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HEALTH RISK ASSESSMENT TROUGH EXPOSURE TO HEAVY METALS IN URBAN AND SUBURBAN DUST EMITTED FROM WORKPLACE IN AQABA INDUSTRIAL ESTATE, JORDAN

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ABSTRACT: The present study assesses health risks associated with heavy metal Pb, Zn, Cu, Cr, Mn, Ni and Fe exposure to workplace residents activates in Aqaba Industrial Estate (AIE). The children's and adults' average daily intake (*ADI*), Quotation Index (*HQ*) and Hazard Index (*HI*) were assessed. Non-carcinogenic health risk assessment for Pb, Zn, Cu, Cr, Mn, Ni and Fe (*HQ* >1) indicated strong chances of adverse effects on children and adults living around the workplace area. The *HI>1* analysis for heavy metals, which is considered a threat to children and adults, but the highest risk contributor is the inhalation pathway. Child and adult cancer risk followed the same decreasing order, Pb> Cr > Ni Children were found to have higher than permissible limits (10^{-6}), which is considered a threat to children as they cause a variety of diseases.

Keywords: Heavy metals, Exposure, Human health risk, Dust materials, Jordan

1. INTRODUCTION

Heavy metals can possibly contain inside the dust particles such as dust from the industrial sector and can be distributed or redistributed into the atmosphere directly from sources such as road traffic, road dust resuspension and industrial processes. [1-7]. Dust particulates from these sources may contain hazardous metals and can have both carcinogenic and non-carcinogenic effects. Heavy metals have long been well-known toxicity, as well as their threat to the environment and public health [8-9].

In previous studies, industrial activities have had risk consequences for different environmental components such as soils, sediments, surface water and groundwater. [10-12] suggests that a certain distribution of heavy metal contaminants is transferred from the workplace into dust, road dust and soils. A study by [13] also shows that the surface soil samples of the Hassi Messaoud, Algeria, are highly contaminated with heavy metals such as Cu, Ni, Co, Cr, Mn and Pb. Street dust contaminated with these elements is the most appropriate route for human toxic element exposure. Through various pathways such as ingestion, inhalation and dermal absorption, these contaminants enter the human body. Once they enter the human body, most toxic elements are adsorbed, accumulated and biomagnified in the human body, resulting in a wide variety of diseases. [14-15]. Heavy metal contamination has been a serious human health problem, such as damaging neurological system, kidney function, ossification process and various other health issues [16].

Extensive studies have been reported for heavy metals concentrated in the finer particles (e.g. dust), and then can be easily transferred and accumulated to the human body among three exposure ways, mainly inhalation, ingestion and absorption [17], affecting on the nervous system, cardiovascular system, blood and bone diseases, kidney failure, tremors or promoters of other diseases. These metals are easily released into the environment through anthropogenic activities such as metal plating facilities, mining and agricultural activities. Heavy metal contamination is one of the primary environmental issues surrounding industrial activities. Soil inhalation and ingestion, however, were the primary routes for exposure to heavy metals and posed carcinogenic and non-carcinogenic health risks for residents in the industrial activates of the area. [18]. The potential health risk posed by heavy metals, such as Cd, Cr, Cu, Pb, Mn, and Zn which are of concern if they are direct ingestion, dermal absorption, and inhalation, such soil substrate particles [19]. Health risk research in Aqaba Industrial Estate, Jordan was highly frightful due to the exposure to fine particulate matter (dust). The main objectives of this study: (1) measuring heavy metal

concentrations of Pb, Zn, Cu, Cr, Mn, Ni, and Fe in soil dust and street dust; (2) assessment health risk of the carcinogenic and non-carcinogenic for adults and children; (3) estimating the three exposure pathways due to inhalation, ingestion and dermal contact.

2. MATERIALS AND METHODS

2.1 The Study Area

The study area is located in the southwestern part of Jordan on the north shore of the Gulf of Aqaba. It is approximately 51 m above sea level, limited by latitude (29º 33' N) and longitude (35º 0' E) (Fig.1). The main industries of Aqaba town include the Jordan Phosphate Company, cement and petroleum industries, the Jordan fertilizer industry, and the plant and chemical industry. It has 120 000 residents. The climate of Jordan is predominantly Mediterranean; it is marked by sharp seasonal variations in both temperature and precipitation. Aqaba city climate is very hot in summer and warm in winter and is characterized by an extremely small amount of precipitation, which is around 17.0 mm/year [20].

The geological setting of the study area generally represents the Precambrian igneous rock complex associated with the metamorphic rocks covered an area of about 896 km². This formation unconformable overlain by the Late Proterozoic sedimentary sandstone sediments. The Precambrian rocks are also unconformably overlain by the Lower Paleozoic marine to continental sediments dipping to the north and north-east. The Gulf of Aqaba occupies these plains and receives its products of floods. The area is generally covered by Quaternary sediments consisting of a stream type of alluviums with a valley fill type of sediments in the lower part of the basin. Two geological formations occur predominantly in and around the study area. Jordan's oldest rocks (pre-Cambrian age, 570 million years old) are the main component of the mountains behind Aqaba [21].

2.2 Samples Collection

Ninety-four samples were collected from eight sites around the workplace in Aqaba Industrial Estate (AIE), mainly soil dust and street dust. Sites were selected to represent a variety of industrial activates including soil area, residential area, car service, furniture, steel and non-steel, ovens and smelters, mechanical, construction materials, and reference soil (Fig. 1). The original composite sample was approximately 500 g passed through (<63 microns), dried and stored at a temperature of 105°C in cloth bags and was homogenized. The reference soil was collected 1000 m west of the workplace as the wind direction in the area under study was to the west. The selected samples were stored in polyethylene containers and prepared for analysis. The sampling was chosen at the end of the dry summer months following at least four rainless months.

