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Potential risk assessment of respiratory exposure to heavy metals in the air dust for the metropolitans of Khuzestan Province, Iran

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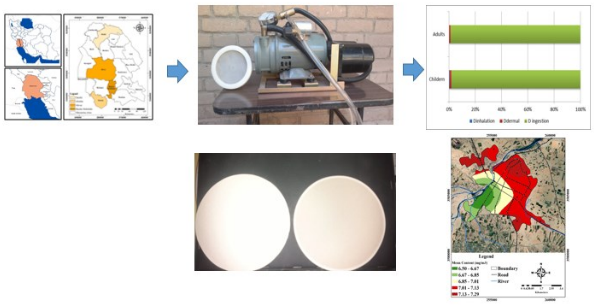
Graphical abstract



Abstract

The present study aimed to compare the concentration of 13 metals in the air of 4 cities of Khuzestan province (Ahvaz, Dezful, Mahshahr, and Abadan) in dust and non-dust conditions, and determine risk and non-carcinogenic risk in a nine-month period from 2017 to 2018 (autumn, winter, and spring). A total of 72 samples were collected in dusty and 72 samples in non-dusty conditions at different locations and times using a high volume sampling pump with 110 lit/s flow rate and a fiberglass filter with the pore size of 1µm for 6 hours. Additionally, the concentration of metals was measured using the Spectro Acros Model (Germany) device. Risk assessment and probable ways of entering the body of these metals were determined using U.S. Environmental Protection Agency (USEPA) indicators. The average concentration of metals (except for Ni, Mg, and Mn) were higher in dusty conditions than in non-dusty conditions ($p < 0.05$). The concentration order of heavy metals in dusty and non-dusty conditions was Zn>Mn>Pb>Ni>Cr>Fe>Cu, and Mg >Mn>Pb>Ni>Cr>Fe, respectively, showing the origin of Zn in the polluted air caused by dust and pollution transfer from outside into cities by this phenomenon. In children and adults of all 4 Ding cities (inhalation of dust particles via direct ingestion of dust) was the main route of absorption of most metals. Chromium and nickel, chromium and magnesium, and nickel and magnesium were observed among the children of Abadan, Ahvaz, and Dezful and Mahshahr, respectively. The maximum Hazard Index (HI) indicator was observed for magnesium in Abadan, copper, and magnesium in Ahvaz, chromium, zinc, nickel, and ferrous in Mahshahr in dusty and non-dusty conditions. Moreover, lead had the maximum HI indicator in Abadan and Ahvaz in the non-dusty condition. According to the standard HI<1, in dusty and clean air conditions, all of the four cities had no concerning issues of non-carcinogenic effects for children and adults.

Keywords: Risk assessment, respiration exposure, metals, dust, air, Khuzestan province.

1. Introduction

Along with the rapid development of global urbanization in recent decades, the deterioration of the natural environment has spread (Yin *et al*. 2023). Air pollution is one of the environmental factors that can have many acute and chronic effects directly and indirectly on human health (Kamani *et al*. 2023).

The International Agency for Cancer Research has found air pollution in Group 1 of cancer-producing agents (Cancer IAFROIARC 2013), since heavy metals in the air enter the body through respiration. The remarkable point is that the diffusion of metals due to adsorption, reserve, and lack of decomposability in the human body is considered the main factor in the pollution of cities (Farahmandkia *et al*. 2017; Asl *et al*. 2022). Normally, in the prone areas of metals pollution, the risk assessment of exposure to heavy metals is particularly implemented in the most vulnerable individuals (WHO 2016). The aerosol in the air consists of various suspended particles, including dust particles, salt particles arising from the sea surface, pollutants from burning of fossil fuels, which their concentration fluctuates rapidly over time due to the dynamic nature of atmospheric (Vichova *et al*. 2021). The WHO (2016) has introduced atmospheric fine dust as a major pollutant factor in cities, which unfortunately in the last decade, many southern and southwestern regions of Iran were exposed to thousands of tons of dust particles from the southern desert of Saudi Arabia, Yemen, Iraq, Syria, etc. In addition to dust from the external origin, Khuzestan province is one of the most vulnerable regions of Iran with 25.1 million hectares of dessert (Tarahi & Arzani 2017; Asl *et al*. 2023).

In addition, global warming caused by the increase in temperature with the intensification of drought has increased the challenge of dust particles (Shang *et al*. 2021). Moreover, Khuzestan is considered one of the most important industrial-petroleum poles of Iran increasing the risk of disease in the province. The phenomenon of dust storm has direct effects on air pollution, prevalence of respiratory diseases, visual and infectious disorders, and pollution of the urban environment.

The metals joined to respirable particles of less than 10µm can penetrate the lung and remain there, causing health disorders for humans (Zmijkova *et al*. 2019; Loupa *et al*. 2021). Particulate matter blocks blood circulation and causes high blood pressure, coronary heart disease, cerebral hemorrhage, and respiratory disease (Chen *et al*. 2023). In urban environments, metals are caused by different stationary and moving sources such as industries, atmospheric deposition, and natural-chemical processes and they are important after adsorption by particles from the public health point of view (Shi *et al*. 2018). Farahmandkia *et al*. (2017) in Zanjan, Dibert, and Paul (2018) in Abidjan, Esfandiari *et al*. (2019) in Yazd and Joshirvani *et al*., (2021) emphasize the negative effects of dust particles on the residents' health. In most cases where several sources of pollution exist in one area, enhancement of pollution risk is extremely difficult, since it is difficult to identify the source of pollutant emissions and enhance them. Therefore, continuous monitoring of the pollution to design a strategy is indispensible (Hajduga *et al*. 2019; Delfani *et al*. 2022). This issue matches the conditions in Dezful, Ahvaz, Mahshahr, and Abadan, which are industrial cities and are exposed to dust. The number of dusty days at the stations of Dezful and Ahvaz as well as southern cities of Khuzestan such as Mahshahr, and Abadan are at the highest level, and these regions are among the most critical parts of Iran (Ghodarzi *et al*. 2018). According to the mentioned points, this study aims to evaluate the health potential of respiratory exposure to metals in the air dust of 4 metropolitans of Dezful, Ahvaz, Mahshahr, and Abadan in Khuzestan.

