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Total Excess Lifetime Cancer Risk Estimation from Enhanced Heavy Metals Concentrations Resulting from Tailings in Katsina Steel Rolling Mill, Nigeria

Bello S[1]*, Muhammad BG[1] and Bature B[2]

[1]Department of Physics, Faculty of Natural and Applied Sciences, Umaru Musa Yar'adua University Katsina, Nigeria
[2]Department of Mathematics, Faculty of Natural and Applied Sciences, Umaru Musa Yar'adua University Katsina, Nigeria

Abstract

Soil samples were randomly collected from the dump-yard of Katsina steel rolling mill and were analyzed for the presence and concentrations of the carcinogenic heavy metals namely: Chromium (Cr), Arsenic (As), Cadmium (Cd), Cobalt (Co) and Lead (Pb) using flame atomic absorption spectrophotometry instrumental method. The obtained concentrations were used to estimate the excess lifetime cancer risk due to exposure from these metals using models provided by the United State Environmental protection Agency for the population ages. The total estimated excess lifetime cancer risk due to exposure from these heavy metals via ingestion, inhalation and dermal pathways was found to be in the range of 2.73E-04 to 9.23E-07 for children, 6.07E-07E-07 to 5.64E-02 for adults and were majorly contributed by Chromium (Cr). These range clearly indicated the existence of values far above the USEPA recommended threshold of 1.00E-06 and consequently indicating that there is high risk of lifetime cancer development in the inhabitants around the study area.

Keywords: Excess lifetime cancer; Heavy metals; Annual daily intake; Cancer risk; Exposure pathways

Introduction

It has been established that heavy metals originate from natural sources at concentrations mostly within the safe limit [1,2]. In urban systems, human activities contribute to the enhancement of the natural concentrations of this heavy metals through activities such as traffic, industrial and weathering of buildings and pavements [3,4]. Rigorous monitoring of heavy metals concentrations is necessary to avert their potential of continuous exposure in order to prevent damage to health. Steel production by iron extraction from metal scraps generates waste that are of serious environmental concern when deposited on soil [5-7] have established the existence of high levels of some heavy metals in the tailings from steel scraps. The relatively large surface area of soil fine particles facilitates heavy metals absorption and binding to iron and organic matter [8,9]. Polluted soils when blown by wind can cause aerial dispersion of these heavy metals [10]. These heavy metals may get in to the human system through various exposure pathways such as direct ingestion of soils and dust inhalation. It is important to study the bioavailability of these heavy metals in order to understand the possible effect on biota and particularly on human health [7,8,10-15]. Most metals are very toxic when they exist in excess and might be capable of causing major health effects such as developmental retardation, kidney damage, neurological and immunological effects as well as several types of cancer [16]. The importance of risk quantification through identifying, defining and characterizing adverse exposure consequences cannot be overemphasized [17]. Arsenic (As), Chromium (Cr), Lead (Pb) is known to be toxic to humans and was classified as carcinogens. Human exposure to heavy metals has unsurprisingly increased over the last few decades worldwide [18]. The use of synthetic products such as batteries, pesticides, paints and industrial/domestic wastes can result in heavy metal contamination of agricultural and urban soils [18]. The rapid urbanization and industrialization of the world have increased heavy metal emissions and consequent human exposures to them. Arsenic and its compounds are used in herbicides, pesticides and insecticides which may form part of the exposure sources to humans in addition to air, water, cigarette smoking and contaminated food [19,20]. Lead contamination may result from industrial sources such as manufacturing activities and lead smelting [21]. Lead and some other heavy metals remains a major hazard for human health because of their inherent nature of accumulation and non-bio-degradability especially when they accumulate in the body tissues faster than the body's detoxification pathway can dispose of them [22,23]. Acute poisoning from heavy metals occurs through ingestion and dermal contact. Exposure to heavy metals is normally chronic due to food chain transfer and repeated long term contact with them can cause cancer [24]. It has been revealed that waste disposal as an integral part of industrial activities may be directly linked to the increase in the metal load of the ambient environment by virtue of metal bearing wastes introduction [25,26]. This work therefore investigates the carcinogenic risk values due to exposure to chromium, arsenic, cadmium, cobalt and lead concentrations in soils from Katsina steel rolling dump-yard using united states environmental protection agency guidelines.