2.3 Chemical Analysis

The soil samples were then analyzed for heavy metals using Shimadzu's Atomic Absorption Spectrophotometer (AAS), model AA-6200 at Bin Hayyan Laboratories Management, Aqaba, Jordan. Acetylene gas was used as support for fuel and air. In all cases, an oxidizing flame was used. Total digestion was performed on 120 samples. One gram of each dust, street dust and soil sample was accurately weighed into a digestion Teflon beaker and 50 mL of aqua-regia mixture (HCl/HNO_3, 1:3 v/v added). The sample was then heated for 15 min without boiling at 95ºC on a hot plate. After cooling, the sample was filtered through a 45 µm pore size Millipore filter into a 25 ml volumetric flask, and then diluted to the mark with 1% HNO_3 solution [22]. The supernatant solutions were prepared for chemical analysis by AAS. The pH and EC of soil samples were determined by mixing 1:2.5 (w/v) soil-distilled water suspension (Model Perkin Elmer A800 "Graphite and Flame"). Accuracy and precision of the analyses were controlled by duplicate measurements of the certified standard stock from Merck. For trace elements, the errors in accuracy were < 7%.

2.4 Health Risk Assessment

Risk assessment is a process used to estimate the human increased risk of health problems as a result of exposure to a toxic pollutant. Risk assessment methods can be used to estimate the increased risk of adverse health effects in humans due to toxic pollutants in the environment [23].

2.4.1 Non-carcinogenic risk assessment

Hazard identification

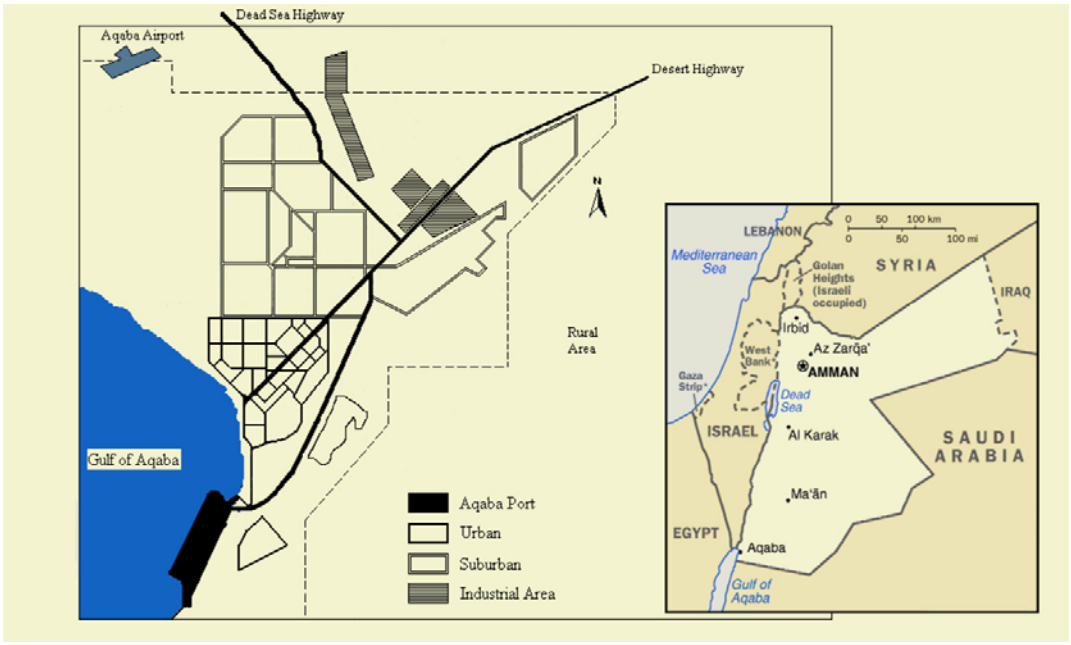

Fig. 1 Location map of the study area.

Hazard Identification (*HQ*) is basically intended to investigate chemicals that are present at any given location, their concentrations, and spatial distribution. For example, heavy metals such as Pb, Cr, Ni, Cu, Mn, Fe and Zn were investigated as potential workplace health risks in the study area. Exposure assessment is the process of measuring the intensity, frequency, and duration of human exposure to an environmental agent. Exposure to contaminants can occur through inhalation, ingestion, or absorption through the skin upon dermal contact [24].

The average daily intake (*ADI*) is a very important concept in chemicals exposure assessment. The average daily intake is calculated by measuring the intakes of toxic metals through the three pathways inhalation, ingestion, or absorption through the skin upon dermal contact. The study conducted an exposure assessment by measuring the (*ADI*) of earlier identified heavy metals through ingestion, inhalation, and dermal contact by children and adults from the study area. Due to their behavioral and physiological differences, adults and children are separated [25]. Using the formula that shows in Table 1, the daily intake of exposed heavy metals can be determined by quantitatively calculated. Table 2 shows the input parameters were employed in determining *ADI* values through pathways of human exposure, such as ingestion, dermal contact and inhalation.

