Health Risk Assessment of Heavy Metals in the Contaminated and Uncontaminated Soils

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Abstract**—**Application of health risk assessment methods is important in order to comprehend the risk of human exposure to heavy metals and other dangerous pollutants. Four soil samples were collected at distances of 10, 20, 30 m and the control 100 m away from the dump site at depths of 0.3, 0.6 and 0.9 m. The collected soil samples were examined for Zn, Cu, Pb, Cd and Ni using standard methods. The health risks via the main pathways of human exposure to heavy metal were detected using relevant standard equations. Hazard quotient was calculated to determine non-carcinogenic health risk for each individual heavy metal. Life time cancer risk was calculated to determine the cumulative life cancer rating for each exposure pathway. The estimated health risk values for adults and children were generally lower than the reference dose. The calculated hazard quotient for the ingestion, inhalation and dermal contact pathways were less than unity. This means that there is no detrimental concern to the health on human exposure to heavy metals in contaminated soil. The life time cancer risk 5.4×10^{-2} was higher than the acceptable threshold value of 1×10^{-4} which is reflected to have significant health effects on human exposure to heavy metals in contaminated soil. Good hygienic practices are recommended to ease the potential risk to children and adult who are exposed to contaminated soils. Also, the local authorities should be made aware of such health risks for the purpose of planning the management strategy accordingly.

Keywords**—**Health risk assessment, pollution, heavy metals, soil.

I. Introduction

OPEN dumps are known of environmental concern with respect to the threat they have created and continue to generate. Leachate is produced generally in connotation with precipitation that infiltrates through the refuse. Migration of leachate contaminated the soil with heavy metals such as Pb, Cu, Zn, Fe, Mn, Cr and Cd and these heavy metals in solid wastes lead to severe harms because they cannot be biodegraded.

Main sources of heavy metals in dumpsites are the co-disposed industrial wastes, incinerator ashes, mine wastes and household hazardous materials such as paints, inks, dyes, batteries etc. Soil contamination by heavy metals from waste disposal sites is a thoughtful problem in industrial and urban area. Soils are considered as the final sink for heavy metals discharged into the environment, as many heavy metals are bound to soils [1]. Reference [2] reported that on average, an individual produces nearly 250-400 gm of wet waste per day. The wet waste contains huge quantity of major and micro nutrients that are useful in agriculture as organic resource. Recycling of waste is possible for better utilization in agriculture if it is appropriately managed, it could be a valuable resource and alternative for the imported and expensive mineral fertilizers. Human beings produce a large quantity of wastes in various forms often making our environment dirty and harmful. Even though the Municipal Solid Wastes Management and Handling Rules, 2000 of India makes it mandatory for all urban local bodies to upgrade their waste collection, transportation, processing and disposal systems, but limited number of urban local bodies made considerable advancement with respect to this guideline. Properly designed and application of justifiable municipal solid waste management systems is a real task for developing countries like Nigeria. This is particularly in places with very high urbanization rates and very low public awareness.

In view of the overhead fact, the present study was considered with the aim to determine the level of metal contamination on soil and to evaluate the health risk associated with exposure to these metals through ingestion, inhalation and dermal contact pathways. Even though some work has been done in this dumpsite on soil, surface and ground water quality valuation, there is limited information on the total hazard that landfills constitute to those who are exposed to heavy metal. In this paper, the health risk assessment model suggested by USEPA was used to assess the health risk for the purpose of providing the contamination level of soil and planning the management strategy accordingly.

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II. Materials and Methods

A. Study Area

Uyo village road is situated in Uyo local government area. It is located at 5.03° North latitude, 7.93° East longitude. The average annual temperature in Uyo is 26.4 °C. The rainfall here averages 2509 mm.

B. Characterization of Soil Samples

A total of four soil samples were collected at 10, 20, 30 and control 100 m radial distance away from the dump site and characterized for its heavy metals properties.

