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Human Health Risk Assessment of Heavy Metals Contaminated Soil at Al-Nasiriyah City, Iraq

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Abstract

This study assesses the health risks on exposed populations caused by heavy metals near Al-Nasiriyah Thermal Electricity Station. In this study, soil samples from seven sites were collected and analyzed for nickel (Ni), lead (Pb), cadmium (Cd), zinc (Zn), Copper (Cu), and Cobalt (Co), using atomic absorption spectrophotometer. Measured concentrations of these heavy metals were then used to estimate the health risk for adults and children. The total Hazard Index values for all pathways were less than 1 indicated no carcinogenic risk except at sites 4 and 5. It found that equal to 2.2744 and 1.6341 respectively. (child) mainly driven by Pb in these sites, making non-carcinogenic effects significant to the child population. The maximum total carcinogenic risk values were found at site 4 which is equal to 0.000133 for adults and 0.000204 for children. This value attributed to the risk value from ingestion of Ni which was 0.000119729 for adults and 0.000191567 for a child. These values were higher than 0.0001 indicated unacceptable carcinogenic risks in these sites. The order of pathways that caused human health risk assessment was ingestion>dermal>inhalation for both adults and Childs.

Keywords: RfD; SF; HI; Risk; Carcinogenic

1. Introduction

Heavy metals are one of the toxic substances for living organisms and soil, and their accumulation in the soil is considered due to their effect on agricultural production and food safety resulting from plant poisoning [1]. Anthropogenic activities were the main reason for air, water, and soil pollution [2-3-4-5-6]. Soil is a complex and non-renewable media, consisting of mineral, organic components, water, and air, and any extra amount of heavy metals are considered one of the important environmental pollutants that threaten the natural ecosystem [7]. Weathering and erosion processes lead to the natural presence of heavy metals in the soil, human activities also can release quantities of heavy metals to the soil to make it a sink or reservoir for pollutants that pose a major threat to the natural environment and human health. One of the characteristics of heavy metals, in addition to being a major pollutant, is that they remain stable and cannot be absorbed by plants. They are also insoluble, which increases their impact on inhalation, ingestion, and skin contact [8], which leads to their entry into the food chain and its bioaccumulation in the bodies of humans and animals. Heavy metals such as nickel (Ni), lead (Pb), cadmium (Cd), zinc (Zn), Copper (Cu), and Cobalt (Co), increase the chances of lung and nose cancers. and skin due to excess levels as well as liver and kidney damage. For example, Ni is considered as the necessary element for plants growth, but its extra amounts can accumulate in humans and animal body causing cancer to the nose, skin, and lung [9].

Handling Plants that contain heavy metals by eating or breathing is considered a way for heavy metals to enter the food chain of animals and humans. By eating plants as food by humans and animals, they enter the food chain as well as by hand contact and inhalation [10].

Environmental Risk Assessment ERA is the method of estimating the risks related to the existence of chemicals, fate, and transport in the environment. It can be said, ERA is an analysis of the chemical(s) possible adverse effects in a specific site to find suitable remedial action. Risks may be as a result of flooding, extreme climate events, processes, technology, practices,

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chemical agents, products, radiological and industrial actions that can cause threats to ecosystems, animals, and people. ERA has two types / Human health risk assessment HHRA and Ecological risk assessment ECRA [11]

Both decision-makers and the general public perceive public health protection to be a primary protection target. As a result, population health is widely acknowledged as a significant protection goal in risk-based soil quality assessment and contaminated site management. [12]. Although the level of health damage caused by soil contamination is discussed, it is widely acknowledged that people must be safe in the locations where they live, work, or play to be part of contemporary society. Soil contamination has a comparatively high potential risk compared with risks from personal decisions since it is uncontrolled and typically unobservable. [13]. Oral, inhalation and dermal exposure to soil contaminants refer to the pathways via which toxins enter the human body by ”mouth, gullet, stomach; nose, trachea, and lungs; and skin, respectively”[14].

Al-Nasiriyah Thermal Electricity Station (NTES) is one of the hotbeds of environmental pollution in Al Nasiriyah city. It contributes to soil pollution with heavy metals resulting from its gaseous and particulate emission, weather conditions help in their transition to the soil.

The objective of this study was to assess the human health risk associated with the presence of Pb, Cd, Zn, Cu, Ni, Co in the soil at six sites Al-Nasiriyah Thermal Electricity Station during three exposure routes ingestion, inhalation, and dermal contact, taking into account three categories of variables to estimate intake/ (1) a contaminant-related variable (exposure concentration), (2) exposed population variables (contact rate, exposure frequency, duration, and body weight), and (3) an assessment-determined variable (averaging time).

2. Material and methods

2.1 Geographical location

The spatial boundaries of the study area are represented by Al-Nasiriyah Thermal Electricity Station in the city of Nasiriyah, located astronomically between two latitudes (31.5-31.7) north, and two length arcs (20,46) east. It represents the administrative center of Dhi Qar province in southern Iraq, about (346) km from Baghdad, the capital as shown in Fig 1.

