Rafidain Journal of Science
https://rsci.mosuljournals.com
Vol. 33, No. 3, pp. 74-84, 2024

Assessment of Heavy Metal Contamination in Dust Samples from Industrial and Non-Industrial Sites in Erbil Governorate

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p-ISSN: 1608-9391
e -ISSN: 2664-2786

Article information

Received: 3/7/2023
Revised: 21/ 9/ 2023
Accepted: 29/ 9/ 2032

DOI: 10.33899/rjs.2024.184537

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ABSTRACT

The rapid process of industrialization and urbanization has led to the release of substantial amounts of heavy metals into the atmosphere, posing a significant threat to human health. This study aimed to collect dust samples from two different locations in Erbil Governorate: One from an industrial site (S1) and the other from a non-industrial site (S2) in Erbil Governorate. The sampling took place during July, August, and September 2021. Atomic absorption spectroscopy was used to evaluate the concentrations of different elements (Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co, and Cd) in the dust samples. The study also analyzed the health hazards, both carcinogenic and non-carcinogenic, associated with these metals for the residents. Non-carcinogenic hazards were assessed by computing the values of hazard index (HI) and hazard quotient (HQ) individually for children and adults. The results showed that the HI values of all elements were less than one at both sites for both children and adults, except for Cr and as at the industrial area (site 1), where the HI values for children were 2.68E+00 and 3.85E+00, and for adults were 1.55E+00 and 1.03E+00, respectively. Thus, it was found that children faced a higher non-carcinogenic health risk compared to adults at both locations. Furthermore, the study evaluated the carcinogenic risks associated with elements such as As, Cr, Cd, and Ni. The carcinogenic risk (CR) values for these elements exceeded that range (10^{-4} - 10^{-6}), indicating that there is no significant carcinogenic risk present in the studied areas.

Keywords: Dust particle, Exposure risk, Heavy metals, Pollution, Risk assessment.

INTRODUCTION

Heavy metals are constantly discharged into the terrestrial environment as a result of continued industrialization and urbanization in many nations across the world, posing a significant hazard to human health. Heavy metals are one of the most dangerous contaminants. In contrast to other contaminants, these metals do not break down and stay in the environment for an extended period of time (Mohammed *et al.,* 2011). Heavy metals refer to a group of metallic elements characterized by high density, atomic weight, and toxicity (Rasheed, 2012). The ecological system may be considerably impacted by the accumulation of heavy metals in the environment. However, heavy metals are dangerous for those who live in urban areas and suburbs. They could have carcinogenic, teratogenic, and mutagenic effects (Du *et al.,* 2013). Dust particles are considered a primary source of air pollution, emanating from various activities and processes that generate fine, airborne particles containing harmful substances (Namuq, 2022). Pollutant metals are often found in upper soil and dust, and they can enter human bodies by food, inhalation, and skin adsorption. As a result, any excessive concentration of heavy metals will endanger biological life (Briffa *et al.,* 2020). Dust's effects on the human body vary depending on parameters such as particle size, concentration of metals, and particulate matter. The toxicity of various heavy metals in the human body varies (Batool *et al.,* 2020). The size of dust particles has a significant influence on the transport of pollutants and is proportional to their concentration (Alghamdi *et al.,* 2022). Heavy metals accumulate in our bodies and are transferred via the circulatory system, causing harm to our internal organs and neurological system (Lu *et al.,* 2014 a; Lu *et al.,* 2014 b). Selenium (Se), Cadmium (Cd), Cobalt (Co), Mercury (Hg), Chromium (Cr), Nickel (Ni), Manganese (Mn), Lead (Pb), Antimony (Sb), Arsenic (As) were identified as hazardous air pollutants. Among these, Nickel (Ni), Chromium (Cr), Cadmium (Cd), Arsenic (As) were classified as carcinogens (Zheng *et al.,* 2015). The persistent, toxic, and bio accumulative qualities of heavy metals, which constitute a major fraction of dust (0.02-5.7%), have attracted greater attention in recent years because of the threats they represent to the environment and human health (Wang *et al.,* 2020). Toxic metals linked with dust particles can enter the body via inhalation, digestion, and dermal (skin) absorption (Faisal *et al.,* 2022). Heavy metals are everywhere in nature and can accumulate in many bodily organs, including the kidneys, bones, and liver, through vegetable consumption, direct cutaneous contact, or ingestion. This disrupts the equilibrium of nature and is harmful to people's health (Moni *et al.,* 2023). Heavy metals are released into the air as dust accumulates and become more enriched, eventually harming people to varied degrees (Song *et al.,* 2022). The main goals of this study were to (1) measure the concentrations of Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co, and Cd in an industrial site (S1) and a non-industrial site (S2) in Erbil, Governorate (2) to assess the carcinogenic and non-carcinogenic hazards of these heavy metals.