2. Materials and methods

2.1. Regions of study

Abadan, Ahvaz, Dezful, and Mahshahr are located in western, central, northern, and southern districts of Khuzestan province and are considered the most populous cities in the province. In this study, sampling points were determined by cooperation with the Meteorological Organization and the Department of Environment for Locations with Pollution Assessment in the province. The points were adapted to the geographic location of meteorological stations, which are listed in Table 1 and Figure 1.

Table 1. Geographic coordinates of sampling points in the cities of Khuzestan province

City / Geographic	Latitude (N)	Longitude (E)	Elevation (m)
Abadan industrial-petroleum	30.22	48.15	6.6
Ahvaz industrial-petroleum	31.20	48.40	22.5
Dezful industrial-agricultural	32.24	48.23	143
Mahshahr industrial-petroleum	30.33	49.09	6.2

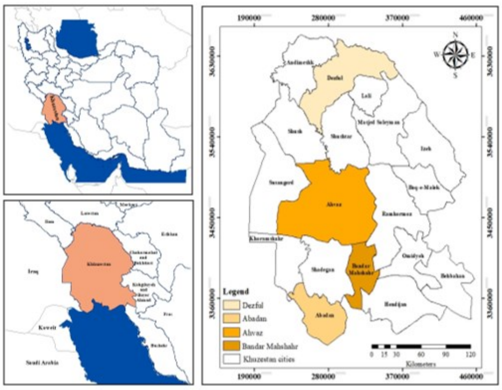


Figure 1. Location of sampling stations in Khuzestan province of Iran

2.2. Sampling and the analysis of the samples

This study was conducted for 9 months (3 seasons: autumn, winter, and spring) from 2017 to 2018 at the high- traffic of four cities of Ahvaz, Abadan, Mahshahr, and Dezful.As the largest and most important cities of Khuzestan province, it has been done in terms of industry, agriculture and urbanization

Sampling was also carried out in two weather conditions of dusty and non-dusty during the dust storm. A total of 72 samples were collected in polluted and non-polluted conditions at the same points and time. Based on the standard procedure of the EPA (1989), the sampling was performed twice the distance from the obstacles and 1.5 m from the ground surface. In addition, the sampling was carried out using a high-volume sampling pump with 110 lit/min of flow rate, and a filter was placed for six hours (EPA 1989). After sampling, 0.2 g of the fiberglass filter (11 cm of diameter and pore diameter of 0.8-8 µm) was crushed and poured into the 8 ml Propylene acid (65%) and 2 ml Hydrofluoric acid (48%) and was placed in three stages under being exposed to microwave radiation. In the first stage, the samples were under the radiation for 60 minutes and 140°C. Afterwards, 1 ml of $HClO_4$ was added, and they were placed at 160 C for 45 min. After cooling, the samples were passed through a Whatman filter paper of 11 mm with pores of 45 µm (Neisi *et al*. 2016). In the next step, the volume of the filtered solution was increased to 50 mL with distilled water. The concentration of metals (Co, Cr, Cu, Zn, Pb, Ni, As, Ba, V, Al, Mn, Mg, and Fe) were identified using the inductively coupled plasma optical emission spectroscopy (Spectro Arcos Model, Germany).

2.3. The risk assessment model

The modified model presented by USEPA was used to calculate the risks of exposure of children and adults to metal-contained dust (Zheng *et al*. 2016). The exposure to each element was assessed individually and through each confrontation route, including 1) direct ingesting of dust particles (Dingestin), 2) inhalation of dust particles through the mouth and nose (Dinhalation), 3) dermal absorption (Ddermal). Eqs. 1-3 and Table 2 present the mentioned paths (EPA 1989).

$$AD_{ing}\left(mgkg^{1-}day^{-1}\right)=C\left(mgkg^{-1}\right)\times\frac{IngR\times EF\times ED}{BW\times AT}\times10^{-6} \quad (1)$$

$$AD_{inh}\left(mgkg^{1-}day^{-1}\right)=C\left(mgkg^{-1}\right)\times\frac{InhR\times EF\times ED}{BW\times PEF\times AT} \quad (2)$$

$$AD_{dermal}\left(mgkg^{1-}day^{-1}\right)=C\left(mgkg^{-1}\right)\times\frac{SA\times SL\times ABS\times EF\times ED}{BW\times AT}\times10^{-6} \quad (3)$$

Table 2. The parameters used in the risk assessment models of exposure

Parameter	Definition	Unit	Children	Adults	Source
InhR	Inhalation rate	m^3/day	7.6	20	Van den berg 1995
BW	Body Weight	kg	15	70	United States Environmental Protection Agency 1989
IngR	Ingestion rate	mg/day	200	100	United States Environmental Protection Agency. Supplemental guidance for developing soil screening levels for superfund sites 2001
SA	Exposed skin area	cm^2	2800	5700	
SL	Skin adherence factors	mg/cm day	0.2	0.07	
PEF	Particle emission factor	m^3/kg	1.36×10^9		
EF	Exposure Frequency	d/yea	180		
ED	Exposure Duration	year	6	24	
AT	Average Time	day	365 day × ED		Ferreira-Baptista and De Miguel 2005
ABS	Dermal absorption factor	-	0.001		

2.4. Non-carcinogenic risk assessment

The non-carcinogenic risk assessment was performed using Eq.4 with the HQ (Hazard Quotients) indicator (EPA 1989; Ferreira-Baptista *et al*. 2005).

$$HQ=\frac{D}{RfD} \quad (4)$$

D=Contract Dosage; RfD=Reference chronic Dosage

The Hazard Index (HI) indicator is calculated using Eq. 5 (EPA 1989).

$$HI=\sum_{1}^{n}HQ \quad (5)$$

Where n is the number of metals. If HI<1, there is no non-carcinogenic risk in the polluted population, and if HI>1, there is concern for non-carcinogenic risk (EPA 1989).