Fig. 1. Show the location of Al-Nasiriyah Thermal Electricity Station according to Dhi Qar province and Iraq.

2.2 Soil Sampling and Analysis

Through the study, seven sites were selected to conduct the laboratory analysis of soil samples, three of which are in the opposite direction of the prevailing winds (northwest), and the other sites are in the direction of the prevailing winds, with different distances ranging between (500-1500 m) from Nasiriyah Thermal Electricity Station chimney. The first three sites (Site 1, Site 2, Site 3) are located at a distance equal to the other three sites (Site 4, Site 5, Site 6) from the pollution source but in the opposite direction, the seventh site (a reference site) was far from the impact of the pollutants of the Nasiriyah thermal power station, and it was located in agricultural lands, about 12 km away from the pollution source as shown in Fig .2 and table .1

Six heavy metals (lead, cobalt, zinc, copper, nickel, cadmium) were analyzed, and samples were taken at a depth of (0-30) cm, with a rate of (42) samples for each season(winter and summer). To identify the level of concentrations of heavy metals in soil, an atomic absorption spectrophotometer was used.

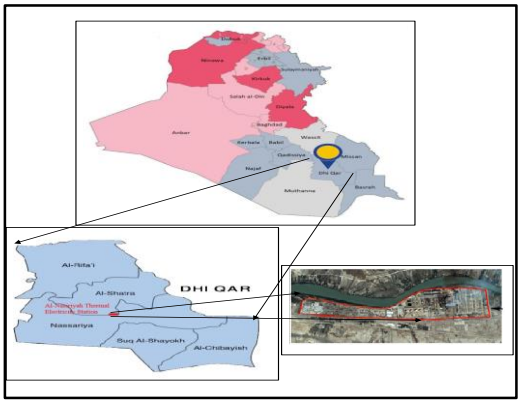

Fig. 2. Sites location in study area

Table 1. Sites Coordinates in study area

Sites	Distance from Al-Nasiriyah Thermal Electricity Station –	Longitude Coordinate	Latitude Coordinate
Al-Nasiriyah Thermal Electricity Station		46 °11 ' 38.02 " E	31 °02 ' 12.09 " N
Site 1	1500	46 °10 ' 49.08 " E	31 °02 ' 42.10 " N
Site 2	1000	46 °11 ' 04.05 " E	31 °02 ' 32.08 " N
Site 3	500	46 °11 ' 20.03 " E	31 °02 ' 22.13 " N
Site 4	500	46 °11 ' 59.09 " E	31 °02 ' 02.06 " N
Site 5	1000	46 °12 ' 16.15 " E	31 °01 ' 54.09 " N
Site 6	1500	46 °12 ' 34.11 " E	31 °01 ' 48.14 " N
Site 7	12000	46 °05 ' 05.07 " E	31 °05 ' 53.12 " N

2.3 Human Health Risk Assessment HHRA methodology

Hazard identification is the process of determining which chemicals are present in a given site, as well as their concentrations and spatial extent. As, Pb, Hg, Cd, Cr, Co, Ni, Cu, and Zn were recognized as possible community hazards in the research region. The goal of exposure assessment is to determine the magnitude, frequency, and existing period of human exposure to a pollutant in the environment. The average daily intake (ADI) of toxic substances previously discovered by ingestion, inhalation, and skin contact by children and adults from the study area was measured in the research. Because of behavioral and physiological differences, adults and children are kept separate. Dose-response analysis calculates the toxicity of substances based on their exposure levels. Two key toxicity indices are the cancer slope factor (SF, a carcinogen potency factor) and the reference dosage (RfD, a non-carcinogenic threshold). The "No observable effect level" concept is often used to determine RfD values from animal research. To correct for uncertainties, RfD values for humans are multiplied by ten [15]. By combining all of the data acquired to get at quantitative estimations of cancer risk and hazard indices, risk characterization estimates the possibility for carcinogenic and non-cancerous risks in adults and children in the research region. Heavy metal exposure pathways in polluted soils are computed using suggestions from multiple American publications. The following exposure was used to compute ADI (mg/kg-day) for the various routes. (1)–(3) as indicated by [16]

$$\boldsymbol{ADI\ ing} = \frac{C*IR*EF*ED*CF}{BW*AT} \quad \textbf{(1)}$$

$$\boldsymbol{ADI\ inh} = \frac{C*Inh\ R*ET*EF*ED}{PEF*BW*AT} \quad \textbf{(2)}$$

$$\boldsymbol{ADI\ der} = \frac{C*SA*AF*ABS*EF*ED*CF}{BW*AT} \quad \textbf{(3)}$$

Where:

ADI ing / is the average daily intake of heavy metals ingested from the soil in mg/kg per day.

ADI inh / is the average daily intake of heavy metals inhaled from the soil in mg/kg-day

ADI der / is the exposure dose via dermal contact in mg/kg/day

C/ the concentration of heavy metals available in soil (mg/ kg).

IR/ Soil Ingestion Rate.

BW/ Body Weight.