C. Collection of Soil Samples

Soil samples at 0.3, 0.6 and 0.9 m depth and radial distance 10, 20, 30 and control 100 m away from the dump site were collected for this study. Reference [3] reported that analysis of upper layers is important in understanding soil interactions with other environment compartments and the pathways of pollutant between them.

D. Soil Analysis

The collected soil samples were air-dried. The air-dried samples were crushed and passed through a 2 mm sieve for metal analysis. The following heavy metals were analyzed; Zn, Cu, Pb, Cd and Ni. The method developed by [4] using DTPA (diethylene triamine penta acetic acid) extractant was followed for the estimation of Zn, Cu, Pb, Cd and Ni.

III. Heavy Metal Risk Assessment

A. Health Risk Assessment

In the waste dump site, there are three key pathways of human exposure to heavy metal. These are: ingestion (Ding); inhalation (Dinh); and dermal contact. The health risks through the main pathways can be identified using (1)-(3) as reported by [5]:

$$Ding = [(C \times Ring \times ED \times EF)/(AT \times BW)] \times 10^{-6} \quad (1)$$

$$Dinh = (C \times Rinh \times ED \times EF)/(AT \times BW \times PEF) \quad (2)$$

$$Ddermal = [(C \times AF \times SA \times ED \times EF \times ABS)/(AT \times BW)] \times 10^{-6} \quad (3)$$

where C is the concentration of heavy metals in contaminated and uncontaminated soil (mg kg^{-1}); R_{ing} is the soil ingestion rate 100 mg day^{-1} (adult), 200 mg day^{-1} (children); ED is the soil exposure duration 24 years (adult), 6 years (children); EF is the soil exposure frequency 180 days $year^{-1}$; AT is the average time 365 × ED adult/children; BW is the average body weight 70 kg (adult), 15 kg (children); R_{inh} is the soil inhalation rate 20 mg cm^{-2}; PEF is the soil particle emission factor 1.36×10^9 m^3 kg^{-1}; AF is the skin adherence factor for soil 0.07 mg cm^{-2} day^{-12} (adult), 0.2 mg cm^{-2} day^{-1} (children); SA is the surface area of the exposed skin that is in contact with the soil 2145 cm^2 $event^{-1}$ (adult), 1150 cm^2 $event^{-1}$ (children); ABS is the dermal absorption factor 0.001 unit less. Reference values used in computing the ingestion, inhalation and dermal contact path ways were obtained from [6].

B. Hazard Quotient

Hazard quotient (HQ) was calculated to determine non-carcinogenic health risk for each heavy metal at different depths and distances as described in (4) [7]:

$$HQ = D/RFD \quad (4)$$

where RfD is the chronic reference dose for each heavy metal (mg/kg/day) as given in Table II [8]. A risk index (HI) is the sum of the three major pathways' HQ as shown in (5) [5]:

$$HI = HQ = HQing + HQinh + HQderma \quad (5)$$

The values of HI are classified into two categories. HI < 1 means no harmful effect associated with the contaminated soil. HI > 1 means there is potential for adverse effects on health associated with contaminated soil.

C. Life Time Cancer Risk

Life time cancer risk (LCR) was calculated by calculating the cumulative life cancer risk rating as shown in (6) for each exposure pathway for Cd and Pb [5]:

$$LCR = \text{cancer risk}_{ing} + \text{cancer risk}_{inh} + \text{cancer risk}_{dermal} \quad (6)$$

where SF is the slope factor for carcinogenicity (mg/kg/day) presented by [7] for the related heavy metal Cd and Pb which are 6.3 and 0.0085 mg/kg/day [7]. The tolerable threshold value of LCR is 1×10^{-4} considered to have adverse health effects, LCR of $1 \times 10^{-6} – 1 \times 10^{-4}$ is considered acceptable [5], and LCR below 1 × 10−6 is regarded as negligible [9]