MATERIALS AND METHODS

Description of the Study Area

Erbil has had significant air pollution problems in recent decades as a result of growing industrialization and urbanization. Tymar village, located at coordinates 36°06′32.98″N 43°58′44″E, is situated approximately 13 km south of Erbil city, which represents an industrial area (S1), there are many factories and industrial activity in Tymar village. On the other hand, Haji Wsu village, positioned at coordinates 36°09′10.58″N 44°19′04.19″E situated about 42 km east of Erbil city and represent non-industrial areas (S2), which are free from any pollution sources such as factories and industrial facilities as shown in Fig. (1).

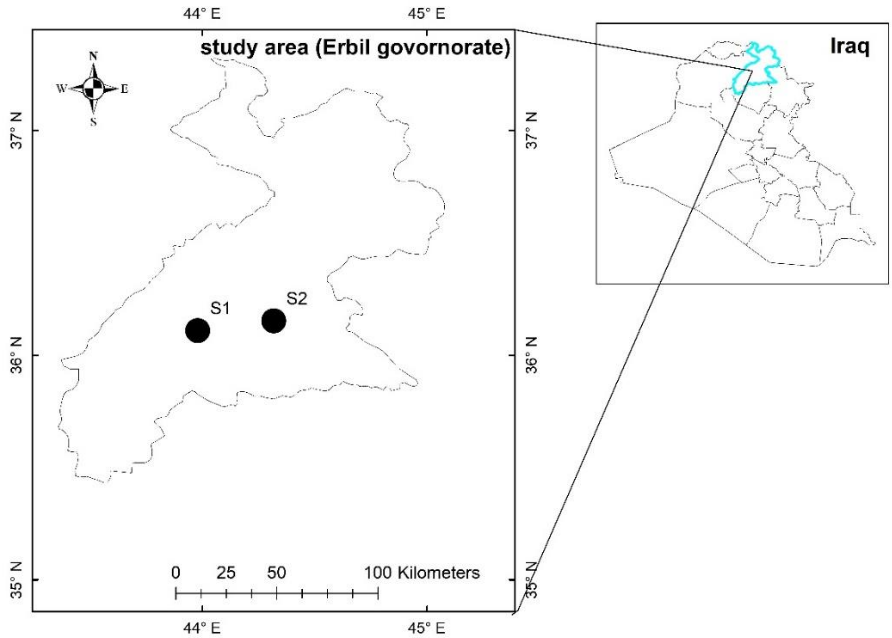

Fig. 1: Map of the study area

Sample collection, preparation and analysis

Dust samples were collected in July, August, and September 2021, with three samples obtained at each site (industrial and non-industrial). The samples were placed in clean plastic jars that had a 30 cm broad opening and a 40 cm height. Each collector has a funnel in the mouth to keep dust from escaping into the atmosphere. The base of each container was cemented to the ground to sustain the connection and prevent movement caused by winds or other circumstances. Each collector was placed on a platform 1-1.5 meters above the ground. The funnel was removed throughout the months of dust collection, and the dust was carefully collected with a little clean brush, sieved through 2 mm mesh, and kept in clean plastic bags for examination, Samples were analyzed by (AAS Perkins Elmer USA 1100D) after acid digestion (Hseu *et al.*, 2002).

Human health risk assessment

The non-carcinogenic and carcinogenic risk factors can be used to determine health risks for both adults and children. The main components of a health risk assessment are the identification of hazards, evaluation of exposure, evaluation of dose response, and characterization of risks (Shen *et al.*, 2019).

The USEPA (United States Environmental Protection Agency). approach (USEPA, 1986), HI, and CR were used in the study to evaluate the non-carcinogenic and carcinogenic risks that heavy metals bring to human health.