EF/ Exposure Frequency.

ED/ Exposure Duration.

ATc/ Carcinogenic risk Averaging Time .

ATnc/ Noncarcinogenic risk Averaging Time.

SA/ Skin Surface Area available for contact.

CF/ Conversion Factor.

AF/ Soil-to-Skin adherence factor.

ABS/ Absorption Factor.

InhR/ Inhalation Rate.

ET/ Exposure Time.

PEF/ Particle emission factor.

USEPA variables above the range used for calculating CDI for adults and children during three exposure routes with their units are illustrated in **Table 2** [17].

Determining carcinogens and noncarcinogens risk for all exposed receptors through different (ingestion and inhalation and dermal) for both noncarcinogens and carcinogens were as follow. Eq.4 illustrate Noncarcinogenic risk NCR as Hazard Index (HI)

$$\mathbf{HI} = \frac{\mathbf{ADI}}{\mathbf{RfD}} \quad \textbf{(4)}$$

Where**:**

ADI= Average Daily intake (mg/kg.day).

HI = Dimensionless Hazard Index.

RfD = Reference Dose (mg/kg.day).

If HI value <1.0 indicates acceptable risk, It noteworthy that the summation of HI for all contaminants and exposure route should be less than 1 to say it is accepted. HI, value less than 1 indicates that the hazard concentration does not present a risk to the exposed population. HI is not a value of risk, it does not provide a value for the probability of harm as the result of exposure. Instead, the HI measures the nonappearance of

noncarcinogenic exposure effects. To account HI for numerous elements in one way, HI values summation were adopted as follows [11] :

Hazard Index $_T$ = ∑HIi
For numerous routes /
Hazard Index $_T$ = ∑ HIij
Where:
i=the compound and j= routes.

$$\textbf{Risk}_T = \sum \textbf{Risk}_{ij}$$
Where:
i=the compound and j= routes[16].

If the R < 1E − 06, the cancer risk is acceptable for individual contaminants; if the 1E − 06 < R < 1E − 04, the cancer risk is acceptable for a combination of contaminants; if the R > 1E − 04, the cancer risk is not acceptable (Li et al., 2019)Both non-carcinogenic and carcinogenic risk assessment of heavy metals are calculated using RfD and CSF values derived largely from the Department of Environmental Affairs (South Africa) and USEPA as shown in **Table 3**. [18]

Table 2.
USEPA range for variables used in ADI , HI and Risk calculation

Parameter	Units	Adult	Children
IR	mg day^{-1}	100	200
EF	Days year $^{-1}$	312	312
ED	Years	35	6
BW	kg	70	15
ATnc	Days	365 × 35	365 × 6
ATc	Days	365 × 70	365 × 70
CF	mg day^{-1}	10^{-6}	10^{-6}
SA	cm^2	6032	2373
AF	mg cm^{-2}	0.07	0.2
ABS	Unitless	0.001	0.001
InhR	m^3 h^{-1}	1.56	1.2
ET	h day^{-1}	8	4
PEF	m^3 kg^{-1}	1.36 × 10^9	1.36 × 10^9

Table 3 .
RfDs and SFs values for selected heavy metals

Heavy metals	Reference dose (RfD)			Slope Factor (SF)		
	Ingestion	Inhalation	Dermal	Ingestion	Inhalation	Dermal
Cu	0.04	0.04	0.012	–	–	–
Cd	0.001	0.001	0.000025	–	6.30	–
Pb	0.0014	0.00352	0.000524	0.0085	–	–
Zn	0.3	0.30	0.06	–	–	–
Ni	0.02	0.0206	0.0054	1.7	–	40.25
Co	0.02	0.0000057	0.0000057		9.8	

Carcinogenic risk can be expressed as the Chronic Daily Intake dose CDI obtained from exposure assessment steps multiplied by the carcinogenic Slope Factor SF as shown in Eq.5.

Risk (R) = ADI x SF (5)

Where:
Risk ; the dimensionless probability of carcinogenic risk.
SF = carcinogen slope factor (kg.day/mg).
In a similar method, the risk for multiple elements and routes is calculated as:

3. Results and Discussion

3.1 Non-carcinogenic human health risks

Non-carcinogenic human health risk assessment of six heavy metals (Co, Zn, Pb, Cd, Cu, Ni,) in the study area via three exposure pathways/ ingestion (ADI ing), inhalation(ADI inh), and dermal contact (ADI der), were calculated for adults and children using Eq1-3. Noncarcinogenic risk HI for adults and children was calculated based on RfD values for ingestion, inhalation, and dermal pathways. As shown in **table (4) and fig (3a-b)**, HI ing, HI inh, and HI der values for all heavy metal selected were showed the trend of Adults< Children and this may be attributed to parameters used in ADI calculation, for example, IR for children was 200 bur for an adult was 100 mg/day, the other reason was the Body Weight for children that receive this metal was low, thus ADI for adults was less than for children.