3. Results and discussion

Table 3 shows the concentration of metals in the dust of different cities of Khuzestan province (Ahvaz, Abadan, Mahshahr, and Dezful). All four cities surveyed in the dusty and clear air lacked CO, Cd, As, Ba, V, and Al. Among the 13 metals and in the non-polluted condition, the concentration of Mg in Abadan, Ahvaz, Dezful, and Mahshahr was 17.36, 41.59, 10.51, and 19.38 mg/m^3, respectively, which were the highest concentrations among all metals. In the polluted weather conditions (dusty), Zn had the highest concentration, and Mg had the highest concentration in Dezful (P<0.05). Nearly all metals had higher concentrations in non-polluted conditions than in polluted conditions (P<0.05).

The concentration of chromium, copper, zinc, lead, and iron was higher in dusty conditions than in non-dusty conditions (P<0.05), confirming the importance of dust in the increase of these metals. According to Figure. 2, the concentration of nickel, manganese, and magnesium had no significant difference in the un pollution or non-pollution conditions.

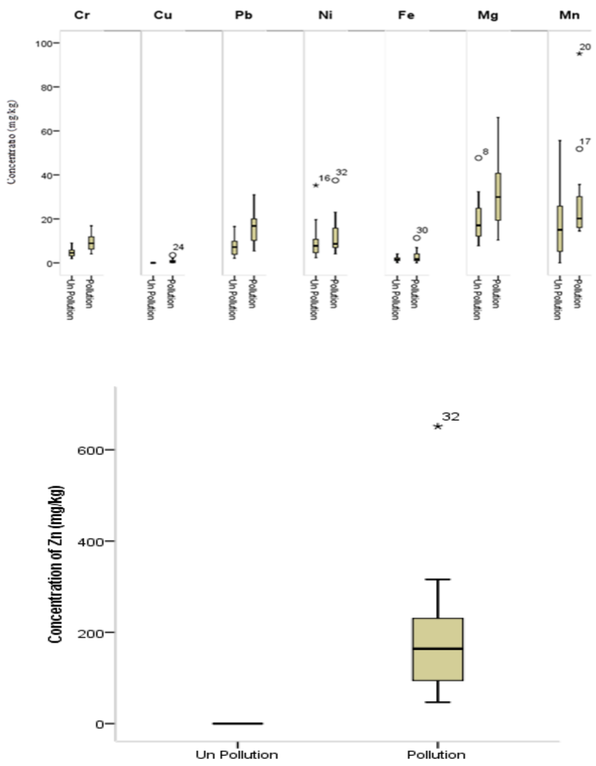


Figure 2. Box diagram comparing the concentrations of A: Cr, Cu, Pb, Ni, Fe, Mg, Mn, and B: Zn metals in the dust of polluted and non-polluted air

(Due to the high concentration of Zn metal, the graph of this metal was drawn separately)

The orientation of metals in dust and non-dusty conditions was used from the dendrogram (Figure 3). In dusty and non-dusty conditions, the metal was placed in a separate cluster compared to other metals concerning a weak correlation with the other cluster. In non-dusty condition, magnesium and manganese (natural origin) were placed in a cluster, nickel in separate clusters, and other metals were placed in separate clusters (human origin) due to the lack of a significant difference between the concentration of nickel, manganese, and magnesium in two conditions (0.05). The dust had no significant effect on the concentration increase of these three metals (P>0.05) (Table 4).

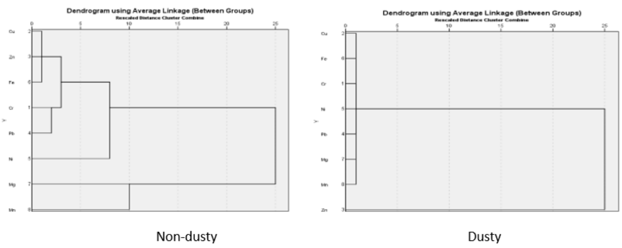


Figure 3. The dendrogram of the cluster analysis of the studied regions in Khuzestan province

The zoning diagram of the average concentration of heavy metals in polluted and non-polluted air conditions is shown in Figure 4. Increased pollution levels can be seen with the entry of dust in zoning maps.