TABLE I
REFERENCE DOSE RFD (MG/KG/DAY) FOR EACH HEAVY METAL

Heavy metal	RfD (mg/kg/day)
Cu	0.0371
Pb	0.0035
Zn	0.3
Ni	0.91
Cd	0.001

IV. Results and Discussion

A. Health Risk Assessment

Table I provides reference dose RfD (mg/kg/day) for each heavy metal. Tables II-IV present summary of the calculated health risks for Cd, Cu, Pb, Ni and Zn on soil at different depths and distances for adults and children for three exposure routes; ingestion, inhalation and dermal contact pathways. The calculated values for adults and children were generally lower than the reference dose. This poses no risk or hazard to adults and children who are exposed to heavy metal. The extent of soil contamination depends on composition of the wastes, age of the leachate and type of soil.

B. Hazard Quotient

Tables V-VII provides the summary of HQ calculated to determine non-carcinogenic health risk at different depth and distances for adults and children through three main pathways. Table VIII presents summary of risk index (HI) sum of the three key Pathway's HQ. Hazard quotient for ingestion, inhalation and dermal contact path ways were less than unity. This means that no human health risk on adults and children that are exposed to contaminated soil. The ingestion of dumpsite soil was proven as the key route for non-carcinogenic risk through exposure to heavy metal in adults and children, with following dermal contact and third inhalation as the sum of each pathway HQ recorded as HQ_{ing} = 1.4E-1; HQ_{dermal} 1.4E-3 and HQ_{inh} = 1.2E-5. That is, $HQ_{ing} > HQ_{dermal} > HQ_{inh}$. Risk index levels were higher for children than for adults.

TABLE II
SUMMARY OF CALCULATED HEALTH RISK FOR ADULTS AND CHILDREN THROUGH INGESTION PATHWAY

Metal	SP1(10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
(Adults)												
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	9.2E-8	5.6E-8	3.5E-8	4.9E-8	4.9E-8	3.5E-8	4.9E-8	3.5E-8	2.8E-8	2.8E-8	1.4E-8	1.4E-8
Cu	1.0E-6	2.9E-7	1.6E-7	1.8E-7	1.8E-7	1.6E-7	1.6E-7	1.4E-7	3.3E-8	1.4E-7	1.3E-7	9.9E-8
Pb	7.2E-6	2.7E-6	1.5E-6	6.2E-6	5.4E-6	2.4E-6	4.8E-6	4.3E-6	2.3E-6	2.9E-6	2.3E-6	1.6E-6
Ni	3.8E-6	3.6E-6	3.2E-6	3.2E-6	3.2E-6	2.9E-6	3.1E-6	1.3E-6	1.2E-6	5.2E-7	4.8E-7	3.3E-7
Zn	9.1E-6	6.1E-6	3.5E-6	6.1E-6	2.6E-6	7.8E-7	3.8E-6	3.2E-6	2.0E-6	3.7E-6	2.4E-6	3.7E-6
(Children)												
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	8.5E-7	5.3E-7	3.3E-7	4.6E-7	4.6E-7	3.3E-7	4.6E-7	3.3E-7	2.6E-7	2.6E-7	1.3E-7	1.3E-7
Cu	9.5E-6	2.7E-7	1.5E-6	1.6E-6	1.6E-6	1.5E-6	1.5E-6	1.3E-6	1.2E-6	1.3E-6	1.2E-6	9.2E-7
Pb	6.8E-5	2.5E-5	1.4E-5	5.8E-5	5.0E-5	2.3E-5	4.5E-5	4.0E-5	2.0E-5	2.7E-5	2.1E-5	1.5E-5
Ni	3.6E-5	3.3E-5	2.7E-5	3.0E-5	3.0E-5	2.7E-5	2.9E-5	1.2E-5	1.1E-5	4.9E-6	4.5E-6	3.1E-6
Zn	8.5E-5	5.7E-5	3.2E-5	5.7E-5	2.5E-5	1.0E-5	3.5E-5	3.0E-5	1.9E-5	3.4E-5	2.3E-5	3.4E-5

SP1, 2, 3, 4 – Sampling Point No: 1, 2, 3, 4 at 10, 20, 30, and 100 m lateral spacing and Suffix A, B, C- 0.3, 0.6 and 0.9 m Depth.