Table 1 Equations of average daily intake with different exposure pathways (units in mg kg^{-1} day^{-1})

	Exposure pathways Average daily intake
Ingestion of soil	$ADI_{ing} = (Cs \times IR \times EF \times ED)/(BW \times AT)$
Dermal contact with soil	$ADI_{der} = (Cs \times CF \times SAe \times AF \times Abs \times EF \times ED)/(BW \times AT)$
Inhalation of dust	$ADI_{inh} = (TSP \times frs \times CRi \times t \times tf) \times Cs \times fr \times fa \times EF \times ED/(BW \times AT)$

Cs = concentration of metal in the sample (Cs for soil and dust)
TSP = Total Suspended Particle

Table 2 Parameters used to evaluate the exposure risk due to soil elements [23]

Factor/Parameter	Symbol	Media	Units	Residents
Exposure duration	ED	Soil and dust	years	Carcinogen-70 Non-carcinogen-30
Exposure Frequency	EF	all	days/year	365
Averaging time	AT	all	days	ED×EF
Body weight	BW	all	kg	60

Ingestion rate	IR	all	kg/day	0.0001
Skin area exposed	SAe	all	cm2	5700 (adults), 2800 (children)
Adherence factor	AF	all	mg/cm2	0.07
Absorption factor	ABS	all	unitless	0.006 (Pb), 0.001 (Cr), 0.1 Cu), 0.02 (Zn), 0.001(Ni), 0.001(Mn)0.001(Fe)
Total Suspended Particle	TSP	Soil	mg/m3	
		indoor		0.07
		outdoor		0.053
Soil fraction in dust soil -	frs	all	-	
		indoor	-	0.8
		outdoor	-	0.5
Inhalation rate	Cri	all	m3/day	20
Exposure time/day	t	all	h/d	8
Exposure ratio	tf	indoor	-	2.86
		outdoor	-	0.143
Retention factor particles in lung soil	fr	all	-	0.75
Relative Absorption factor soil	fa	all	-	1

Table 3 Reference Doses (RfD) in (mg/kg-day) and Carcinogenic Slope Factors (SF) (mg kg^{-1} day^{-1}) for the different heavy metals

Heavy metal	RFDing	RFDder	RFDinh	SFing	SFder	SFinh	References
Pb	3.50E-03	5.25E-04	3.52E-03	8.50E-03	-	4.20E-02	[29]
Zn	3.00E-01	6.00E-02	3.01E-01	-	-	-	[29]
Cu	4.00E-02	1.20E-02	4.02E-02	-	-	-	[29]
Cr	3.00E-03	6.00E-05	2.86E-05	5.00E-01	-	4.10E+01	[29]
Mn	2.00E-02	2.00E-02	2.00E-02	-	-	-	[29]
Ni	7.00E-01	5.40E-03	3.52E-03	-	-	8.40E-01	[29]
Fe	2.40E-02	2.40E-02	2.40E-02	-	-	-	[29]

Non-carcinogenic hazards are reported as hazard quotient. Hazard quotient is a unitless number expressed as the probability of an individual having an adverse effect. The *HQ* is defined as *ADI* calculated for each element and for each exposure route per day is then divided by the reference dose (*RfD* in mg kg^{-1} day^{-1}. The *HQ* for non-carcinogenic hazards was calculated using the following equation [26]:

$$HQ=\frac{ADI}{RfD} \quad (1)$$

According to [27], HQ less than 1 refers to no adverse health effect whereas HQgreater than 1 refers to an adverse health effect.[28] reported the RfD values for heavy metals through ingestion, dermal contact and inhalation, and are given in Table 3.

RFDing: Ingestion reference dose.
RFDinh: Inhalation reference dose.
RFDder: Dermal contact reference dose.

Hazard Index (*HI*) is expressed as the sum of all *HQ* for a specific exposure pathway [30]. If *HI* is greater than 1, it is revered that adverse health effects while *HI* below 1, it is revered no adverse health effects, as reported by the [26]. Hazard Index is calculated by using the given formula:

$$HI=\sum HQ=\sum\frac{ADI}{RfD} \quad (2)$$

2.4.2 Carcinogenic risk assessment

Carcinogens risks are estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The equation for calculating the excess lifetime cancer risk is:

$$Risk_{pathway}=\sum ADI^{s} \quad (3)$$

where risk is a unitless probability of an individual developing cancer over a lifetime. The

ADI ($mgkg^{-1}day^{-1}$) and the cancer slope factor (*SF*) ($mgkg^{-1}day^{-1}$) are for the heavy metal, for n number of heavy metals. The slope factor converts the estimated daily intake of the heavy metal

The total excess lifetime cancer risk for an individual is finally calculated from the average contribution of the individual heavy metals for all the pathways using the following equation:

$$Risk_{(total)} = Risk_{(ing)} + Risk_{(dermal)} Risk \quad (4)$$

where $Risk_{(ing)}$, $Risk_{(inh)}$, and $Risk_{(dermal)}$ are risk contributions through ingestion, dermal and inhalation pathways. Table 3 shows both non-carcinogenic and carcinogenic heavy metal risk assessments using *RfD* and SF values.

2. RESULTS AND DISCUSSION

3.1 Contamination of Heavy Metals

The descriptive statistical analysis of heavy metals in dust parameters is given in Table 4. The results showed that the average concentrations of heavy metals in workplace dust samples varied significantly and decreased in the order of Zn > Pb

averaged over a lifetime of exposure directly into an incremental risk of an individual developing cancer [26].