Materials and Methods

Study area and sample analysis

Figure 1 shows the study area from where all the soil samples were collected. The collected soil samples were prepared and analyzed using standard flame atomic absorption spectrophotometry method as described in [27,28].

***Corresponding author:** Suleiman Bello, Department of Physics, Faculty of Natural and Applied Sciences, Umaru Musa Yar'adua University Katsina, Nigeria, Tel: +234-8166791940; E-mail: suleiman.bello@umyu.edu.ng

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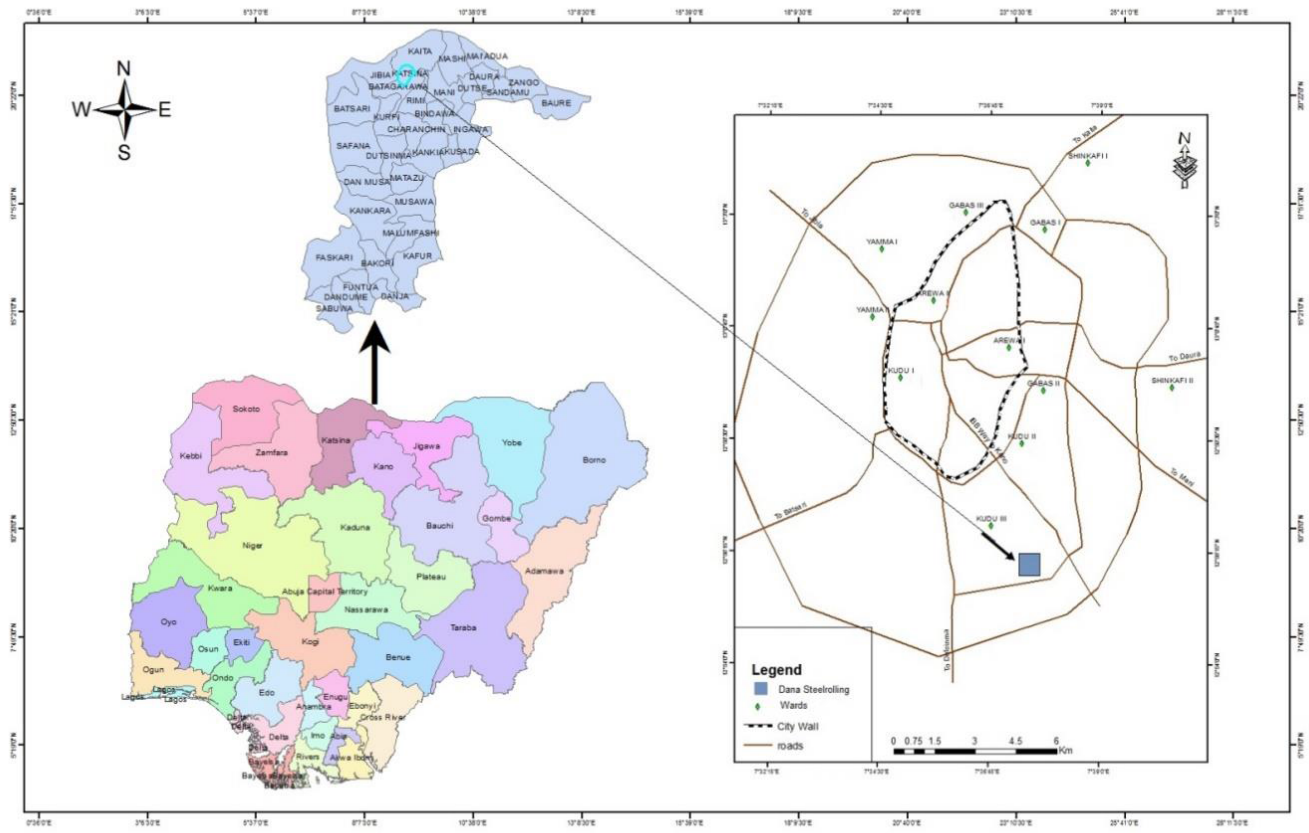

Figure 1: Map of the study area.