Noncarcinogenic Risk

This model focuses on the three main routes through which humans are exposed to metal contaminants: Inhalation, ingestion, and skin contact (Oguri *et al.*, 2018). The USEPA’s exposure handbook provides estimated data for average daily intake (ADI) in both children and adults for each exposure route (Epa, 2011) (Table 1). The ADIs from inhalation, ingestion, and cutaneous contact are calculated using Equations (1), (2), and (3), respectively.

$$\text{Adling} = \frac{C \times IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\text{AdlDermal} = \frac{C \times AF \times SA \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\text{Adlinh} = \frac{C \times InhR \times EF \times ED}{BW \times AT \times PEF} \quad \text{………………………………………… (3)}$$

AdIing (oral ingestion), AdIDermal (dermal contact), and AdIinh (inhalation). The predicted dosage for each element and exposure route is divided by the relevant reference dose value (Rfd) to determine the hazard quotient (HQ) for noncarcinogens (Table 2). C is the concentration of heavy metals (mg/kg).

Hazard index (HI)

The hazard index (HI) is the total of individual HQ values. If the HI value is ≤1, it is assumed that there are minimal or no significant noncarcinogenic impacts in the area. On the other hand, If the HI values ≥ 1, the area is more likely to have chronic health concerns (Xie *et al.*, 2022), and it is defined (Epa, 2011) as the following Eqs. (4), (5), (6) and (7):

$$\text{HQ}_{ingestion} = \left(\frac{D}{R_f D}\right)_{ingestion} \quad \text{…………………………………… (4)}$$

$$\text{HQ}_{ihalation} = \left(\frac{D}{R_f D}\right)_{ihalation} \quad \text{…………………………………… (5)}$$

$$\text{HQ}_{dermal} = \left(\frac{D}{R_f D}\right)_{dermal} \quad \text{…………………………………… (6)}$$

$$\text{HI} = \sum_{i=0}^{n} HQI \quad \text{…………………………………… (7)}$$

Table 1: The exposure factors frequently cited for the assessment of human health risks

Definition (Factor)	Unit	Children	Adult	References
Ingestion rate (IngR)	mg/day	200	100	(EPA, 2001)
Inhalation rate (InhR)	m^3/day	7.63	12.8	(Aminiyan *et al.*, 2018)
Particle emission factor (PEF)	m^3 /kg	1.36 *10^9	1.36 *10^9	(EPA, 2001)
Exposed skin area (SA)	cm^2	2800	5700	(EPA, 2001)
Dermal adsorption factor (ABS)	unitless	0.001	0.001	(EPA, 2001)
		0.03 for As	0.03 for As	
Skin adherence factor (SL)	mg/cm^2 /h	0.2	0.07	(EPA, 2001)
Exposure duration (ED)	years	6	24	(EPA, 2001)
Exposure frequency (EF)	day/year	350	350	(Leung *et al.*, 2008)
Average time non-carcinogens (AT)	days	ED*365	ED*365	(Alharbi *et al.*, 2020)
Average time for carcinogens (AT)	days	70*365	70*365	(Alharbi *et al.*, 2020)
average body weight (BW)	kg	15	70	(EPA, 2001)
Conversion factor (CF)	1 x 10^{-6}			(Alharbi *et al.*, 2020)

Table 2: Values of reference dose (RfD) and slope factor (SF)

Metals	R_fD_{ing}	R_fD_{inh}	R_fD_{dermal}	SFinh
Fe	84×10^{-1}	2.20×10^{-4}	7×10^{-2}	
Cu	4×10^{-2}	1.2×10^{-2}	4×10^{-2}	
Mn	4.6×10^{-2}	1.84×10^{-3}	1.43×10^{-5}	
Ni	2×10^{-2}	5.4×10^{-3}	2.06×10^{-2}	8.40E-01
Cr	3×10^{-3}	6×10^{-5}	2.86×10^{-5}	4.20E+01
Zn	3×10^{-1}	6×10^{-2}	3×10^{-1}	
As	3×10^{-4}	1.23×10^{-4}	3.01×10^{-4}	1.51E+01
Pb	3.5×10^{-3}	5.25×10^{-3}	3.52×10^{-3}	
Co	2×10^{-2}	1.60×10^{-2}	5.71×10^{-6}	
Cd	1×10^{-3}	5.71×10^{-5}	2.5×10^{-5}	6.30E+00

(Rabin *et al.*, 2023), (Aguilera *et al.*, 2020)