> Cu > Fe > Ni > Mn > Cr. The average ranges were as follows: Zn (4-561 $mgkg^{-1}$); Pb (3-263 $mgkg^{-1}$); Cu (1-217 $mgkg^{-1}$); Fe (8-114 $mgkg^{-1}$), Ni (5-34 $mgkg^{-1}$); Mn (10-62 $mgkg^{-1}$); Cr (1-24 $mgkg^{-1}$). It can be concluded that the minimum mean concentration of Zn (4 $mgkg^{-1}$) was recorded from the soil dust area (site 1) and a maximum mean concentration of 560 $mgkg^{-1}$ (site 7). At Cr, the minimum mean concentration was 1.00 $mgkg^{-1}$ in site 2 (Residential area) and the site 6 (Ovens and Smelters) mean maximum was 24 $mgkg^{-1}$. On the other hand, Cu recorded at site 2 (Residential area) a minimum mean concentration of 1.00 $mgkg^{-1}$, while a maximum of mean 217.00 $mgkg^{-1}$ was recorded in soil dust (site 1). Table 5 shows the maximum allowable limit on concentrations of heavy metals in urban soil ($mgkg^{-1}$) for different countries compared with the recommended maximum. In the present study, Cu and Cr were found to be the highest. Pb, Zn, and Fe, however, were below the maximum permissible limits, while Mn and Ni were comparable to other countries

Table 4 Descriptive statistical analysis for the heavy metal concentrations in dust samples from different workplace locations.

	Location	Pb	Zn	Cu	Cr	Mn	Ni	Fe
		(N= 26)						
Minimum	Site 1: Soil area	1.85	3.60	212	6.50	12.9	21.9	8.14
Maximums		5.65	7.15	231	17.7	20.5	30.3	18.9
Mean		3.45	3.55	217	8.70	12.5	24.53	8.10
Standard deviation		1.05	1.92	21	2.83	3.45	5.21	2.96
		(N= 26)						
Minimum	Site 2: Residential area	0.83	99	0.50	0.24	4.60	1.20	22.5
Maximums		18.9	375	1.32	3.20	15.6	30.5	78.1
Mean		4.20	239	0.52	1.25	9.59	10.65	35.9
Standard deviation		0.95	20	0.04	0.25	1.84	1.96	5.65
		(N= 7)						
Minimum	Site 3: Car service	231	244	21	2.22	32	22	25
Maximums		286	265	26	3.60	39	38	154
Mean		263	300	23	3.40	35	34	114
Standard deviation		18	7	2	0.48	2	5	16
		(N= 7)						
Minimum	Site 4: Furniture	21.2	195	11	2.25	12	2	19
Maximums		26.5	233	18	4.20	22	8	117
Mean		23.5	221	14	3.10	18	5	85
Standard deviation		1.82	14	2	0.73	3	2	9
		(N= 7)						
Minimum		44.5	233	23	6	35	8	30
Maximums		65.3	276	36	18	49	15	142

Mean	Site 5: Steel and non-steel	55.85	256	33	10	44	12	93
Standard deviation		5.7 (N= 7)	13	4	4.34	5	2.	10
Minimum	Site 6: Ovens and smelters	174	266	24	22	52	19	28
Maximums		198	310	48	29	64	25	133
Mean		185	287	38	24	62	22	88
Standard deviation		8.25 (N= 7)	16	8	2.85	5.27	1.97	9
Minimum	Site 7: Mechanical and electrical	155	542	21	6	2	27	11
Maximums		185	695	38	16	56	38	13
Mean		170	561	28	12	35	31.5	85
Standard deviation		9 (N= 7)	65	6	3	9	4.07	11
Minimum	Site 8: Construction materials	136	658	35	5	5	7.1	10
Maximums		176	895	69	16	11	11.2	106
Mean		156	225	42	11	19	15.8	78
Standard deviation		11	75	11	4.18	2	1.50	11
Reference		24	1	3	4	4	0.45	3

* N= number of sample

Table 5 Maximum allowable limit of heavy metals concentrations in urban soil (mg kg^{-1}) for different countries

Workplace Location	Pb	Zn	Cu	Cr	Mn	Ni	Fe	References
Sohar Industrial Estate	30.2	2060	5.0	-	3.9	3.9	-	[30]
Madrid	161	210	71.7	-	437	14.1	-	[31]
Hong Kong	93.4	168	24.8	2.2	-	-	-	[32]
Bangkok	47.8	118	41.7	0.3	340	24.8	-	[33]
Aberdeen	94.4	58.4	27	-	286	14.9	-	[34]
Italy	149	183	90	-	-	209	-	[35]
Karak, Jordan	94.4	60.8	20.9	-	-	4.9	93.8	[7]
China	53.5	294.2	94.5	1.1	926.6	43.3	-	[36]
Ulaanbaatar	63.9	158.2	35.9	0.8	-	18.7	-	[37]
Aqaba, Jordan	3. 5	3.6	216.8	8.7	12.5	24.5	8.1	This study

3.2 Heavy Metal Exposure Dose

Table 6 shows the calculated daily intake of heavy metal dose from the various pathways. The daily dose intake of heavy metals for Pb was the highest, followed by Zn, Cu, Cr, Mn, Ni and Fe in descending order. The intake of heavy metal dose through the various pathways was the highest for dust inhalation, followed by dust in ingestion and dust contact dermal in descending order. The average daily dose for both adults and children through different exposure pathways follows the same trend, $ADI_{inh} > ADI_{ing} > ADI_{der}$. It is clear that the average daily dose for children is 2-folds, 1-folds, and 42-folds, respectively for ingestion, contact dermal, and inhalation pathways higher than the adult dose, which means that more heavy metals are exposed to all children than adults. These results were consistent with other studies reported by [38-39].

3.3 Non-Carcinogenic Risk Assessment

Non-carcinogenic risk values result for children and adults is shown in Table 6. These results for the pathways of ingestion, dermal and inhalation are all presented in terms of HQs as shown in Table 7. There is no obvious risk to the population when *HQ* and *HI* values are less than 1, but if these values exceed one, there may be a concern for potential non-carcinogenic effects [23].

