dust samples, the results in Table 3 show that the average concentrations of Mn found in the analyzed house dust samples ranged from 73.0 to 166 mg/kg with a mean of 139 mg/kg in the winter season (for details refer to Table S2). The maximum Mn concentration permitted in the soil is 2000 mg/kg according to WHO/FAO standards [49]. These findings indicate that the average concentrations of Mn in the analyzed dust samples were found to be within the permissible limits set by WHO/FAO. The presence of Mn in the analyzed dust samples might be due to Ni-Mn batteries, household cleaning agents, and infiltration of vehicle emissions [51]. The average concentrations of Mn in the analyzed house dust samples followed the order of commercial zone (Mafraq) > residential zone (Mafraq) > Irbid-Mafraq highway > residential zone (Irbid)> industrial zone (Irbid) > commercial zone (Irbid) in the winter season (Table 3). Compared to other studies, the average concentration of Mn found in this study was higher than those found in Australia [54] and Turkey [26], but lower than those found in Canada [58], the Kingdom of Saudi Arabia [57], Jordan, Al-Karak city [25], Egypt [55], and Jordan, Amman city [43] as described in Table 4.

Enrichment Factor

In order to determine whether the origin of heavy metal pollution in the analyzed house dust samples is due to anthropogenic or natural sources, the enrichment factor (EF) for selected heavy metals (Pb, Cd, Zn, Cu, and Cr) was calculated and listed in Table 5 (for details refer to Table S3). The EF for a given metal is usually used to assess the degree of anthropogenic pollution in environmental media based on the normalization of the concentration of the investigated metal in a house dust sample against background or crustal metals such as Al or Fe [35]. In this study, the EF for metal in the analyzed dust samples is calculated using the Eq. (3) [35,47]:

$$EF = \frac{[M]_{dust}/[Fe]_{dust}}{[M]_{crust}/[Fe]_{crust}} \quad (3)$$

where $[M]_{dust}$ is the concentration of metal in the house dust sample, $[Fe]_{dust}$ is the concentration of Fe (as reference metal) in the house dust sample, $[M]_{crust}$ is the concentration of metal in the earth crust, and $[Fe]_{crust}$ is the concentration of Fe in the earth crust. Aprile and Bouvy [62] classified contamination levels into five categories based on the EF values: (i) no enrichment (EF = 1 to < 2); (ii) minor enrichment (EF = 2 to < 5); (iii) moderate enrichment (EF = 5 to < 10); (iv) high enrichment (EF = 10 to < 50); and (v) extremely high enrichment (EF > 50). Alsbou and Al-Khashman [47] reported that EF values less than 10 indicate low enrichment, EF values from 10 to 100 indicate medium enrichment, and EF values greater than 100 indicate high enrichment.

In this study, the average EF values for the investigated metals were calculated in the dust samples collected during the summer season and listed in Table 5. According to these results, the high enrichments of the studied metals were obtained in the dust samples collected from the residential zone (Irbid) and commercial zone (Mafraq). These findings can be attributed to the presence of steel factories in the Irbid city, traffic emissions, brake linings, and vehicle wear. The average EF values of the studied metals followed the order of Cd > Zn > Cu > Pb > Cr (Table 5). The results show that Cd has an extremely high enrichment factor (ranging from 471 to 1069) in all sampling sites (Table 5). These results indicate that the origin of this metal in the analyzed dust samples is due to anthropogenic sources like smoking, building paint, fossil fuel combustion, vehicle emissions, and old car tires [35]. In addition, the the results listed in Table 5 show that Pb, Zn, and Cu have medium enrichment (10 ≤ EF ≤ 100). These results confirm that the presence of these metals in the analyzed dust samples is due to different anthropogenic sources (mainly related to vehicle emissions and industrial activities). For Cr, the average EF values were found to be lower than 10 in all sampling sites, which implies that the origin of this metal in the analyzed dust samples is due to natural sources.

Influence of Different Heating Systems

With the aim to investigate the influence of different heating systems on the concentration of the

Table 5. Average values (±SD) of enrichment factor for selected heavy meals in dust samples collected during the summer season from different studied areas in Irbid and Mafraq cities, Jordan

Heavy metal	Industrial zone (Irbid)	Commercial zone (Irbid)	Residential zone (Irbid)	Irbid-Mafraq highway	Commercial zone (Mafraq)	Residential zone (Mafraq)
Pb	21 (±9)	18 (±6)	18 (±11)	15 (±6)	19 (±8)	17 (±6)
Cd	471 (±248)	670 (±332)	1069 (±854)	585 (±347)	739 (±405)	684 (±272)
Zn	27 (±13)	31 (±13)	35 (±11)	19 (±10)	37 (±12)	29 (±15)
Cu	19 (±15)	21 (±13)	24 (±13)	12 (±8)	23 (±9)	14 (±8)
Cr	5 (±2)	5 (±1)	6 (±2)	4 (±1)	5 (±2)	5 (±1)

studied metals in the collected house dust, a total of 30 samples were collected during the winter season from houses using different heating systems including (i) kerosene (indoor combustion of kerosene), (ii) gas (indoor combustion of natural gas), (iii) central heating (outdoor diesel boilers), and (iv) wood (indoor combustion of wood).