It was noticed that the values of HI ing>HI derm>HI inh for both adults and children and the same order for ADI values, this may be attributed to parameters value entered for ADI calculation. The maximum value of noncarcinogenic ADI was for adults equal to 0.000286 and 0.00267 for children resulting from the ingestion of Pb in the study area at site 4 [18-19]. **From table (5) and fig (4a-b)**, in comparison all HI values for all metals, sites, and exposure pathways, it was noticed that the maximum total HI values were 0.2040168 (adults) and 1.90416 (child) resulting from Pb in site 4 during ingestion pathway were resulted from Pb due to high concentration level in soil due to the slow movement Pb and may be affected by leaching processing and soil development degrees are not similar at sites. This can be clarified by numerous factors for example pH, grain size, surface complex formation, adsorption processes, ionic exchange, and temperature. [10]

For the adult population, total HI values calculated were less than 1 in all exposure pathways. However, total HI for all the pathways was equal to 2.2744 and 1.6341 (child) in site 4 and 5, respectively, a value greater than one due to the ingestion pathway mainly driven by Pb in these sites for reasons mentioned above.

This meant that the child population was at risk of non-carcinogenic effects and heavy metals may pose a very high noncancer health risk to children living around the Al-Nasiriyah Thermal Electricity Station area. Childs met more potential harmful health risks from the heavy metals in the urban surface soils than adults and HI was found in the order Pb> Cd> Ni> Co> Cu> Zn for both adults and children in the Al-Nasiriyah Thermal Electricity Station area [16].

3.2 Carcinogenic human health risks

The carcinogenic risk (R)for adults and children are determined based on ADI values for ingestion, inhalation and dermal exposure pathways and SF values the results of the risks are shown in table 6 and figure (5a-b). It was noticed that the values of R ing>R derm>R inh for adults, this may be attributed to ADI and parameters entered for calculation [19-20]. From table (7) and fig (6a-b), in comparison to all R values for all metals, sites, and exposure pathway, it was noticed that maximum total carcinogenic risk values were found at site 4 which equal to 0.000133 for adults and 0.000204 for the child. This value attributed to the risk value from ingestion of nickel which was 0.000119729 was for adults and 0.000191567 for. This value was high than 0.0001 indicated unacceptable carcinogenic risk in this site due to the high concentration level in soil which and high SF value of 1.7 through ingestion.

The carcinogenic risk was calculated based on Co, Pb, Cu, Cd, Ni, Zn, and Ni was found to be the main cancer risk cause. As compared with the acceptable value obtained from USEPA, it considers acceptable for regulatory purposes a cancer risk in the range of 1 ˆ 10´6 to 1 ˆ 10´4. The cancer risk for adults was found to be between 0.0001-0.000001 which is considered acceptable for a combination of compounds and the same case for adults in 1,2,3, and 7. At another site, R total values were more than 0.0001, higher than acceptable values, thus Childs are therefore more at risk than adults attributed to ingestion pathways in order Ni > Pb > Cd > Co> Cu> Zn for both adults and children in Al-Nasiriyah Thermal Electricity Station area.

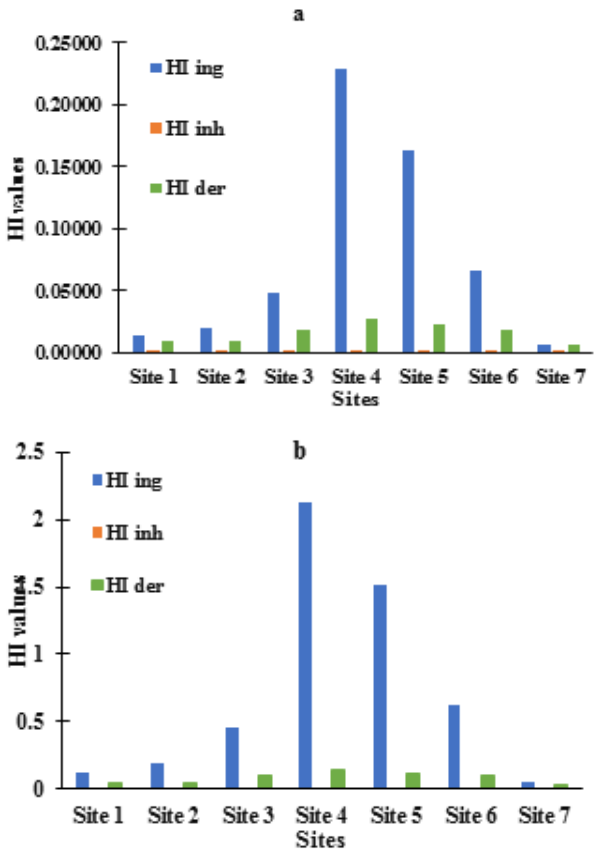

Fig 3. Sum HI values for (a)/Adults and (b)/Childs for ingestion, inhalation and dermal pathways at study area.

Table 4.