TABLE III
SUMMARY OF CALCULATED HEALTH RISK FOR ADULTS AND CHILDREN THROUGH INHALATION PATHWAY

Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
(Adults)												
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	1.3E-11	8.3E-12	5.2E-12	7.3E-12	7.3E-12	5.2E-12	7.3E-12	5.2E-12	4.1E-12	4.1E-12	2.1E-12	2.1E-12
Cu	1.5E-10	1.5E-11	2.4E-11	2.6E-11	2.6E-11	2.4E-11	2.4E-11	2.1E-11	2.0E-11	2.1E-11	1.9E-11	1.5E-11
Pb	1.1E-9	4.0E-10	2.2E10	9.1E-10	7.9E-10	3.6E-10	7.1E-10	6.3E-10	3.2E-10	4.3E-10	3.4E-10	2.4E-10
Ni	5.6E-10	5.3E-10	4.2E-10	4.7E-10	4.7E-10	4.2E-10	4.5E-10	2.0E-10	1.8E-10	7.7E-11	7.0E-11	4.9E-11
Zn	1.3E-9	9.0E-10	5.1E-10	9.0E-10	3.9E-10	1.5E-10	5.6E-10	4.7E-10	2.9E-10	5.4E-10	3.6E-10	5.4E-10
(Children)												
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	6.3E-11	3.9E-11	2.4E-11	3.4E-11	3.4E-11	2.4E-11	3.4E-11	2.4E-11	1.9E-11	1.9E-11	9.7E-12	9.7E-12
Cu	7.0E-10	2.0E-10	1.1E-10	1.2E-10	1.2E-10	1.1E-10	1.1E-10	9.7E-11	9.2E-11	9.7E-11	8.7E-11	6.8E-11
Pb	5.0E-9	1.9E-9	1.0E-9	4.3E-9	3.7E-9	1.7E-9	3.3E-9	2.9E-9	1.5E-9	2.0E-9	1.6E-9	1.1E-9
Ni	2.6E-9	2.5E-9	2.0E-9	2.2E-9	2.2E-9	2.0-8E	2.1E-9	9.2E-10	8.4E-10	3.6E-10	3.3E-10	2.3E-10
Zn	6.3E-9	4.2E-9	2.4E-9	4.2E-9	1.8E-9	7.5E-10	2.6E-9	2.2E-9	1.4E-9	2.5E-9	1.7E-9	1.5E-9

SP1, 2, 3, 4 – Sampling Point No: 1, 2, 3, 4 at 10, 20, 30, and 100 m lateral spacing and Suffix A, B, C- 0.3, 0.6 and 0.9 m Depth.