The average concentrations of the studied metals in the analyzed dust samples are listed in Table 6. As a general trend, dust samples collected from houses using indoor combustion of wood for heating contain the highest concentrations of Pb, Cd, Zn, Fe, Cr, Co, and Mn as compared to other heating systems. Wood ash is the residue remaining after the complete burning of wood. It is mostly composed of several essential metals (e.g., Ca, K, P, Mg, Mn, Na, Fe, or Al) that are needed for adequate plant growth. On the other side, wood ash contains some toxic heavy metals (e.g., Pb, Cd, Co, As, or Cr) that pose health and environmental problems. Wood ash is considered as the major constituent of dust in houses using wood for heating. The presence of elevated levels of the studied metals in dust samples collected from houses using wood for heating can be explained based on the fact that plants absorb heavy metals from soil, irrigation water, and the atmosphere during their growth cycle. Results in Table 6 show that the average concentrations of Fe in the analyzed dust samples were the highest among all investigated metals. For example, the average concentration of Fe in the wood samples is 8403 followed by 5360, 4648, and 3766 mg/kg for kerosene, central heating, and gas, respectively (Table 6). Furthermore, results presented in Table 6 show that dust samples collected from houses using central heating contain the highest concentrations of Cu and Ni as compared to all other heating systems.

The overall results for the analyzed dust samples collected from different houses using different heating systems indicated that the average concentrations of the studied metals in the house dust samples followed the order of wood samples > kerosene samples> gas samples> central heating samples (Table 6). These results were in good agreement with those reported by Al-Momani et al. [24]. The author reported that dust samples collected from houses (Ajlune city, Jordan) using wood and/or olive residue for heating contain the highest concentrations of Al, As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Sr, V, Ti and Zn followed by kerosene, natural gas, and central heating [24].

Statistical Analysis of Results

In the present study, analysis of variance (ANOVA) was employed to decide whether there is a significant difference in metal concentrations between dust samples collected from the different studied areas investigated in this study (industrial zone (Irbid), commercial zone (Irbid), residential zone (Irbid), Irbid-Mafraq highway, commercial zone (Mafraq), and residential zone (Mafraq)). From the statistical analysis of the results obtained in the summer season, the P values for Zn, Cu, Cd, and Cr concentrations were found

Table 6. Average concentrations (±SD) of heavy metals (mg/kg) in house dust samples collected from houses using different heating systems

Heavy metal	Gas N = 13	Kerosene N = 5	Wood N = 8	Central heating N = 4
Pb	75 (±24)	106 (±43)	132 (±111)	56 (±7.7)
Cd	4.8 (±4.6)	4.6 (±3.6)	7.7 (±5.8)	1.3 (±1.0)
Zn	322 (±148)	314 (±176)	332 (±202)	185 (±38)
Cu	103 (±69)	169 (±136)	138 (±143)	255 (±373)
Fe	3766 (±2244)	5360 (±2153)	8403 (±5592)	4648 (±2195)
Cr	25 (±18)	26 (±16)	31 (±13)	27 (±11)
Co	18 (±3.0)	19 (±3.3)	22 (±3.0)	15 (±3.0)
Ni	43 (±20)	45 (±11)	39 (±9.0)	44 (±16)
Mn	112 (±40)	102 (±24)	206 (±85)	134 (±70)

to be 0.08, 0.16, 0.18, and 0.08, respectively. These findings indicate that there was no significant difference in metal concentration between the analyzed dust samples collected from the different studied areas ($p > 0.05$). On the other side, the p values for Pb and Fe were 6.62×10^{-6} and 0.04, indicating that there was a significant difference in the concentrations of these metals between the analyzed dust samples collected from the different studied areas ($p < 0.05$). One possible explanation for the variation of the concentrations of Pb and Fe between the analyzed dust samples might be due to anthropogenic sources such as traffic emissions, industrial emissions, and smoking. In addition, ANOVA was also employed for the results obtained during the winter season. According to these results, the p values obtained for Pb, Cd, Zn, Cu, Fe, Cr, Ni, Mn, and Co concentrations were found to be 0.88, 0.53, 0.84, 0.53, 0.34, 0.47, 0.67, 0.23, and 0.64, respectively. These findings confirm that there was no significant difference in metal concentration in dust samples collected from the different studied areas investigated in this study ($p > 0.05$).

■ CONCLUSION

This study showed a significant concentration of metals in dust samples collected from Irbid and Mafraq cities. For the dust samples collected during the summer season, it is found that the highest concentration of Cd is present at the residential zone (Irbid), Fe at the Irbid-Mafraq highway, and Zn at the commercial zone (Mafraq). The average concentrations of the studied metals in dust samples collected from houses using different heating systems followed the order of wood samples > kerosene samples> gas samples > central heating samples. The enrichment factor results showed that Pb, Zn, Cu, and Cd were found to be highly enriched in the analyzed dust samples, indicating heavy metal pollution from anthropogenic sources such as smoking, building paint, and traffic emissions. Vehicle emissions appear to be the major outdoor source of heavy metal pollution in the analyzed house dust samples in Irbid and Mafraq cities. Therefore, the use of fuel without lead and vehicles with catalytic converters are highly recommended and should be encouraged to reduce vehicle emissions yielded toxic heavy metals in house dust. The results of this study suggest that the levels of the studied heavy metals (Pb, Cd, Zn, Cu, Fe, Cr, Co, Ni, and Mn) in the analyzed house dust should be monitored regularly.

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■ AUTHOR CONTRIBUTIONS

Asmaa Al-Serhan collected and prepared dust samples for analysis. Idrees Faleh Al-Momani performed the FAAS studies. “Ayat Allah” Al-Massaedh and Asmaa Al-Serhan wrote the draft of the manuscript. All authors analyzed and interpreted the results obtained during this study. All authors read and approved the final manuscript.

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