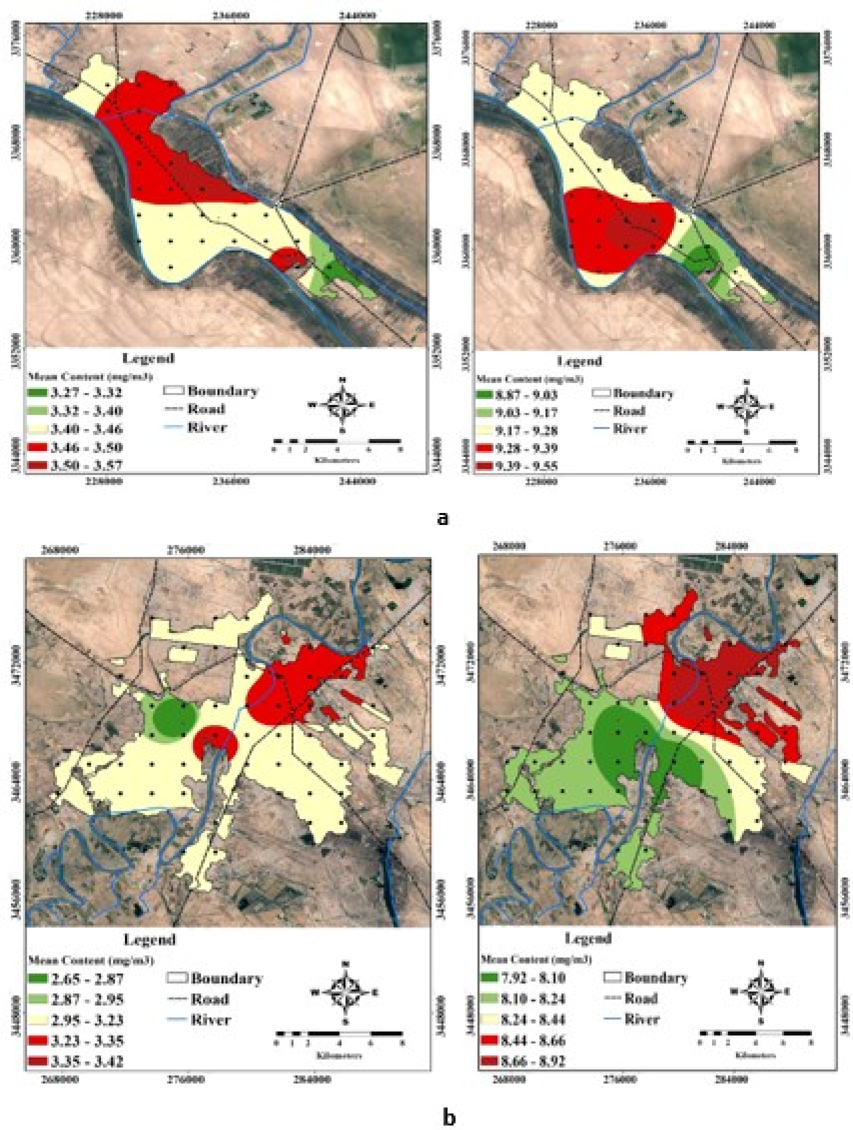
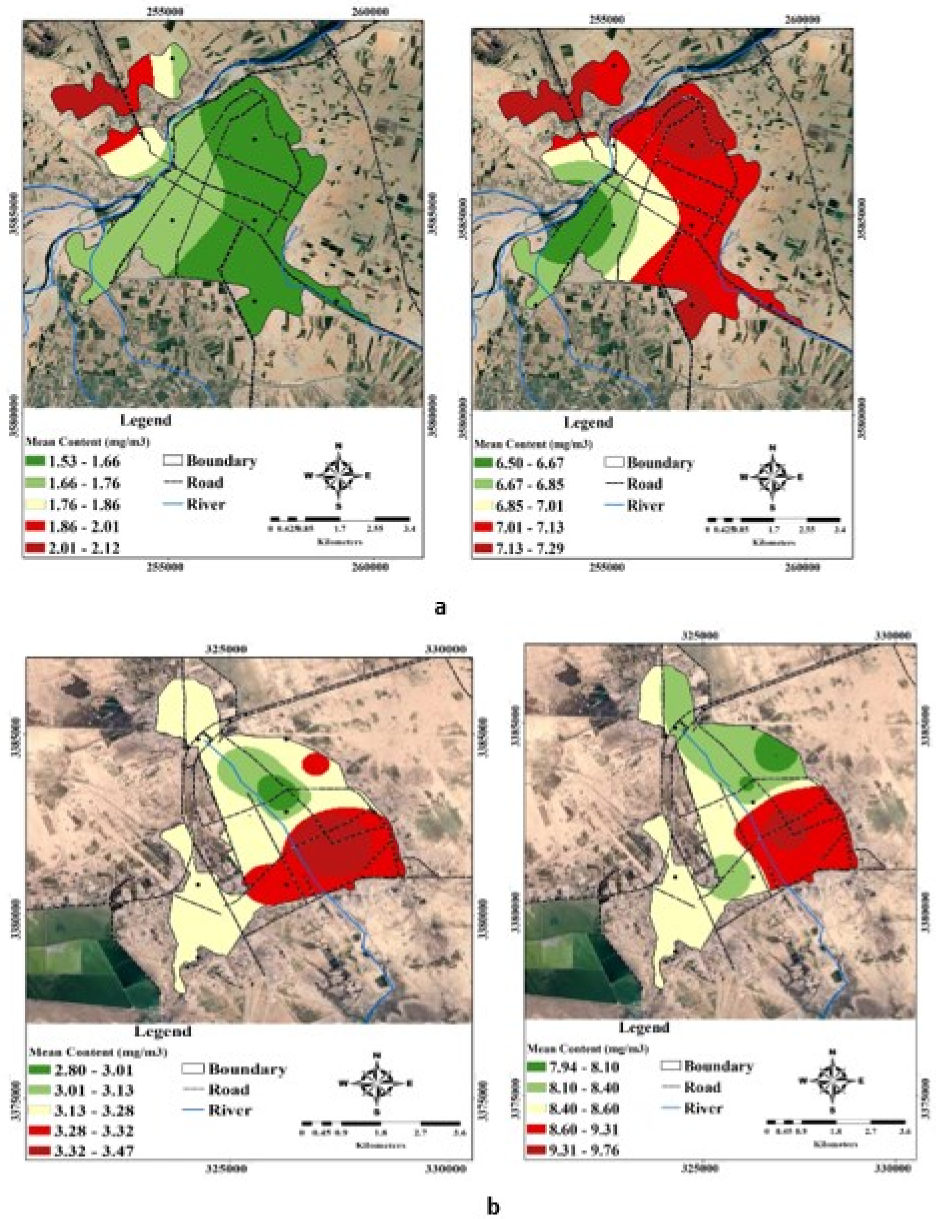


Figure 4. Heavy metal concentration zoningmetals in the dust of polluted and non-polluted aira. Abadan b. Ahvaz



Continues Figure 4. Heavy metal concentration zoningmetals in the dust of polluted and non-polluted air. a Dezfol, b. Mahshahr

Table 3. The concentration of metals in the collected dust from the cities of Khuzestan (2018-2019, mg/Kg)