Table 6 Average daily intake (ADI) values in mg/kg/day for adults and children in the studied samples

	Site 1						Site 2					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	4.9E-06	2.1E-06	1.2E-07	1.7E-07	4.7E-02	1.1E-03	6.0E-06	2.6E-06	1.4E-07	2.0E-07	5.8E-02	1.4E-03
Zn	5.1E-06	2.2E-06	1.2E-07	1.7E-07	4.9E-02	1.2E-03	3.4E-04	1.5E-04	8.2E-06	1.1E-05	3.3E+00	7.8E-02
Cu	3.1E-04	1.3E-04	1.2E-04	1.7E-04	3.0E+00	7.0E-02	7.4E-07	3.2E-07	3.0E-07	4.2E-07	7.1E-03	1.7E-04
Cr	1.2E-05	5.3E-06	5.0E-07	7.0E-07	1.2E-01	2.8E-03	1.8E-06	7.6E-07	7.1E-08	1.0E-07	1.7E-02	4.1E-04
Mn	1.8E-05	7.6E-06	7.1E-07	1.0E-07	1.7E-01	4.1E-03	1.4E-05	5.8E-06	5.5E-07	7.7E-08	1.3E-01	3.1E-03
Ni	3.5E-05	1.5E-05	1.4E-06	2.0E-06	3.4E-01	8.0E-03	1.5E-05	6.5E-06	6.1E-07	8.5E-07	1.5E-01	3.5E-03
Fe	1.2E-05	4.9E-06	4.6E-07	6.5E-07	1.1E-01	2.6E-03	5.1E-05	2.2E-05	2.0E-06	2.9E-06	4.9E-01	1.2E-02

	Site 3						Site 4					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	3.8E-04	1.6E-04	9.0E-06	1.3E-05	3.6E+00	8.5E-02	3.4E-05	1.4E-05	8.0E-07	1.1E-06	3.2E-01	7.6E-03
Zn	4.3E-04	1.8E-04	1.0E-05	1.4E-05	4.1E+00	9.8E-02	3.2E-04	1.3E-04	7.6E-06	1.1E-05	3.0E+00	7.2E-02
Cu	3.3E-05	1.4E-05	1.3E-05	1.8E-05	3.2E-01	7.5E-03	2.0E-05	8.5E-06	8.0E-06	1.1E-05	1.9E-01	4.6E-03
Cr	4.9E-06	2.1E-06	1.9E-07	2.7E-07	4.7E-02	1.1E-03	4.4E-06	1.9E-06	1.8E-07	2.5E-07	4.3E-02	1.0E-03
Mn	5.0E-05	2.1E-05	2.0E-06	2.8E-07	4.8E-01	1.1E-02	2.6E-05	1.1E-05	1.0E-06	1.4E-07	2.5E-01	5.9E-03
Ni	4.9E-05	2.1E-05	1.9E-06	2.7E-06	4.7E-01	1.1E-02	7.1E-06	3.1E-06	2.9E-07	4.0E-07	6.9E-02	1.6E-03
Fe	1.6E-04	7.0E-05	6.5E-06	9.2E-06	1.6E+00	3.7E-02	1.2E-04	5.2E-05	4.8E-06	6.8E-06	1.2E+00	2.7E-02

	Site 5						Site 6					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	8.0E-05	3.4E-05	1.9E-06	2.7E-06	7.7E-01	1.8E-02	2.6E-04	1.1E-04	6.3E-06	8.9E-06	2.5E+00	6.0E-02
Zn	3.7E-04	1.6E-04	8.7E-06	1.2E-05	3.5E+00	8.3E-02	4.1E-04	1.8E-04	9.8E-06	1.4E-05	3.9E+00	9.3E-02
Cu	4.6E-05	2.0E-05	1.9E-05	2.6E-05	4.5E-01	1.1E-02	5.4E-05	2.3E-05	2.2E-05	3.0E-05	5.2E-01	1.2E-02
Cr	1.4E-05	6.1E-06	5.7E-07	8.0E-07	1.4E-01	3.3E-03	3.4E-05	1.5E-05	1.4E-06	1.9E-06	3.3E-01	7.8E-03
Mn	6.3E-05	2.7E-05	2.5E-06	3.5E-07	6.0E-01	1.4E-02	8.9E-05	3.8E-05	3.5E-06	5.0E-07	8.5E-01	2.0E-02
Ni	1.7E-05	7.3E-06	6.8E-07	9.6E-07	1.6E-01	3.9E-03	3.1E-05	1.3E-05	1.3E-06	1.8E-06	3.0E-01	7.2E-03
Ee	1.3E-04	5.6E-05	5.3E-06	7.4E-06	1.3E+00	3.0E-02	1.3E-04	5.3E-05	5.0E-06	7.0E-06	1.2E+00	2.8E-02

	Site 7						Site 8					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	2.4E-04	1.0E-04	5.8E-06	8.1E-06	2.3E+00	5.5E-02	2.2E-04	9.5E-05	5.3E-06	7.5E-06	2.1E+00	5.1E-02
Zn	8.0E-04	3.4E-04	1.9E-05	2.7E-05	7.7E+00	1.8E-01	3.2E-04	1.4E-04	7.7E-06	1.1E-05	3.1E+00	7.3E-02
Cu	3.9E-05	1.7E-05	1.6E-05	2.2E-05	3.8E-01	8.9E-03	6.1E-05	2.6E-05	2.4E-05	3.4E-05	5.8E-01	1.4E-02
Cr	1.6E-05	7.0E-06	6.6E-07	9.2E-07	1.6E-01	3.7E-03	1.6E-05	6.7E-06	6.3E-07	8.8E-07	1.5E-01	3.6E-03
Mn	5.0E-05	2.1E-05	2.0E-06	2.8E-07	4.8E-01	1.1E-02	2.6E-05	1.1E-05	1.1E-06	1.5E-07	2.5E-01	6.0E-03
Ni	4.5E-05	1.9E-05	1.8E-06	2.5E-06	4.3E-01	1.0E-02	2.3E-05	9.6E-06	9.0E-07	1.3E-06	2.2E-01	5.1E-03
Ee	1.2E-04	5.2E-05	4.8E-06	6.8E-06	1.2E+00	2.8E-02	1.1E-04	4.7E-05	4.4E-06	6.2E-06	1.1E+00	2.5E-02

Table 7 Non-carcinogenic risks (HQ) through four exposure pathways in heavy metals.