Results of non-carcinogenic via ingestion, inhalation, and dermal pathways for adults and child for all heavy metals and sites in the study area

Heavy metals	Sites	Conc (mg/kg)	Adults				Child			
			HI Ing (1)	HI Inh(2)	HI der(3)	Sum HI(1+2+3)	HI Ing(1)	HI Inh(2)	HI der(3)	Sum HI(1+2+3)
Cd	**Site 1**	0.35	0.0004274	3.92E-08	7.219E-05	0.0005	0.00399	7.039E-08	0.000379	0.0044
	Site 2	0.5	0.0006106	5.60E-08	1.031E-04	0.0007	0.00570	1.006E-07	0.000541	0.0062
	Site 3	1.8	0.0021980	2.02E-07	3.712E-04	0.0026	0.02052	3.620E-07	0.001947	0.0225
	Site 4	10.4	0.0126998	1.17E-06	2.145E-03	0.0148	0.11853	2.092E-06	0.011251	0.1298
	Site 5	4.75	0.0058004	5.32E-07	9.797E-04	0.0068	0.05414	9.554E-07	0.005139	0.0593
	Site 6	4.3	0.0052509	4.82E-07	8.869E-04	0.0061	0.04901	8.649E-07	0.004652	0.0537
	Site 7	0.15	0.0001832	1.68E-08	3.094E-05	0.0002	0.00171	3.017E-08	0.000162	0.0019
Zn	**Site 1**	11.05	0.0000450	4.13E-09	9.496E-07	0.0000	0.00042	7.408E-09	0.000005	0.0004
	Site 2	14.185	0.0000577	5.30E-09	1.219E-06	0.0001	0.00054	9.510E-09	0.000006	0.0005
	Site 3	37.7	0.0001535	1.41E-08	3.240E-06	0.0002	0.00143	2.528E-08	0.000017	0.0014
	Site 4	79.85	0.0003250	2.98E-08	6.862E-06	0.0003	0.00303	5.353E-08	0.000036	0.0031
	Site 5	47.9	0.0001950	1.79E-08	4.116E-06	0.0002	0.00182	3.211E-08	0.000022	0.0018
	Site 6	46.595	0.0001897	1.74E-08	4.004E-06	0.0002	0.00177	3.124E-08	0.000021	0.0018
	Site 7	5.8	0.0000236	2.17E-09	4.984E-07	0.0000	0.00022	3.888E-09	0.000003	0.0002
Ni	**Site 1**	26.725	0.0016317	1.45E-07	2.552E-05	0.0017	0.01523	2.609E-07	0.000134	0.0154
	Site 2	31.25	0.0019080	1.70E-07	2.984E-05	0.0019	0.01781	3.051E-07	0.000157	0.0180
	Site 3	59.65	0.0036420	3.24E-07	5.696E-05	0.0037	0.03399	5.824E-07	0.000299	0.0343
	Site 4	115.35	0.0070429	6.27E-07	1.101E-04	0.0072	0.06573	1.126E-06	0.000578	0.0663
	Site 5	97	0.0059225	5.28E-07	9.262E-05	0.0060	0.05528	9.471E-07	0.000486	0.0558
	Site 6	86.85	0.0053028	4.72E-07	8.293E-05	0.0054	0.04949	8.480E-07	0.000435	0.0499
	Site 7	10.45	0.0006380	5.68E-08	9.978E-06	0.0006	0.00596	1.020E-07	0.000052	0.0060
Pb	**Site 1**	11.55	0.0100744	3.68E-07	1.137E-04	0.0102	0.09403	6.600E-07	0.000596	0.0946
	Site 2	18.35	0.0160056	5.84E-07	1.806E-04	0.0162	0.14939	1.048E-06	0.000947	0.1503
	Site 3	45.9	0.0400358	1.46E-06	4.517E-04	0.0405	0.37367	2.623E-06	0.002369	0.3760
	Site 4	233.9	0.2040168	7.45E-06	2.302E-03	0.2063	1.90416	1.336E-05	0.012072	**1.9162**
	Site 5	168.95	0.1473648	5.38E-06	1.662E-03	0.1490	1.37541	9.654E-06	0.008720	1.3841
	Site 6	60	0.0523344	1.91E-06	5.904E-04	0.0529	0.48845	3.428E-06	0.003097	0.4916
	Site 7	5.15	0.0044920	1.64E-07	5.068E-05	0.0045	0.04193	2.943E-07	0.000266	0.0422
Co	**Site 1**	9.85	0.0006014	1.94E-04	8.910E-03	0.0097	0.00561	3.476E-04	0.046737	0.0527
	Site 2	9.45	0.0005770	1.86E-04	8.548E-03	0.0093	0.00539	3.334E-04	0.044839	0.0506
	Site 3	19.2	0.0011723	3.77E-04	1.737E-02	0.0189	0.01094	6.775E-04	0.091101	0.1027
	Site 4	24.65	0.0015050	4.85E-04	2.230E-02	0.0243	0.01405	8.698E-04	0.116961	0.1319
	Site 5	21.45	0.0013097	4.22E-04	1.940E-02	0.0211	0.01222	7.569E-04	0.101777	0.1148
	Site 6	18.5	0.0011295	3.64E-04	1.673E-02	0.0182	0.01054	6.528E-04	0.087780	0.0990
	Site 7	5.95	0.0003633	1.17E-04	5.382E-03	0.0059	0.00339	2.099E-04	0.028232	0.0318
Cu	**Site 1**	17.4	0.0005312	4.87E-08	7.476E-06	0.0005	0.00496	8.749E-08	0.000039	0.0050
	Site 2	23.75	0.0007250	6.65E-08	1.020E-05	0.0007	0.00677	1.194E-07	0.000054	0.0068
	Site 3	50.8	0.0015508	1.42E-07	2.183E-05	0.0016	0.01447	2.554E-07	0.000114	0.0146
	Site 4	94.5	0.0028849	2.65E-07	4.060E-05	0.0029	0.02693	4.752E-07	0.000213	0.0271
	Site 5	63.75	0.0019462	1.79E-07	2.739E-05	0.0020	0.01816	3.205E-07	0.000144	0.0183
	Site 6	63.75	0.0019462	1.79E-07	2.739E-05	0.0020	0.01816	3.205E-07	0.000144	0.0183
	Site 7	13.3	0.0004060	3.73E-08	5.715E-06	0.0004	0.00379	6.688E-08	0.000030	0.0038