	Total		Mahshahr		Dezful		Ahvaz		Abadan			
Sig	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	**Sampling Method**	**Element (mg/m^3)**
0.012	0.46	4.29	0.48	2.90	0.24	1.42	0.44	2.09	0.24	2.53	Non-dust	Cr
	0.8	6.84	0.37	5.64	1.04	4.99	1.04	3.50	0.41	3.24	Dusty	
0.011	0.0	0.0	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	Non-dust	Cu
	0.31	0.95	n.d	n.d	0.04	0.19	0.21	0.77	0.09	0.31	Dusty	
0.001	0.0	0.0	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	Non-dust	Zn
	29.70	128.42	44.34	118.15	2.07	22.65	12.06	64.97	5.07	79.08	Dusty	
0.009	1.22	7.56	0.11	0.68	0.09	0.59	0.23	0.9	0.32	1.17	Non-dust	Pb
	2.56	16.05	0.31	1.53	0.09	1.07	0.24	2.53	0.45	2.44	Dusty	
0.05	0.81	6.38	2.32	8.18	0.41	3.79	0.60	2.38	0.09	1.79	Non-dust	Ni
	2.47	12	2.14	9.58	0.94	3.99	1.06	0.72	0.14	3.10	Dusty	
0.010	0.17	1.22	0.15	1.34	0.05	0.2	0.07	0.59	0.05	0.67	Non-dust	Fe
	0.30	2.21	0.66	3.06	0.09	0.28	0.19	32.51	0.18	0.96	Dusty	
0.279	3.38	19.9	2.19	19.38	1.10	10.15	5.67	41.59	2.69	17.36	Non-dust	Mg
	4.02	25.74	9.77	40.23	5.50	30.55	6.44	11.04	3.05	16.68	Dusty	
0.148	4.97	17.95	0.82	6.85	n.d	n.d	1.72	10.79	4.29	12.91	Non-dust	Mn
	6.71	30.48	0.96	8.9	0.10	6.73	1.82	-	6.81	23.05	Dusty	

Table 4. Presents the average concentration of metals with the collected data from other cities or points in previous studies and with the acute and chronic concentrations

As	Ba	V	Al	Mn	Mg	Fe	Ni	Pb	Zn	Cu	Cr	Cd	CO	Location	Author
				0.24		0.43		0.09	0.07	0.14	0.46			environment of King Faisal University Campus (mg/Kg)	El-Sergany and El-Sharkawy 2011
		82.2		566.3					77.5	31.5	247.8		56.2	Baotou, China (mg/Kg)	Xu *et al*. 2015
	990.1	84.8					29.9	61.4	134.9	34.8	76.5		15.5	Urban area, Topsoil Xi'an, China (mg/Kg)	Li and Feng 2010
				365.1		11280	79	68.1	170	54	35.7		11.7	atmospheric dust from southwestern Iran(mg/Kg)	Naderizadeh *et al*. 2016
					32.6	3285	36.6		91.5	11.6	17.8			Kermanshah Province, Iran (mg/Kg)	Ahmadi Doabi *et al*. 2016
				139			20	84	890	159	26	0.8	11.5	S_1 ahvaz (μg/g)	Neisi *et al*. 2016
				129			18	124	701	131	25	0.65	10	S_2 ahvaz (μg/g)	Neisi *et al*. 2016
				826			10	39.6	386	72	20	0.42	6.1	S_3 ahvaz (μg/g)	Neisi *et al*. 2016
12.02				3407.3			31.25	183.93	299.37	36.39	141.24	2.20	26.94	(Bayan Obo), China (mg/Kg)	Kexin *et al*. 2017

							151.24	191.71	85.39	432.58	105.82	3.10		Attinguieollbooth, Abidjan (mg/Kg)		Dibert and Paul 2018
					788.97		24.93	46.77	333.73	171.33	122.17	5.13		Cracow, Poland (mg/Kg)		Hajduga *et al*. 2019
				2256		160170	4.04	19.12	22.87	8.63		1.56	2.6	Falling dust, Yazd, Iran (mg/Kg)		Esfandiari *et al*. 2019
n.a	n.a	n.a	n.a	23.05	16.68	0.96	3.10	2.44	79.7	0.31	3.24	n.a	n.a	Abadan	mg/kg	this study
n.a	n.a	n.a	n.a	10.79	41.59	0.59	3.7	2.53	64.97	0.77	3.50	n.a	n.a	Ahvaz		
n.a	n.a	n.a	n.a	6.73	30.55	0.27	3.99	1.07	22.65	0.19	4.99	n.a	n.a	Dezful		
n.a	n.a	n.a	n.a	8.9	40.23	3.06	9.58	1.53	118.15	n.a	5.64	n.a	n.a	Mahshahr		
0.004				0.02			0.003			10.77	0.04	0.002	0.002	Reference acute concentration (mg/Kg)	EPA 2005	
0.06			0.07			2.49		37.39				0.006	-	Reference chronic concentration (mg/Kg)		

Table5. The exposure to metals through ingestion of dust in the cities of Khuzestan (2018-2019)