Total excess lifetime cancer risk assessment

Carcinogenic risk assessment: Carcinogenic risk assessment was carried out in the following chronological order: Identification of the hazard, assessment of exposure, dose-response (toxicity) assessment and risk characterization as suggested by Namgung and Xia [20,29]. Identification of hazard was done by taking the carcinogenic heavy metals as hazards for the population and obtaining their concentrations using flame atomic absorption spectrophotometry method. Assessment of exposure was done by estimating the frequency, intensity and duration of human exposures to the studied heavy metals separately for adults and children because of their physiological and behavioral differences [30]. Cancer slope factors were the toxicity index used in this assessment. Risk characterization was carried out by integrating all the gathered information in order to quantitatively estimate the excess lifetime cancer risk of children and adults [31]. Annual daily intake values were calculated for the various exposure pathways using eqns. (1)-(3) as recommended in ref. [32].

Ingestion of heavy metals through soil

$$ADIing = C * IR * EF * ED * \frac{CF}{BW * AT} \quad (1)$$

Where,

ADI_{ing}: Average daily intake of heavy metals ingested from soil in mg/kg-day;

C: Concentration of heavy metal in mg/kg for soil;

IR: Ingestion rate in mg/day;

EF: Exposure frequency in days/year;ED: exposure duration in years;

BW: Body weight of the exposed individual in kg;

AT: Time period over which the dose is averaged in days;

CF: Conversion factor in kg/mg.

Inhalation of heavy metals via soil particulates

$$ADIinh = Cs * IRair * EF * ED * \frac{CF}{BW * AT * PEF} \quad (2)$$

Where,

ADI inh: Average daily intake of heavy metals inhaled from soil in mg/kg-day;

CS: Concentration of heavy metal in soil in mg/kg;

IRair: Inhalation rate in m^3/day;

PEF: Is the particulate emission factor in m^3/kg;

EF, ED, BW and AT are as defined earlier in eqn. (1) above.

Dermal contact with soil

$$ADIderm = Cs * SA * FE * AF * ABS * EF * ED * \frac{CF}{BW * AT} \quad (3)$$

Where,

ADI derm: exposure dose via dermal contact in mg/kg/day;

CS: concentration of heavy metal in soil in mg/kg;SA=exposed skin area in cm^2;

FE: fraction of the dermal exposure ratio to soil;

AF is the soil adherence factor in mg/cm^2; ABS=fraction of the applied dose absorbed across the skin;

EF, ED, BW, CF and AT are as defined earlier in eqn. (1) before. Table 1 provides the exposure parameters that are used for health risk assessment for a typical residential exposure scenario [31-33].

Total excess lifetime cancer risk assessment: Carcinogenic risk assessment was carried out by estimating the incremental probability of an individual developing cancer over his lifetime as a result of exposure to the identified carcinogens. The excess lifetime cancer risk was calculated from the following equation:

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k CSF_k \quad (4)$$

Where, Risk is a unit less probability of an individual developing cancer over a lifetime. ADI_k (mg/kg/day) and CSF_k are the average daily intake and the cancer slope factor respectively for the K^{th} heavy metal, for n number of heavy metals. The slope factor converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer [31]. The total excess lifetime cancer risk for an individual was finally calculated by summing the average contribution of the individual heavy metals for all the pathways (ingestion, inhalation and dermal) using the following equation:

$$Risk_{total} = Risk_{ing} + Risk_{inh} + Risk_{dermal} \quad (5)$$

Where Risk (ing), Risk (inh) and Risk (derm) are the risks contributions through ingestion, inhalation and dermal pathways. The carcinogenic risk assessment was calculated using cancer slope factors provided by Table 2 below [31-33].

Results and Discussion

Carcinogenic health risk of heavy metals for adults and children

The concentrations of heavy metals (mg/kg) in the analyzed soil samples from Katsina steel rolling mill dumpsite were used for the computations of annual daily intake values (mg/kg/day) using the models provided by eqns. (1), (2) and (3) for ingestion, inhalation and dermal pathways respectively. The exposure parameters provided by Environmental protection agency were used for the computation [34-37]. The obtained annual daily intake values were subjected to descriptive statistics using MS Excel 2010 and the Mean, minimum and maximum values corresponding to each heavy metal for a particular receptor (adult and children) via a particular pathway were presented in Table 3. The obtained annual daily intake values were further used for the computations of cancer risk using eqns. (4) and (5) and the cancer slope factors provided by ref. [29] in Table 2. The total excess lifetime cancer risk in adults and children for each pathway due to exposure from all the studied heavy metals was also calculated and the results were also subjected to descriptive statistics with the mean, minimum and maximum presented in Table 4.