Table 5. summary of HI values for all exposure pathways, heavy metals and sites for adults and child in study area.

Sites	Adults				Child			
	Sum HI ing	Sum HI inh	Sum HI der	Total HI	Sum HI ing	Sum HI inh	Sum HI der	Total HI
Site 1	0.01331	0.00019	0.00913	0.02264	0.1242	0.0003	0.0479	0.1725
Site 2	0.01988	0.00019	0.00887	0.02894	0.1856	0.0003	0.0465	0.2325
Site 3	0.04875	0.00038	0.01827	0.06740	0.4550	0.0007	0.0958	0.5516
Site 4	0.22847	0.00049	0.02690	0.25587	2.1324	0.0009	0.1411	**2.2744**
Site 5	0.16254	0.00043	0.02217	0.18514	1.5170	0.0008	0.1163	**1.6341**
Site 6	0.06615	0.00037	0.01833	0.08485	0.6174	0.0007	0.0961	0.7142
Site 7	0.00611	0.00012	0.00548	0.01170	0.0570	0.0002	0.0287	0.0859

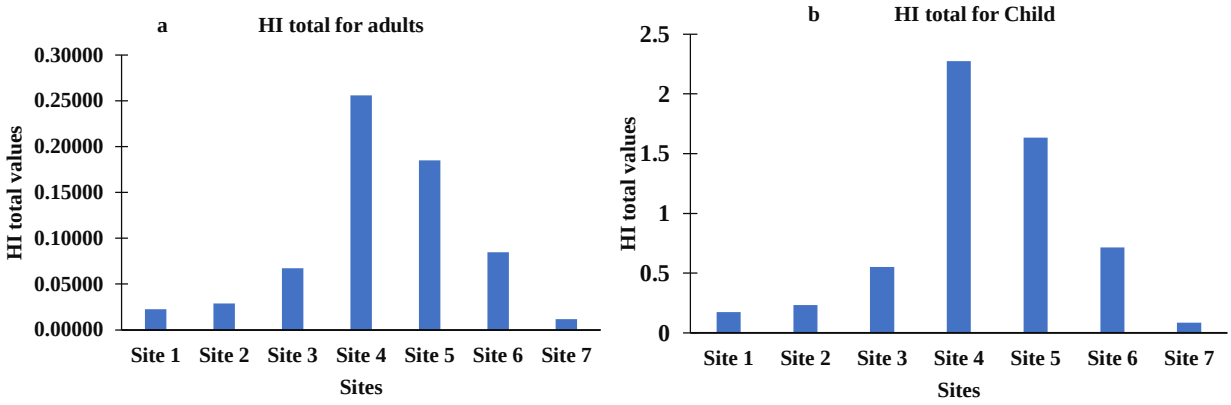

Fig 4. total HI values for all exposure pathways and heavy metals in each sites for (a) adults and (b) Childs