D_{ing} (mg/kg/day)									
Mahshahr		**Dezful**		**Ahvaz**		**Abadan**		**air pollution**	**meta**
Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**Adult**	**Children**		
2.04305E-06	1.90685E-05	1.00039E-06	9.33699E-06	1.47241E-06	1.37425E-05	1.78239E-06	1.66356E-05	Non-dust air	Cr
3.97339E-06	3.70849E-05	3.51546E-06	3.2811E-05	2.46575E-06	2.30137E-05	2.28258E-06	2.13041E-05	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Cu
-	-	1.33855E-07	1.24932E-06	5.42466E-07	5.06301E-06	2.18395E-07	2.03836E-06	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Zn
8.32368E-05	0.000776877	1.59569E-05	0.000148932	4.57714E-05	0.0004272	5.57119E-05	0.000519978	Dusty air	
4.79061E-07	4.47123E-06	4.15656E-07	3.87945E-06	6.34051E-07	5.91781E-06	8.24266E-07	7.69315E-06	Non-dust air	Pb
1.07789E-06	1.00603E-05	7.53816E-07	7.03562E-06	1.78239E-06	1.66356E-05	1.71898E-06	1.60438E-05	Dusty air	
5.76282E-06	5.37863E-05	2.67006E-06	2.49205E-05	1.67671E-06	1.56493E-05	1.26106E-06	1.17699E-05	Non-dust air	Ni
6.74912E-06	6.29918E-05	2.81096E-06	2.62356E-05	2.60665E-06	2.43288E-05	2.18395E-06	2.03836E-05	Dusty air	
9.44031E-07	8.81096E-06	1.409E-07	1.31507E-06	5.07241E-07	4.73425E-06	4.72016E-07	4.40548E-06	Non-dust air	Fe
2.15577E-06	2.01205E-05	1.9726E-07	1.8411E-06	4.15656E-07	3.87945E-06	6.76321E-07	6.31233E-06	Dusty air	
1.36532E-05	0.00012743	7.15068E-06	6.67397E-05	2.29033E-05	0.000213764	1.22301E-05	0.000114148	Non-dust air	Mg
2.83421E-05	0.000264526	2.15225E-05	0.000200877	2.93002E-05	0.000273468	1.17511E-05	0.000109677	Dusty air	
4.82583E-06	4.50411E-05	-	-	7.77769E-06	7.25918E-05	9.09511E-06	8.48877E-05	Non-dust air	Mn
6.27006E-06	5.85205E-05	4.74129E-06	4.42521E-05	7.60157E-06	7.09479E-05	1.62387E-05	0.000151562	Dusty air	

Table 6. Inhalation of the metals of dust particles through the mouth and nose in the cities of Khuzestan province (2018-2019)

Mahshahr		Dezful		Ahvaz		Abadan		air pollution	metal
Adult	Children	Adult	Children	Adult	Children	Adult	Children		
3.00449E-10	5.32796E-10	1.47116E-10	2.60886E-10	2.17E-10	3.84E-10	2.62116E-10	4.64819E-10	Non-dust air	Cr
5.84321E-10	1.0362E-09	5.16979E-10	9.16777E-10	3.62611E-10	6.4303E-10	3.35674E-10	5.95262E-10	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Cu
0	0	1.96846E-11	3.49073E-11	7.97744E-11	1.41467E-10	3.2117E-09	5.69541E-11	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Zn
1.22407E-08	2.17068E-08	2.34661E-09	4.16132E-09	6.73109E-09	1.19365E-08	8.19293E-09	1.45288E-08	Dusty air	
7.04501E-11	1.24932E-10	6.11258E-11	1.08396E-10	9.32E-11	1.65E-10	1.21216E-10	2.14956E-10	Non-dust air	Pb
1.58513E-10	2.81096E-10	1.10855E-10	1.96583E-10	2.62116E-10	4.64819E-10	2.52792E-10	4.48284E-10	Dusty air	
8.47473E-10	1.50285E-09	3.92656E-10	6.96309E-10	2.47E-10	4.37E-10	1.8545E-10	3.28864E-10	Non-dust air	Ni
9.92518E-10	1.76006E-09	4.13376E-10	7.33054E-10	3.83331E-10	6.79774E-10	3.2117E-10	5.69541E-10	Dusty air	
1.38828E-10	2.46189E-10	2.07206E-11	3.67446E-11	7.46E-11	1.32E-10	6.94141E-11	1.23094E-10	Non-dust air	Fe
3.17025E-10	5.62192E-10	2.90089E-11	5.14424E-11	6.11258E-11	1.08396E-10	9.9459E-11	1.76374E-10	Dusty air	
2.00783E-09	3.56055E-09	1.05157E-09	1.86479E-09	3.37E-09	5.97E-07	1.79855E-09	3.18943E-09	Non-dust air	Mg
4.16795E-09	7.39117E-09	3.16507E-09	5.61273E-09	4.30885E-09	7.64103E-09	1.7281E-09	3.0645E-09	Dusty air	
7.09681E-10	1.2585E-09	-	-	1.14E-09	2.03E-09	1.33752E-09	2.37186E-09	Non-dust air	Mn
9.22067E-10	1.63513E-09	6.97249E-10	1.23645E-09	1.11788E-09	1.98237E-09	2.38805E-09	4.23481E-09	Dusty air	

Table 7. The dermal absorption of metal in the dust in the cities of Khuzestan (2018-2019)

Mahshahr		Dezful		Ahvaz		Abadan		air pollution	metal
Adult	Children	Adult	Children	Adult	Children	Adult	Children		
2.86027E-09	5.33918E-08	1.40055E-09	2.61436E-08	2.06137E-09	3.84789E-08	2.49534E-09	4.65797E-08	Non-dust air	Cr
5.56274E-09	1.03838E-07	4.92164E-09	9.18707E-08	3.45205E-09	6.44384E-08	3.19562E-09	5.96515E-08	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Cu
-	-	1.87397E-10	3.49808E-09	7.59452E-10	1.41764E-08	3.05753E-10	5.7074E-09	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Zn
1.16532E-07	2.17525E-06	2.23397E-08	4.17008E-07	6.408E-08	1.19616E-06	7.79967E-08	1.45594E-06	Dusty air	
6.70685E-10	1.25195E-08	5.81918E-10	1.08625E-08	8.87671E-10	1.65699E-08	1.15397E-09	2.15408E-08	Non-dust air	Pb
1.50904E-09	2.81688E-08	1.05534E-09	1.96997E-08	2.49534E-09	4.65797E-08	2.40658E-09	4.49227E-08	Dusty air	
8.06795E-09	1.50602E-07	3.73808E-09	6.97775E-08	2.3474E-09	4.38181E-08	1.76548E-09	3.29556E-08	Non-dust air	Ni
9.44877E-09	1.76377E-07	3.93534E-09	7.34597E-08	3.64932E-09	6.81205E-08	3.05753E-09	5.7074E-08	Dusty air	
1.32164E-09	2.46707E-08	1.9726E-10	3.68219E-09	7.10137E-10	1.32559E-08	6.60822E-10	1.23353E-08	Non-dust air	Fe
3.01808E-09	5.63375E-08	2.76164E-10	5.15507E-09	5.81918E-10	1.08625E-08	9.46849E-10	1.76745E-08	Dusty air	
1.91145E-08	3.56804E-07	1.0011E-08	1.86871E-07	3.20647E-08	5.9854E-07	1.71222E-08	3.19614E-07	Non-dust air	Mg
3.96789E-08	7.40673E-07	3.01315E-08	5.62455E-07	4.10203E-08	7.65712E-07	1.64515E-08	3.07095E-07	Dusty air	