Carcinogenic risk

Carcinogenic risk is the possibility of finding any type of cancer in a person as a result of lifetime exposure to carcinogenic risks (Haleem *et al.*, 2022). The lifetime average daily dose (LADD) for Ni, Cr, Cd, and As through the inhalation exposure route was computed using Eq. (8):

$$LADD_{inhlation} = \frac{C\times EF}{PEF\times AT} \times \left(\frac{InhR_{Child}\times ED_{Child}}{BW_{Child}} + \frac{InhR_{Adult}\times ED_{Adult}}{BW_{Adult}}\right) \quad \ldots\ldots (8)$$

LADD is defined as the incremental possibility that a person would get cancer as a result of long-term exposure to carcinogens, often throughout a lifetime (Iakovides *et al.*, 2021). Eq. (9) could be used to determine the carcinogenic risk (CR):

$$\text{Carcinogenic Risk (CR)} = \text{LADD} \times \text{SF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where the cancer slope or slope factor is denoted by SF (unitless) (Table 2). The cancer risk is regarded as acceptable if the cancer risk value falls within the range of threshold values (10^{-4}-10^{-6}) (Epa, 2011).

RESULTS AND DISCUSSION

Tables (3 and 4) present the HQ (hazard quotient) and HI (hazard index) values for noncarcinogenic health risks with various tested metals. The order of these values differs for children and adults. For children at Site 1, the order of metals with the highest Hi values are As> Cr> Pb> Mn> Co> Fe> Cd> Cu> Ni> Zn. For adults at the same site, the order is Cr> As>Co> Pb> Mn> Fe> Cd> Cu> Ni> Zn. On the other hand, Tables 5 and 6 provide the HQ and HI values for noncarcinogenic health risks at Site 2. For children, the order of metals with the highest HI values is Cr> Mn> As> Co> Pb> Cd> Fe> Ni> Cu> Zn. For adults, the order is Cr> Mn> Co> As> Pb> Fe>

Cd> Ni> Cu> Zn. All HI values were below 1, indicating no significant carcinogenic effects, except for Cr, which had a value of 2.68E+00, and as, which had a value of 3.85E+00 for children at (Site 1). For adults at the same site, Cr had a value of 1.55E+00 and as had a value of 1. 03E+00. These elevated values suggest potential carcinogenic effects associated with these metals in the industrial area (Site 1). Arsenic and chromium (Cr) are common environmental pollutants that have a negative impact on world health due to their toxicity and carcinogenicity (Vimercati *et al.*, 2017). Different oxidation states of certain metals, such As and Cr, have a direct impact on their bioavailability and environmental toxicity in dust deposits (Tang *et al.*, 2017). Chromium (Cr) is a significant metal with several industrial uses, including catalysts, pigments, and steel alloys. Chromite is one of the most hazardous elements in the environment, particularly Cr (VI) (Huang *et al.*, 2022). The lengthy persistence of Cr (VI) contamination in the environment and its extremely lethal character in living things have made it one of the most significant environmental issues in the world. Cr (VI), one of the most prevalent environmental pollutants due to its widespread usage in industries, is extremely hazardous (Sharma *et al.*, 2022). According to the EPA, those who are exposed to Cr at levels that might harm their liver, kidneys, circulatory systems, and nerve tissues may have skin irritation or ulceration. If there are significant concentrations of Cr (VI) compounds, lung cancer risk may rise (Thakur *et al.*, 2007).

Arsenic, a naturally occurring metalloid, is one of the most abundant elements in the earth's crust and may be found everywhere. Arsenic can adhere to extremely small particles in the air, allowing it to linger for several days and travel long distances (Chung *et al.*, 2014). Arsenic has been responsible for a wide range of issues in bodily organ systems, including the integumentary, nervous, respiratory, cardiovascular, hematological, immunological, endocrine, hepatic, renal, reproductive, and developmental systems (Abdul *et al.*, 2015). Similar results were obtained by (Pan *et al.*, 2019), who conducted a study on pollution caused by the eight metals Hg, As, Cr, Cu, Ni, Pb, Zn, and Cd, which is a major concern in Zhongshan, China. The results indicated that the HI values for As and Cr in children were more than 1. At both sites, children had higher HI values than adults and were exposed to more heavy metals. According to some research, children are more likely to be subjected to hazardous substances (Behrooz *et al.*, 2021; Diganta *et al.*, 2020; Liang *et al.*, 2017). Children's bodies are still developing, and their organs, including the brain, are more sensitive to the toxic effects of metals. Exposure to these substances during critical developmental stages can lead to long-term health issues (Perlroth and Branco, 2017). Shao *et al.* (2018) stated that they conducted research that measured the levels of Cr, Pb, Cu, Ni, and Cd in dust samples and discovered that the average non-carcinogenic risk value of Cr is the highest and poses the greatest hazard to health in Yanta District, Xi'an.