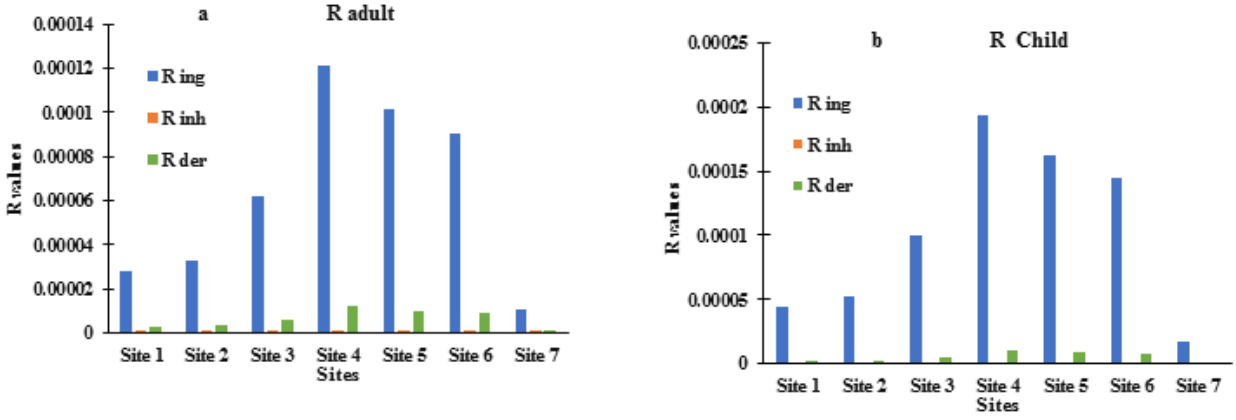

Fig 5. Sum R values for (a) Adults and (b)Childs for ingestion , inhalation and dermal pathways at study area

Table 6.

Results of carcinogenic via ingestion, inhalation, and dermal pathways for adults and child for all heavy metals and sites in the study area.

Heavy Metals	Sites	Conc.	Adult				Child			
			R ing (1)	R inh(2)	R der(3)	Sum R(1+2+3)	R ing(1)	R inh (2)	R der(3)	Sum R(1+2+3)
Cd	Site 1	0.35	0	1.23543E-10	0	1.23543E-10	0	3.80132E-11	0	3.80E-11
	Site 2	0.5	0	1.7649E-10	0	1.7649E-10	0	5.43046E-11	0	5.43E-11
	Site 3	1.8	0	6.35364E-10	0	6.35364E-10	0	1.95497E-10	0	1.95E-10
	Site 4	10.4	0	3.67099E-09	0	3.67099E-09	0	1.12954E-09	0	1.13E-09
	Site 5	4.75	0	1.67665E-09	0	1.67665E-09	0	5.15894E-10	0	5.16E-10
	Site 6	4.3	0	1.51781E-09	0	1.51781E-09	0	4.6702E-10	0	4.67E-10
	Site 7	0.15	0	5.2947E-11	0	5.2947E-11	0	1.62914E-11	0	1.63E-11
Zn	Site 1	11.05	0	0	0	0	0	0	0	0
	Site 2	14.185	0	0	0	0	0	0	0	0
	Site 3	37.7	0	0	0	0	0	0	0	0
	Site 4	79.85	0	0	0	0	0	0	0	0
	Site 5	47.9	0	0	0	0	0	0	0	0
	Site 6	46.595	0	0	0	0	0	0	0	0
	Site 7	5.8	0	0	0	0	0	0	0	0
Ni	Site 1	26.725	2.77396E-05	0	2.77317E-06	3.05128E-05	4.43834E-05	0	2.49365E-06	4.69E-05
	Site 2	31.25	3.24364E-05	0	3.24272E-06	3.56791E-05	5.18982E-05	0	2.91586E-06	5.48E-05
	Site 3	59.65	6.19146E-05	0	6.1897E-06	6.81043E-05	9.90634E-05	0	5.5658E-06	1.05E-04
	Site 4	115.35	0.000119729	0	1.19695E-05	0.000131699	0.000191567	0	1.0763E-05	2.02E-04
	Site 5	97	0.000100683	0	1.00654E-05	0.000110748	0.000161092	0	9.05084E-06	1.70E-04
	Site 6	86.85	9.01472E-05	0	9.01216E-06	9.91594E-05	0.000144236	0	8.10377E-06	1.52E-04
	Site 7	10.45	1.08467E-05	0	1.08436E-06	1.19311E-05	1.73548E-05	0	9.75065E-07	1.83E-05
Pb	Site 1	11.55	5.99425E-08	0	0	5.99425E-08	9.59079E-08	0	0	9.59E-08
	Site 2	18.35	9.52333E-08	0	0	9.52333E-08	1.52373E-07	0	0	1.52E-07
	Site 3	45.9	2.38213E-07	0	0	2.38213E-07	3.81141E-07	0	0	3.81E-07
	Site 4	233.9	1.2139E-06	0	0	1.2139E-06	1.94224E-06	0	0	1.94E-06
	Site 5	168.95	8.76821E-07	0	0	8.76821E-07	1.40291E-06	0	0	1.40E-06
	Site 6	60	3.11389E-07	0	0	3.11389E-07	4.98223E-07	0	0	4.98E-07
	Site 7	5.15	2.67276E-08	0	0	2.67276E-08	4.27641E-08	0	0	4.28E-08
Co	Site 1	9.85	0	5.40844E-09	0	5.40844E-09	0	1.66413E-09	0	1.66E-09
	Site 2	9.45	0	5.1888E-09	0	5.1888E-09	0	1.59656E-09	0	1.60E-09
	Site 3	19.2	0	1.05423E-08	0	1.05423E-08	0	3.24379E-09	0	3.24E-09
	Site 4	24.65	0	1.35348E-08	0	1.35348E-08	0	4.16456E-09	0	4.16E-09
	Site 5	21.45	0	1.17778E-08	0	1.17778E-08	0	3.62393E-09	0	3.62E-09
	Site 6	18.5	0	1.0158E-08	0	1.0158E-08	0	3.12553E-09	0	3.13E-09
	Site 7	5.95	0	3.26702E-09	0	3.26702E-09	0	1.00524E-09	0	1.01E-09
Cu	Site 1	17.4	0	0	0	0	0	0	0	0
	Site 2	23.75	0	0	0	0	0	0	0	0
	Site 3	50.8	0	0	0	0	0	0	0	0
	Site 4	94.5	0	0	0	0	0	0	0	0
	Site 5	63.75	0	0	0	0	0	0	0	0
	Site 6	63.75	0	0	0	0	0	0	0	0
	Site 7	13.3	0	0	0	0	0	0	0	0