6.75616E-09	1.26115E-07	-	-	1.08888E-08	2.03257E-07	1.27332E-08	2.37685E-07	Non-dust air	Mn
8.77808E-09	1.63858E-07	6.63781E-09	1.23906E-07	1.06422E-08	1.98654E-07	2.27342E-08	4.24373E-07	Dusty air	

Table 8. The HI index of metals for adults and children

HI									
Mahshahr		**Dezful**		**Ahvaz**		**Abadan**		**air pollution**	**metal**
Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**	**Adult**	**Children**		
2.04E-03	1.91E-02	1.00E-03	9.36E-03	1.47E-03	1.37E-02	1.78E-03	1.66E-02	Non-dust air	Cr
1.33E-03	1.24E-02	1.17E-03	1.10E-02	8.21E-04	7.69E-03	7.61E-04	7.12E-03	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Cu
-	-	3.33E-06	3.11E-05	1.36E-05	1.27E-04	5.54E-06	5.09E-05	Dusty air	
-	-	-	-	-	-	-	-	Non-dust air	Zn
2.78E-04	4.97E-03	5.31E-05	2.60E-03	1.53E-04	1.43E-03	1.86E-04	1.74E-03	Dusty air	
1.37E-04	1.28E-03	1.19E-04	1.11E-03	2.36E-04	1.69E-03	1.81E-03	2.20E-03	Non-dust air	Pb
3.57E-04	3.34E-03	2.51E-04	2.35E-03	5.94E-04	5.55E-03	5.71E-04	5.35E-03	Dusty air	
2.88E-04	2.69E-03	1.34E-04	1.28E-04	8.36E-05	7.82E-04	6.31E-05	5.87E-04	Non-dust air	Ni
1.30E-04	3.15E-03	1.41E-04	1.31E-03	3.42E-05	1.22E-03	1.09E-04	1.02E-03	Dusty air	
1.35E-06	1.26E-05	2.00E-07	1.88E-06	7.25E-07	6.78E-06	6.75E-07	6.30E-06	Non-dust air	Fe
3.08E-06	2.88E-05	2.82E-07	2.64E-06	5.94E-07	5.54E-06	9.66E-07	9.04E-06	Dusty air	
9.73E-05	9.13E-04	5.12E-05	4.78E-04	1.64E-04	1.54E-03	8.73E-05	8.18E-04	Non-dust air	Mg
2.02E-04	1.89E-03	1.54E-04	1.44E-03	2.10E-04	1.96E-03	8.37E-05	7.86E-04	Dusty air	
3.45E-05	3.22E-04	-	-	5.56E-05	5.19E-04	6.50E-05	6.07E-04	Non-dust air	Mn
4.49E-05	4.19E-04	3.39E-05	3.17E-04	5.44E-05	5.08E-04	1.16E-04	1.09E-03	Dusty air	

3.1. Non-carcinogenic risk assessment

According to the results of calculating the exposure to metals through the ingestion of dust or Ding, this amount is usually higher in children than in adults. The highest exposure in adults was in the four mentioned cities with Zinc and Manganese. Amount of exposure in children in Abadan, Ahvaz, Dezful, and Mahshahr were Chromium and Nickel, Chromium and Magnesium, Nickel, and Magnesium, respectively (Table. 5). This procedure is valid for two Ddermal and Dinb indexes, which are presented as follows:

The D_{inh} index in the dust was higher in dusty days than in non-dusty days, indicating an increase in the absorption of dust particles through the mouth and nose in the polluted air (Table 6). The highest amount of metals absorbed by inhalation in the Abadan, Dezful, and Mahshahr for adults and children belonged to Zn and Mn.

According to Table 7, the value of D_{dermal} was higher in dusty days than in non-dusty days. The highest dermal absorption of metals belonged to zinc metal (2.17525 l -06 mg/Kg/day). The dermal absorption of CO, Cd, Cr, Cu, Zn, Pb, Ni, As, Ba, Al, Mn, Mg, Fe, Fe was higher in children than in adults.

Figure 5 depicts a comparison of the risk indexes of D_{dermal}, D_{inh}, and D_{ing} in the children and adults of four Khuzestan cities. Overall, in the children and adults of all four cities, D_{inh} was the main way to absorb more metals. In minor cases, the absorption of zinc, manganese, and magnesium in the children of Abadan, and zinc and manganese in the children of Ahvaz and Dezful were was at a higher level through D_{dermal}.

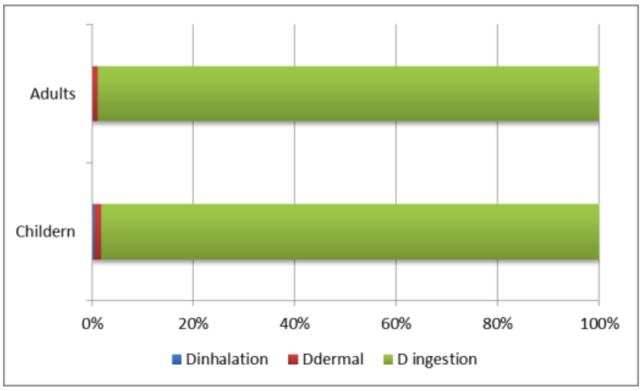


Figure 5. Biological dispersal risk of different exposure ways of children and adults in the cities of Khuzestan province (2018-2019)

To assess the non-carcinogenic risk, HQ was obtained primarily based on different ways of exposure to the metals, and then the HI index was obtained for the elements; Table 8 presents the results. The highest amount of HI was for magnesium in Abadan, copper, and manganese in Ahvaz, chromium, zinc, nickel, and iron in Mahshahr in dusty and non-dusty days. Likewise, lead had the highest Hi in non-dusty days in Abadan and in dusty and non-dusty days in Ahvaz. According to HI <1, the air (clear and dusty) of all four cities of Abadan, Ahvaz, Dezful, and Mahshahr showed no non-carcinogeniceffect on adults and children.