	Site 1						Site 2					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	1.41E-03	6.01E-04	2.25E-04	3.15E-04	1.35E+01	3.19E-01	1.71E-03	7.32E-04	2.74E-04	3.84E-04	1.64E+01	3.88E-01
Zn	1.69E-05	7.21E-06	2.02E-06	2.84E-06	7.40E+01	3.83E-03	1.14E-03	4.87E-04	1.37E-04	1.92E-04	1.09E+01	2.59E-01
Cu	7.74E-03	3.31E-03	1.03E-02	1.45E-02	1.62E-01	1.75E+00	1.86E-05	7.92E-06	2.47E-05	3.46E-05	1.77E-01	4.20E-03
Cr	4.14E-03	1.77E-03	8.27E-03	1.16E-02	4.18E+03	9.89E+01	5.96E-04	2.55E-04	1.19E-03	1.67E-03	6.01E+02	1.42E+01
Mn	8.92E-04	3.81E-04	3.56E-05	4.99E-06	8.57E+00	2.03E-01	6.85E-04	2.92E-04	2.73E-05	3.84E-06	6.58E+00	1.56E-01
Ni	5.01E-05	2.14E-05	2.59E-04	3.63E-04	9.57E+01	2.27E+00	2.17E-05	9.28E-06	1.12E-04	1.58E-04	4.15E+01	9.83E-01
Fe	4.82E-04	2.06E-04	1.92E-05	2.70E-05	4.63E+00	1.10E-01	2.14E-03	9.14E-04	8.54E-05	1.20E-04	2.06E+01	4.87E-01

	Site 3						Site 4					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	1.07E-01	4.58E-02	1.71E-02	2.40E-02	1.03E+03	2.43E+01	9.59E-03	4.10E-03	6.81	9.56	9.17E+01	2.17E+00
Zn	1.43E-03	6.10E-04	1.71E-04	2.40E-04	1.37E+01	3.24E-01	1.05E-03	4.49E-04	62.3	87.41	1.01E+01	2.39E-01.
Cu	8.21E-04	3.51E-04	1.09E-03	1.53E-03	7.85E+00	1.86E-01	5.00E-04	2.14E-04	0.06	0.09	4.78E+00	1.13E-01
Cr	1.62E-03	6.91E-04	3.23E-03	4.53E-03	1.63E+03	3.86E+01	1.48E-03	6.30E-04	0.36	0.50	1.49E+03	3.52E+01
Mn	2.50E-03	1.07E-03	9.98E-05	1.40E-05	2.40E+01	5.69E-01	1.29E-03	5.49E-04	1.44	0.20	1.24E+01	2.93E-01
Ni	6.94E-05	2.96E-05	3.59E-04	5.04E-04	1.33E+02	3.14E+00	1.02E-05	4.36E-06	0.20	0.29	1.95E+01	4.62E-01
Fe	6.82E-03	2.91E-03	2.72E-04	3.82E-04	2.06E+01	4.87E-01	5.04E-03	2.15E-03	10.45	14.67	4.84E+01	1.15E+00

	Site 5						Site 6					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	2.28E-02	9.73E-03	3.64E-03	5.11E-03	2.18E+02	5.16E+00	7.55E-02	3.22E-02	1.21E-02	1.69E-02	7.22E+02	1.71E+01
Zn	1.22E-03	5.20E-04	1.46E-04	2.04E-04	1.17E+01	2.76E-01	1.37E-03	5.84E-04	1.64E-04	2.30E-04	1.31E+01	3.10E-01
Cu	1.16E-03	4.96E-04	1.54E-03	2.17E-03	1.11E+01	2.63E-01	1.36E-03	5.80E-04	1.81E-03	2.53E-03	1.30E+01	3.07E-01
Cr	4.76E-03	2.03E-03	9.50E-03	1.33E-02	4.80E+03	1.14E+02	1.14E-02	4.88E-03	2.28E-02	3.20E-02	1.15E+04	2.73E+02
Mn	3.14E-03	1.34E-03	1.25E-04	1.76E-05	3.02E+01	7.15E-01	4.43E-03	1.89E-03	1.77E-04	2.48E-05	4.26E+01	1.01E+00
Ni	2.45E-05	1.05E-05	1.27E-04	1.78E-04	4.68E+01	1.11E+00	4.49E-05	1.92E-05	2.32E-04	3.26E-04	8.58E+01	2.03E+00
Fe	5.51E-03	2.35E-03	2.20E-04	3.08E-04	5.29E+01	1.25E+00	5.21E-03	2.23E-03	2.08E-04	2.92E-04	5.01E+01	1.19E+00