The study assessed the carcinogenic risk associated with elements such as As, Cr, Cd, and Ni. The calculated carcinogenic risk (CR) values for these elements exceeded that range (10^{-4} - 10^{-6}), indicating that there is no significant carcinogenic risk present in the studied areas as indicated in (Table 7). Rahman *et al.* (2021) obtained similar results in their research. The goal of the study was to gather soil and dust samples from twelve academic institutions along the roadsides of Dhaka. The control site is one of the twelve research locations. The elemental contents (Cu, Fe, K, Ti, Sr, Zn, Zr, Rb, Cr, Ni, Pb, and Ca) in soil and dust samples were assessed by X-ray Fluorescence (XRF). There is evidence that children face greater non-carcinogenic health risks than adults. In the tested area, a lack of carcinogenic health risk was found. Al-Husseini (2018) conducted a study at nine stations to investigate the pollution loads of contaminated dust that fell in the Al-Shaibah neighborhood and close to the oil refinery in Basrah, Iraq, from June 2011 until November 2012. According to the results, neither non-carcinogenic nor carcinogenic effects on human health are present in the area.

Table 3: The non-carcinogenic risk values (for children) associated with exposure to heavy metals at Site 1.

Element	HQ_{ing}	HQ_{derm}	HQ_{inh}	HI
Fe	3.14E-02	1.05E-02	3.66E-02	7.85E-02
Cu	3.30E-02	9.25E-05	3.09E-06	3.31E-02
Mn	6.79E-02	6.12E-01	4.76E-05	6.80E-01
Ni	3.20E-02	8.69E-05	3.32E-06	3.21E-02
Cr	2.07E+00	6.07E-01	2.90E-03	2.68E+00
Zn	4.09E-03	1.15E-05	5.74E-07	4.10E-03
As	3.55E+00	2.98E-01	2.43E-04	3.85E+00
Pb	9.81E-01	2.73E-03	1.84E-05	9.84E-01
Co	2.49E-02	2.44E-01	8.72E-07	2.69E-01
Cd	6.78E-02	7.59E-03	3.33E-05	7.54E-02

Table 4: The non-carcinogenic risk values (for adults) associated with exposure to heavy metals at Site 1.

Element	HQ_{ing}	HQ_{derm}	HQ_{inh}	HI
Fe	3.36E-03	2.30E-02	1.31E-02	3.95E-02
Cu	3.54E-03	2.02E-04	1.11E-06	3.74E-03
Mn	7.28E-03	9.34E-02	1.7118E-05	1.01E-01
Ni	3.42E-03	1.90E-04	1.19E-06	3.62E-03
Cr	2.21E-01	1.32E+00	1.04E-03	1.55E+00
Zn	4.38E-04	2.50E-05	2.06E-07	4.64E-04
As	3.81E-01	6.49E-01	8.74E-05	1.03E+00
Pb	1.05E-01	5.96E-03	6.60E-06	1.11E-01
Co	2.66E-03	5.32E-01	3.13E-07	5.35E-01
Cd	7.26E-03	1.66E-02	1.20E-05	2.38E-02

Table 5: The non-carcinogenic risk values (for children) associated with exposure to heavy metals at Site 2.

Element	HQ_{ing}	HQ_{derm}	HQ_{inh}	HI
Fe	1.32E-02	4.45E-03	1.54E-02	3.31E-02
Cu	7.45E-03	2.09E-05	6.96E-07	7.47E-03
Mn	3.95E-02	3.55E-01	2.77E-05	3.95E-01
Ni	2.59E-02	7.04E-05	2.69E-06	2.60E-02
Cr	7.68E-01	2.26E-01	1.08E-03	9.94E-01
Zn	3.20E-03	8.95E-06	4.48E-07	3.21E-03
As	2.99E-01	2.50E-02	2.04E-05	3.24E-01
Pb	9.68E-02	2.70E-04	1.81E-06	9.71E-02
Co	2.28E-02	2.23E-01	7.98E-07	2.46E-01
Cd	3.32E-02	3.72E-03	1.63E-05	3.70E-02

Table 6: The non-carcinogenic risk values (for adults) associated with exposure to heavy metals at Site 2.