TABLE IV
SUMMARY OF CALCULATED HEALTH RISK FOR ADULTS AND CHILDREN THROUGH DERMAL CONTACT PATHWAY

Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
(Adults)												
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	1.4E-10	8.5E-11	5.3E-11	7.4E-11	7.4E-11	5.3E-11	7.4E-11	5.3E-11	4.2E-11	4.2E-11	2.1E-11	2.1E-11
Cu	1.5E-10	4.3E-10	2.4E-10	2.6E-10	2.6E-10	2.4E-10	2.4E-10	2.1E-10	2.0E-10	2.1E-10	1.9E-10	1.5E-10
Pb	1.1E-8	4.1E-9	2.3E-9	9.3E-9	8.1E-9	3.6E-9	7.3E-9	6.4E-9	3.3E-9	4.3E-9	3.4E-9	2.5E-9
Ni	1.4E-8	9.1E-9	5.2E-9	9.2E-9	4.0E-9	1.6E-9	5.7E-9	4.8E-9	3.0E-9	5.5E-9	3.6E-9	5.5E-9
Zn	5.7E-9	5.4E-9	4.3E-9	4.8E-9	4.8E-9	4.3E-9	4.6E-9	2.0E-9	1.8E-9	7.8E-10	7.2E-10	5.0E-10
(Children)												
Metal	SP1(10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	SP1$_A$	SP1$_B$	SP1$_C$	SP2$_A$	SP2$_B$	SP2$_C$	SP3$_A$	SP3$_B$	SP3$_C$	SP4a	SP4b	SP4c
Cd	9.8E-9	6.0E-9	3.8E-9	5.3E-9	5.3E-9	3.8E-9	5.3E-9	3.8E-9	3.0E-9	3.0E-9	1.5E-9	1.5E-9
Cu	1.1E-7	3.1E-8	1.7E-8	1.9E-8	1.9E-8	1.7E-8	1.7E-8	1.5E-8	1.4E-8	1.5E-8	1.4E-8	1.1E-8
Pb	7.8E-7	2.9E-7	1.6E-7	6.7E-7	5.8E-7	2.6E-7	5.2E-7	4.6E-7	2.3E-7	3.1E-7	2.4E-7	1.8E-7
Ni	9.6E-7	6.6E-7	3.7E-7	6.6E-7	2.8E-7	1.2E-7	4.1E-7	3.5E-7	2.1E-7	3.9E-7	2.6E-7	3.9E-7
Zn	4.1E-7	3.8E-7	3.1E-7	3.5E-7	3.4E-7	3.1E-7	3.3E-7	1.4E-7	1.3E-7	5.6E-8	5.1E-8	3.6E-8

TABLE V
SUMMARY OF HQ CALCULATED TO DETERMINE NON-CARCINOGENIC HEALTH RISK FOR ADULTS AND CHILDREN THROUGH INGESTION PATHWAY

					HQ (Adults)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	9.2E-6	5.6E-5	3.5E-5	4.9E-5	4.9E-5	3.5E-5	4.9E-5	3.5E-5	2.8E-5	2.8E-5	1.4E-5	1.4E-5
Cu	2.7E-7	7.8E-6	4.3E-6	4.9E-6	4.9E-6	4.3E-6	4.3E-6	3.8E-6	8.9E-7	3.8E-6	3.5E-6	2.7E-6
Pb	2.1E-3	7.7E-4	4.3E-4	1.8E-3	1.5E-3	6.9E-4	1.4E-3	1.2E-3	6.6E-3	8.3E-4	6.6E-4	4.6E-4
Ni	4.2E-6	4.0E-6	3.5E-6	3.5E-6	3.5E-6	3.2E-6	3.4E-6	3.4E-6	1.3E-6	5.7E-7	5.3E-7	3.6E-7
Zn	3.0E-5	2.0E-5	1.2E-5	2.0E-5	8.7E-6	2.6E-6	1.3E-5	1.1E-5	6.7E-6	1.2E-5	8.0E-6	1.2E-5
					HQ (Children)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	8.5E-5	5.3E-4	3.3E-4	4.6E-4	4.6E-4	3.3E-4	4.6E-4	3.3E-4	2.6E-4	2.6E-4	1.3E-4	1.3E-4
Cu	2.6E-4	7.3E-5	4.0E-5	4.3E-5	4.3E-5	4.0E-5	4.0E-5	3.5E-5	3.2E-5	3.5E-5	3.2E-5	2.5E-5
Pb	1.9E-2	7.1E-3	4.0E-3	1.7E-2	1.4E-2	6.6E-3	1.3E-2	1.1E-2	5.7E-3	7.7E-3	6.0E-3	4.3E-3
Ni	4.0E-5	3.6E-5	3.0E-5	3.3E-5	3.3E-5	3.0E-5	3.2E-5	1.3E-5	1.2E-5	5.4E-6	4.9E-6	3.4E-6
Zn	2.8E-4	1.9E-4	1.1E-4	1.9E-4	8.3E-5	3.3E-5	1.1E-4	1.0E-4	6.3E-5	1.1E-4	7.7E-5	1.1E-4