	Site 7						Site 8					
	Ingestion		Dermal		Inhalation		Ingestion		Dermal		Inhalation	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Pb	6.92E-02	2.95E-02	1.10E-02	1.55E-02	6.61E+02	1.56E+01	6.37E-02	2.72E-02	2.79	3.92	6.08E+02	1.44E+01
Zn	2.67E-03	1.14E-03	3.20E-04	4.49E-04	2.56E+01	6.06E-01	1.07E-03	4.58E-04	0.88	1.24	1.03E+01	2.43E-01
Cu	9.82E-04	4.19E-04	1.31E-03	1.83E-03	9.39E+00	2.22E-01	1.52E-03	6.48E-04	1.31	1.84	1.45E+01	3.44E-01
Cr	5.48E-03	2.34E-03	1.09E-02	1.53E-02	5.52E+03	1.31E+02	5.24E-03	2.24E-03	1.10	1.54	5.28E+03	1.25E+02
Mn	2.50E-03	1.07E-03	9.98E-05	1.40E-05	2.40E+01	5.69E-01	1.32E-03	5.64E-04	0.42	0.06	1.27E+01	3.01E-01
Ni	6.43E-05	2.75E-05	3.33E-04	4.67E-04	1.23E+02	2.91E+00	3.22E-05	1.38E-05	1.32	1.85	6.16E+01	1.46E+00
Fe	5.04E-03	2.15E-03	2.01E-04	2.82E-04	4.84E+01	1.15E+00	4.63E-03	1.97E-03	0.84	1.18	4.44E+01	1.05E+00

For the population of children and adults, calculated *HQ* values for all heavy metals were less than one in ingestion and contact dermal pathways, with the exception of two sites (4 and 8) for children and adults for which *HQ*>1. For children, on the other hand, the inhalation pathways had *HQ* values greater than 1 driven mainly by Pb, Zn, Cu, Cr, Mn, Ni and Fe, while adults had *HQ* values greater than 1 driven mainly by Pb, Cr, Ni and Fe, indicating inhalation pathways posed a high health risk to children and adults in the studied area. It can also be attributed to the greatest non-carcinogenic risk followed by the contact dermal pathway in both adults and children. Children and adults follow similar rising trends for HQ for all $HQ_{der}<HQ_{ing}<HQ_{inh}$ heavy metals.

Figure 2 shows the total non-carcinogenic *HI* for various heavy metals and three exposure pathways. For the population of children and adults, calculated *HI* values for all heavy metals were less than one in ingestion pathways. However, *HI* (children and adults) primarily driven for dermal and inhalation pathways by Pb, Zn, Cu, Cr, Mn, Ni and Fe was higher than one, which meant that the population of children and adults was at risk for non-carcinogenic effects. Children and adults follow similar increasing trends for *HI* for all $HI_{ing}<HI_{der}<HI_{inh}$ heavy metals. Inhalation is the highest risk contributor. It should be noted that the HI (children) is approximately 4 times greater than *HI* (adults).

The carcinogenic risk values for three exposure pathways in heavy metals Pb, Cr, and Ni for adults and children are listed in Table 8. The order of the *HI* for the three heavy metals is Pb > Cr > Ni. Thus, concentration of Pb, Cr and Ni in dust shows the likelihood of adverse effects on children and adults in the workplace for non-carcinogenic health. The average *HI* value for children and adult's ingestion pathways for Pb, Cr and Ni are well under the safe limit meaning that both children and adults do not have non-carcinogenic adverse effects. Overall assessment of the HI values for children is approximately 10 times higher than *HI* values for adults.