Element	HQ_{ing}	HQ_{derm}	HQ_{inh}	HI
Fe	1.42E-03	6.79E-04	5.55E-03	7.65E-03
Cu	7.98E-04	3.18E-06	2.50E-07	8.01E-04
Mn	4.23E-03	5.43E-02	9.95E-06	5.85E-02
Ni	2.77E-03	1.07E-05	9.67E-07	2.79E-03
Cr	8.23E-02	3.44E-02	3.87E-04	1.17E-01
Zn	3.42E-04	1.37E-06	1.61E-07	3.44E-04

As	3.20E-02	3.82E-03	7.35E-06	3.58E-02
Pb	1.04E-02	4.11E-05	6.51E-07	1.04E-02
Co	2.44E-03	3.41E-02	2.87E-07	3.65E-02
Cd	3.56E-03	5.68E-04	5.87E-06	4.14E-03

Table 7: Carcinogenic risk values index at Site 1 and Site 2.

Elements	**CRinh (Site 1)**	**CRinh (Site 2)**
As	9.44E-08	7.94E-09
CD	2.50E-09	1.23E-09
Cr	5.49E-07	2.04E-07
Ni	3.15E-09	2.55E-09

CONCLUSIONS

In this study, two different areas were investigated to analyze the health hazards associated with exposure to certain metals, (Site 1) represented an industrial area, while (Site 2) represented a non-industrial area. Fe, Cu, Mn, Ni, Cr, Zn, As, Pb, Co, and Cd were among the metals studied. The findings demonstrated that non-carcinogenic risk assessments for Cr and As in the industrial area (Site 1) surpassed a Hazard Index (HI) value of 1 for both children and adults. This shows that exposure to certain metals in the industrial environment may pose a health risk. Furthermore, the findings of the carcinogenic risk assessments in the industrial area surpassed the allowed range, indicating that there was no substantial carcinogenic effect. Additional research in these areas is recommended based on these findings.

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تقييم تلوث المعادن الثقيلة في عينات الغبار من المواقع الصناعية وغير الصناعية في محافظة أربيل

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الملخص

أدت عملية التصنيع والتحضر السريعة إلى إطلاق كميات كبيرة من المعادن الثقيلة في الغلاف الجوي، مما يشكل تهديدًا كبيرًا لصحة الإنسان. هدفت هذه الدراسة إلى جمع عينات الغبار من موقعين مختلفين في محافظة أربيل: أحدهما من موقع صناعي (S1) والآخر من موقع غير صناعي (S2) في محافظة أربيل. تم أخذ العينات خلال أشهر يوليو وأغسطس وسبتمبر 2021. تم استخدام مطيافية الامتصاص الذري لتقييم تركيزات العناصر المختلفة (Fe، Cu، Mn، Ni، Cr، Zn، As، Pb، Co، وCd) في عينات الغبار. حللت الدراسة أيضًا المخاطر الصحية، سواء المسببة للسرطان أو غير المسببة للسرطان، المرتبطة بهذه المعادن للسكان. تم تقييم المخاطر غير المسببة للسرطان عن طريق حساب قيم مؤشر الخطر (HI) وحاصل المخاطر (HQ) بشكل فردي للأطفال والبالغين. أظهرت النتائج أن قيم HI لجميع العناصر كانت أقل من واحد في كلا الموقعين لكل من الأطفال والبالغين، باستثناء Cr وAs في المنطقة الصناعية (الموقع 1)، حيث كانت قيم HI للأطفال 2.68E+00 and 3.85E+00، وبالنسبة للبالغين كان 1.03E+00 and 1.55E+00 على التوالي. وبالتالي، وجد أن الأطفال يواجهون مخاطر صحية غير مسرطنة أعلى مقارنة بالبالغين في كلا الموقعين. علاوة على ذلك، قيمت الدراسة المخاطر المسببة للسرطان المرتبطة بعناصر مثل As وCr وCd وNi. تجاوزت قيم مخاطر الإصابة بالسرطان (CR) لهذه العناصر هذا النطاق (10^{-6} - 10^{-4})، مما يشير إلى عدم وجود مخاطر مسببة للسرطان في المناطق المدروسة.

الكلمات الدالة: المعادن الثقيلة، جزيئات الغبار، التلوث، تقييم المخاطر، مخاطر التعرض.