SP1, 2, 3, 4 – Sampling Point No: 1, 2, 3, 4 at 10, 20, 30, and 100 m lateral spacing and Suffix A, B, C- 0.3, 0.6 and 0.9 m Depth

TABLE VI
SUMMARY OF HQ CALCULATED TO DETERMINE NON-CARCINOGENIC HEALTH RISK FOR ADULTS AND CHILDREN THROUGH INHALATION PATHWAY

					HQ (Adults)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	1.3E-8	8.3E-9	5.2E-9	7.3E-9	7.3E-9	5.2E-9	7.3E-9	5.2E-9	4.1E-9	4.1E-9	2.1E-9	2.1E-9
Cu	4.0E-9	4.0E-10	6.5E-10	7.0E-10	7.0E-10	6.5E-10	6.5E-10	5.7E-10	5.4E-10	5.7E-10	5.1E-10	4.0E-10
Pb	3.1E-7	1.1E-7	6.3E-8	2.6E-7	2.3E-7	1.0E-7	2.0E-7	1.8E-7	9.1E-8	1.2E-7	9.7E-8	6.9E-8
Ni	6.1E-10	5.8E-10	4.6E-10	5.2E-10	5.2E-10	4.6E-10	4.9E-10	2.2E-10	2.0E-10	8.5E-11	7.7E-11	5.4E-11
Zn	4.3E-9	3.0E-9	1.7E-9	3.0E-9	1.3E-9	1.5E-10	1.9E-9	1.6E-9	10.0E-10	1.8E-9	1.2E-9	1.8E-9
					HQ (Children)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	6.3E-8	3.9E-8	2.4E-8	3.4E-8	3.4E-8	2.4E-8	3.4E-8	2.4E-8	1.9E-8	1.9E-8	9.7E-9	9.7E-9
Cu	2.0E-7	5.4E-8	3.0E-8	3.2E-8	3.2E-8	3.0E-8	3.0E-8	2.6E-8	2.5E-8	2.6E-8	2.3E-8	1.8E-8
Pb	1.4E-6	5.4E-7	2.9E-7	1.2E-6	1.1E-6	4.9E-7	9.4E-7	8.3E-7	4.3E-7	5.7E-7	4.6E-7	3.1E-7
Ni	2.9E-9	2.7E-9	2.2E-9	2.4E-9	2.4E-9	2.2E-8	2.3E-9	1.0E-9	9.2E-10	4.0E-10	3.6E-10	2.5E-10
Zn	2.1E-8	1.4E-8	8.0E-9	1.4E-8	6.0E-9	2.5E-9	8.7E-9	7.3E-9	4.7E-9	8.3E-9	5.7E-9	5.0E-9

SP1, 2, 3, 4 – Sampling Point No: 1, 2, 3, 4 at 10, 20, 30, and 100 m lateral spacing and Suffix A, B, C- 0.3, 0.6 and 0.9 m Depth

TABLE VII
SUMMARY OF HQ CALCULATED TO DETERMINE NON-CARCINOGENIC HEALTH RISK FOR ADULTS AND CHILDREN THROUGH DERMAL CONTACT PATHWAY