Air pollution in large cities has been intensified over the recent decades due to various pollutants such as vehicles, industries, heating devices, commercial-building activities, climate change, and natural disasters, increasing the pollution like dust in arid and desert regions (Xu *et al*. 2021).

According to the results of this study, among the 13 metals, the concentration of CO, T, Cd, As, Ba, V, Al in dusty and non-dusty conditions, and Zn, Cu in non-dusty condition were not measurable. In the dusty air, the concentration of heavy metals in order was Zn>Mn>Mg>Pb>Ni>Cr>Fe>Cu and in non-dusty condition, it was Mg>Mn>Pb>Ni>Cr>Fe, which showed that the origin of zinc and copper was dust and transfer of pollution by this phenomenon. Such a result can be seen in zoning metals figures in contaminated and non-contaminated conditions.

Lee and Park (2010) in their study reported that the mean concentration of lead particles and manganese in air pollutants was several times those in the usual air, being consistent with the findings of the present study. In non-dusty days, Mg had the highest concentration in Abadan, Ahvaz, Dezful, and Mahshahr, and in dusty days, Zn in Abadan, Mahshahr, and Ahvaz, and Mg in Dezful and Zn had the highest concentration among metals. The point shared between these three cities was the existence of the oil extraction and refining industry in the vicinity of the three cities, while there was no such industry in Dezful an agricultural city, justifying the higher amount of magnesium (agricultural fertilizer).

In non-polluted condition, the cluster analysis indicated that the origin of magnesium, manganese, and nickel was different from that of other metals, but in polluted condition, the origin of zinc was highly different from that of other metals, which should be categorized in a separate group. This isuue demonstrated that zinc concentration was highly influenced by dust and pollution transfer, especially from around industrial sites. Jafari (2013) reported two natural sources for nickel and manganese and human sources for zinc, copper, and lead by investigating the atmosphere of Kerman using the main component analysis and the cluster analysis. One study in India indicated that the concentration of elements in the dust was affected by meteorological factors, geographical conditions and particle production sources such as industrial resources, traffic, agricultural activity, and natural resources production (Lara *et al*. 2021).

Kamani *et al* (2023) high urban traffic, imperfect combustion of fossil fuels, as well as frequent temperature inversions due to climate changes have been reported as the main causes of the strong growth of pollution in cities with high traffic.

The source of zinc and lead in the dust is the wear of tires and the corrosion of metallic parts of the vehicles. Therefore, it was predictable due to the increased movement and a higher number of vehicles, especially in the Ahvaz metropolis in dusty condition. Likewise, the increase in the concentration of nickel and chromium is also associated with the movement of vehicles and the concentration of dust in the air (Faisal *et al*. 2021).

Al Bakain *et al*., (2012) reported that nickel originated mainly from industrial sources. Wei *et al*., (2010) reported that traffic and industry were the major source of nickel, and reported that the traffic diffusion might be the source of zinc, copper, and chromium pollution, while chromium may have originated from the combination of traffic and industrial sources. The high concentration of heavy metals, especially zinc and chromium in Mahshahr is most likely due to industrial activity, particularly in the existence of large petrochemical complexes transferred from an industrial zone to cities by dust and wind. This indicates that these elements can cause serious problems of pollution by accumulation on the soil surface, and disturb the balance of elements in the soil. Furthermore, with the transition to the food chain and attraction of these elements by humans, the health of the people, especially children and the elderly, would be in danger. A comparison of the concentration of dust metals in the Khuzestan to Kermanshah province, which has a higher number of dust days compared to Khuzestan province, showed higher concentrations of pollution, including CO, Cd, and Cr metals.

Additionally, dust particles are generally made of fine particles in the size of silt and clay. Moreover, owing to their high specific surface and heavy metals tendency for surface absorption of clay (Gujre *et al*. 2021), they are capable of transferring high amounts of heavy metals. Comparison of the density of nickel, manganese, and arsenic in air pollution conditions in four cities investigated with acute and chronic reference concentration (EPA 2005) showed that, apart from copper, other metals had high concentrations. The results of the indexes indicated that the non-carcinogenic risk index HI was highly influenced by the type of activity in the city as this index was highest in Cr, Zn, Fe, Fe, and Mg in the city of Mahshahr due to the high volume of oil-dependent activity compared to Ahvaz and Abadan. In the children and adults of Abadan, Dezful, Mahshahr, and adults of Ahvaz, the inhalation route (D_{inh} and D_{ing}) was the main route of transmission. In general, the HI index for the metals studied through different ways of exposure (oral, dermal, and inhalation) was at a higher level for children than for adults, since children had more contact with dirt and street dust, so that significant amounts of dust entered their mouths. Furthermore, owing to inadequate and poor immune systems, children are more prone to poisoning with heavy metals (Men *et al*. 2018). It should be noted that the analysis of these results requires a more detailed investigation of the atmosphere through atmospheric models (Yin *et al*. 2023) and meteorological factors are less studied. Among the studies that have been done in this field is the study by Chen *et al*. (2023), which investigated the correlation between six meteorological factors, temperature, dew point, humidity, air pressure, wind speed, and visibility. could pointed out to the hourly concentration of PM2.5 in Beijing.

3.1.1. Conclusion

The results of the non-carcinogenic risk index (HI) indicated that the highest amount of HI in children and adults for the samples was in Mahshahr. After this city, the cities of Abadan, Ahvaz, and Dezful had the highest index of the non-carcinogenic risk index; however, due to the low values of this index, non-carcinogenic risk of the dust was low in the four cities.

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