Table 7.

summary of R values for all exposure pathways, heavy metals and sites for adults and child in study area

Sites	Adult				Child			
	Sum R ing	Sum R inh	Sum R der	Total R	Sum R ing	Sum R inh	Sum R der	Total R
Site 1	2.78E-05	5.53E-09	2.77E-06	3.06E-05	4.45E-05	1.7E-09	2.49E-06	4.7E-05
Site 2	3.25E-05	5.37E-09	3.24E-06	3.58E-05	5.21E-05	1.65E-09	2.92E-06	5.5E-05
Site 3	6.22E-05	1.12E-08	6.19E-06	6.84E-05	9.94E-05	3.44E-09	5.57E-06	0.000105
Site 4	1.21E-04	1.72E-08	1.2E-05	1.33E-04	0.000194	5.29E-09	1.08E-05	**0.000204**
Site 5	1.02E-04	1.35E-08	1.01E-05	1.12E-04	0.000162	4.14E-09	9.05E-06	0.000172
Site 6	9.05E-05	1.17E-08	9.01E-06	9.95E-05	0.000145	3.59E-09	8.1E-06	0.000153
Site 7	1.09E-05	3.32E-09	1.08E-06	1.20E-05	1.74E-05	1.02E-09	9.75E-07	1.84E-05

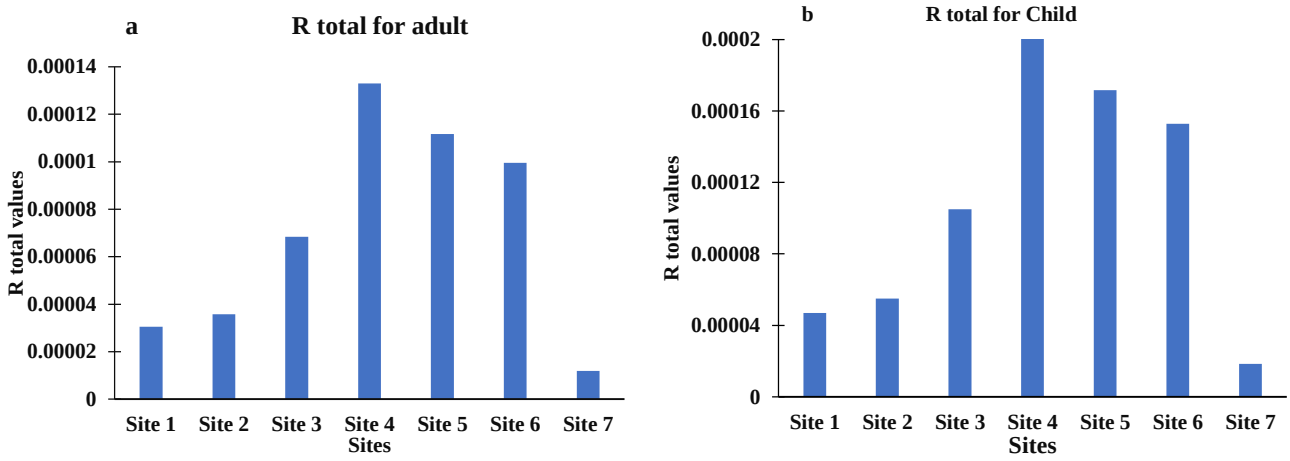

Fig 6. total HI values for all exposure pathways and heavy metals in each sites for (a) adults and (b) Childs

Conclusion

The results showed that, in both adults and children, the ingestion pathway was the highest contributor to the non-carcinogenic risk followed by the dermal route. The inhalation route was the smallest contributor to non-cancer risk. It was found that the ingestion route was the main contributor to the carcinogenic effect followed by the dermal route. from study results, it can be concluded that soils surrounding the Al-Nasiriyah Thermal Electricity Station area are seriously polluted by heavy metals, especially from Pb and Ni. HI, and R values are mostly affected by ADI calculation parameters, RfD, and SF values. The results also indicated that heavy metal contributes to HI values in Pb> Cd> Ni> Co> Cu> Zn and contribution in R values were Ni > Pb > Cd > Co> Cu> Zn for both adults and Childs in Al-Nasiriyah Thermal Electricity Station area.

Conflicts of interest

There are no conflicts to declare.

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