					HQ (Adults)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	1.4E-7	8.5E-8	5.3E-8	7.4E-8	7.4E-8	5.3E-8	7.4E-8	5.3E-8	4.2E-8	4.2E-8	2.1E-8	2.1E-8
Cu	4.0E-9	1.2E-8	6.5E-9	7.0E-9	7.0E-9	6.5E-9	6.5E-9	5.7E-9	5.4E-9	6.5E-9	5.1E-9	4.0E-9
Pb	3.1E-6	1.2E-6	6.6E-7	6.6E-7	2.3E-6	1.0E-6	2.1E-6	1.8E-6	9.4E-7	1.2E-6	9.7E-7	7.1E-7
Ni	1.5E-8	1.0E-8	5.7E-9	5.7E-9	4.4E-9	1.8E-9	6.3E-9	5.3E-9	3.3E-9	6.0E-9	4.0E-9	6.0E-9
Zn	1.9E-8	1.8E-8	1.4E-8	1.6E-8	1.6E-8	1.4E-8	1.5E-8	6.7E-9	6.0E-9	2.6E-9	2.4E-9	1.7E-9
					HQ (Children)							
Metal	SP1 (10 m)			SP2 (20 m)			SP3 (30 m)			Control (100 m)		
	$SP1_A$	$SP1_B$	$SP1_C$	$SP2_A$	$SP2_B$	$SP2_C$	$SP3_A$	$SP3_B$	$SP3_C$	SP4a	SP4b	SP4c
Cd	9.8E.6	6.0E-6	3.8E-6	5.3E-6	5.3E-6	3.8E-6	5.3E-6	3.8E-6	3.0E-6	3.0E-6	1.5E-6	1.5E-6
Cu	3.0E-6	8.4E-7	4.6E-7	5.1E-7	5.1E-7	4.6E-7	4.6E-7	4.0E-7	3.8E-7	4.0E-7	3.8E-7	3.0E-7
Pb	2.2E-4	8.3E-5	4.6E-5	1.9E-4	1.7E-4	7.4E-5	1.5E-4	1.3E-4	6.6E-5	8.9E-5	6.9E-5	5.1E-5
Ni	1.1E-6	7.3E-7	4.1E-7	7.3E-7	3.1E-7	1.3E-7	4.5E-7	3.8E-7	2.3E-7	4.3E-7	2.9E-7	4.3E-7
Zn	1.4E-6	1.3E-6	1.0E-6	1.2E-6	1.3E-6	1.0E-6	1.1E-6	4.7E-7	4.3E-7	1.9E-7	1.7E-7	1.2E-7

SP1, 2, 3, 4 – Sampling Point No: 1, 2, 3, 4 at 10, 20, 30, and 100 m lateral spacing and Suffix A, B, C- 0.3, 0.6 and 0.9 m Depth

TABLE VIII
SUMMARY OF RISK INDEX (HI) SUM OF THE THREE MAIN PATHWAYS' HQ

	Pathways	Adults	Children	∑
1.	HQ_{ing}	1.9E-2	1.2E-1	1.4E-1
2.	HQ_{inh}	1.9E-6	9.6E-6	1.2E-5
3.	HQ_{dermal}	1.7E-5	1.4E-3	1.4E-3
	∑HQ	1.4E-1 or 0.14		

C. Carcinogenic Risk Assessment

Table IX gives summary of the LCR of exposure to heavy metal. This study demonstrates elevated LCR of 5.4×10^{-2} which is higher than tolerable threshold value 1×10^{-6} which is considered to have significant health effects on adults and children who are exposed to heavy metals in contaminated soil.

TABLE IX
SUMMARY OF LCR

	Pathways	Adults	Children
1.	$Cancer_{ing}$	5.1E-3	4.8E-2
2.	$Cancer_{inh}$	6.6E-7	3.6E-6
3.	$Cancer_{dermal}$	8.7E-6	5.5E-4
	∑HQ	5.4E-2	

V. CONCLUSION

The findings of this study revealed that health risk for adults and children were generally lower than the reference dose. Hazard quotient for ingestion, inhalation and dermal contact path ways were less than unity meaning that no harmful effect to the health on adults and children that may be exposed to heavy metals in contaminated soil. The cumulative life time cancer risk of the studied metals was 5.4×10^{-2} which is higher than tolerable threshold value 1×10^{-6} which is considered to have significant health effects on adults and children. Good hygienic practices are recommended to decrease the potential risk on adults and children that may be exposed to contaminated soil.

CONFLICT OF INTEREST

Author has declared that no competing interests exist.

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