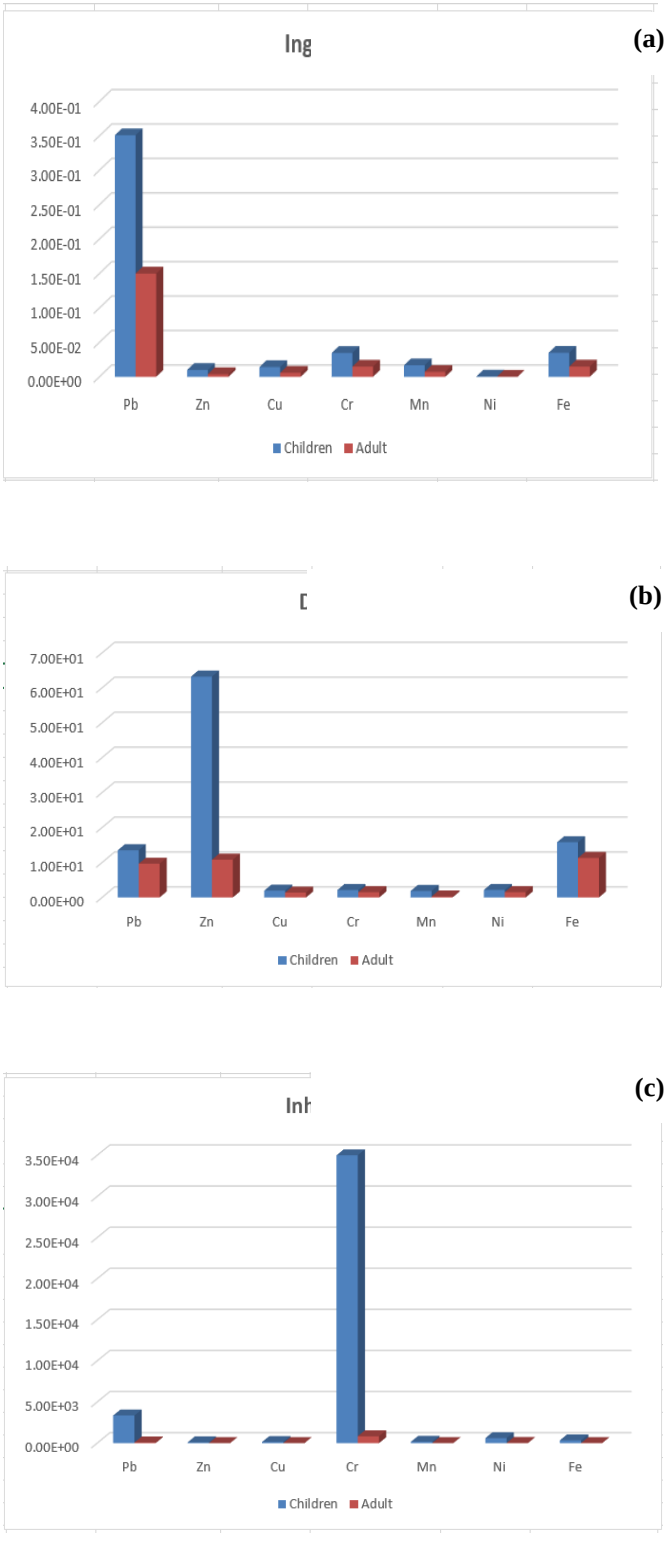

Fig. 2 Non-carcinogenic risks (HI) of seven heavy metals and three pathways, (a): Dermal, (b): Inhalation: and (c): Ingestion.

Table 8 Cancer risks for three exposure pathways in heavy metals

	Pb				Cr				Ni			
	Inhalation		Ingestion		Inhalation		Ingestion		Inhalation		Ingestion	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Site 1	4.19E-08	1.79E-08	4.71E-05	1.99E-03	6.21E-06	2.65E-06	4.90E+00	1.16E-01	-	-	2.83E-01	6.70E-03
Site 2	5.10E-08	2.18E-08	2.42E-03	2.42E-03	8.94E-07	3.82E-07	7.05E-01	1.67E-02	-	-	1.23E-01	2.91E-03
Site 3	3.19E-06	1.36E-06	3.59E-03	1.52E-01	2.43E-06	1.04E-06	1.91E+00	4.53E-02	-	-	3.92E-01	9.28E-03
Site 4	2.85E-07	1.22E-07	7.64E03	1.35E-02	2.21E-06	9.46E-07	1.74E+00	4.13E-02	-	-	5.77E-02	1.37E-03
Site 5	6.78E-07	2.90E-07	7.62E-04	3.22E-02	7.14E-06	3.05E-06	5.63E+00	1.33E-01	-	-	1.38E-01	3.28E-03
Site 6	2.25E-06	9.59E-07	2.53E-03	1.07E-01	1.71E-05	7.32E-06	1.35E+01	3.20E-01	-	-	2.54E-01	6.01E-03
Site 7	2.06E-06	8.79E-07	8.09E-07	1.89E-06	8.21E-06	3.51E-06	6.47E+00	1.53E-01	-	-	3.63E-01	8.60E-03
Site 8	9.77E-02	2.31E-03	3.21E-04	1.35E-02	7.86E-06	3.36E-06	6.19E+00	1.47E-01	-	-	1.82E-01	4.31E-03
∑HI	9.77E-02	2.31E-03	7.64E+03	3.23E-01	5.21E-05	2.23E-05	4.10E+01	9.72E-01	-	-	1.79E+00	4.25E-02

3.4 Carcinogenic Risk Assessment

As and Cr were found to be the highest contributors to the cancer risk [23]. The U.S. Environmental Protection Agency considers a cancer risk in the range of $1x10^{-6}$ to $1x10^{-4}$ acceptable for regulatory purposes. The risk of cancer for children ranged from 1.79E+00 to 7.64E+03 and from 4.25E-02 to 9.72E-01 for adults, which the risk of cancer for children was higher than acceptable values. Therefore, children are more at risk than adults in the study area. The inhalation route seems to be the major contributor to excess lifetime cancer risk followed by the ingestion pathway.

4. CONCLUSIONS

The analyzing heavy metals in soil dust and street dust around various locations of the proposed workplace in Aqaba Industrial Estate, Jordan site is important to establish a critical need to put in place industrial estate regulations to protect residents, especially children from heavy metal pollution in the environment. The results showed that the average concentration levels for heavy metals Zn, Pb, Cu, Fe, Ni, Mn, and Cr are varied significantly and decreased in the order of Zn >Pb>Cu>Fe>Ni>Mn>Cr. Similar increasing trend for HQ for all $HQ_{der} < HQ_{ing} < HQ_{inh}$ heavy metals. For children, the inhalation pathways, the HQ of the heavy element pollutants Pb, Zn, Cu, Cr, Mn, Ni and Fe showed higher levels of hazard quotient for non-cancerous effects, whereas the heavy element pollutants Pb, Cr, Ni and Fe revealed HQ >1 for adults, indicating heavy metal inhalation pathways that may pose a very high non cancer health risk to children and adults living around the workplace area. The HI values exhibited that HI<1 for ingestion pathways and HI>1 due to the contact dermal and inhalation pathway. The health risk assessment Pb, Zn, Cu, Cr, Mn, Ni and Fe showed a higher level of HI for non-carcinogenic risks to the pathway of dermal contact and inhalation of children and adults. In contrast, these metals revealed lower level HI for non-carcinogenic risks ingestion values pathway for children and adults. Carcinogenic heavy metals Pb, Cr, and Ni followed similar trends for both children and adults, Pb> Cr>Ni. The risk of cancer for children and adults ranged between $1x\ 10^{-6}$ to $1\ x\ 10^{-4}$, indicating the risk of cancer for children was higher than adults. Thus, children are more at risk than adults in the study area. With regards to more health risks, bioavailability and mobility of metals can be stated to be of minor significance in the soil and street dust. In future, regular monitoring program to assess metals in soil and street dust quality and further study is needed not only to assess the spatial distribution of metals in materials but also to examine variations on small scale.

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