Parameter	Symbol	Unit	Child	Adult
Body weight(BW)	BW	Kg	15	70
Exposure frequency(EF)	EF	days/year	350	350
Exposure duration(ED)	ED	Years	6	30
Ingestion rate(IR)	IR	mg/day	200	100
Inhalation rate(IRair)	IRair	m^3/day	10	20
Skin surface area(SA)	SA	cm^2	2100	5800
Soil adherence factor(AF)	AF	mg/cm^2	0.2	0.07
Dermal absorption factor(ABS)	ABS	None	0.1	0.1
Dermal exposure ratio(FE)	FE	None	0.61	0.61
Particulate emission factor (PEF)	PEF	m^3/kg	1.3E+09	1.3E+09
Conversion factor (CF)	CF	kg/mg	E-06	E-06
Averaging time (AT)	AT	Days	365 × 70	365 × 70

Table 1: Exposure parameters used for the assessment of carcinogenic health risk.

Heavy metal	Ingestion CSF	Dermal CSF	Inhalation CSF
As	1.50E+00	1.50E+00	1.50E+01
Pb	8.50E-03	-	4.20E-02
Cd	-	-	6.30E+00
Cr	5.00E-01	-	4.10E+01
Co	-	-	9.80E+00

Table 2: Cancer slope factors (CSF) in (mg/kg/day)-1 for the different heavy metals.

The calculated risk indices were compared with the United States environmental protection guidelines for maximum cancer risk of 1E-06. Based on this guideline, it was found that the values of cancer risks for Cr were seriously above the limits for all the exposure pathways (ingestion, inhalation, dermal) in both adults and children implying that both population ages are at serious risk of developing cancer in their lifetime due to Cr exposure. The mean cancer risk values of Cr were found to be 9.654E-03 and 3.045E-06 in adults via ingestion and inhalation pathways respectively with maximum values of 5.63E-02 and 1.778E-05 respectively. For children the mean cancer risk values were estimated to be 4.51E-05 and 1.421E-06 for ingestion and inhalation pathways respectively with maximum values of 2.63E-04 and 8.295E-06. For Pb some cancer risk values were too high for both adults and children in ingestion pathway with maximum values of 4.08E-06 and 7.62E-06 for adults and children respectively. For As the cancer risk values were found to be too high in some samples for ingestion in children with maximum values of 1.22E-06. The cancer risk due to Cd and Co was found to be within the requirement for all the samples in all the exposure pathways. The total cancer risk values due to ingestion pathway in adults and children were found to be above the requirement and were majorly contributed by Cr, Pb and As in both adults and children. For the inhalation pathway, the total cancer risk values were found to be above the requirement with major contribution mainly from Cr. For dermal, the cancer risk values due to As were all within the requirement indicating no risk to members of population. The total excess lifetime cancer risk was found to have maximum and minimum values of 2.73E-04 and 9.23E-07 for children, 5.64E-02 and 6.07E-07 for adult (Table 3).

Conclusions

Soil samples were collected from Katsina steel rolling mill and analyzed using flame atomic absorption spectrophotometry instrumental method for the presence and concentrations of the carcinogenic heavy metals Arsenic (As), Chromium (Cr), Cadmium (Cd), Cobalt (Co) and Lead (Pb). The obtained concentrations were used to obtain the corresponding annual daily intake values through the exposure pathways of ingestion, inhalation and dermal contact. The obtained annual daily intake values were further used for the carcinogenic risk values. It is evident from the obtained results that there is very high probability that the inhabitants around the steel rolling mill will develop one type of cancer or another in their lifetime. This alarming situation should be regularly monitored for cancer health

Parameter	Receptor	Statistical parameter	Average daily intake values (ADI) for heavy metals in (mg/kg/day).				
			Pb	As	Cr	Cd	Co
ADI_{ing}(mg/kg/day)	Adult	Mean	5.93E-05	3.31E-07	4.83E-04	8.82E-06	3.66E-05
		Minimum	N/D	2.52E-07	N/D	2.35E-07	3.99E-06
		Maximum	4.80E-04	4.34E-07	2.82E-03	1.84E-05	4.83E-05
	Children	Mean	1.11E-04	6.18E-07	9.01E-04	1.65E-05	6.83E-05
		Minimum	N/D	4.71E-07	N/D	4.38E-07	7.45E-06
		Maximum	8.97E-04	8.11E-07	5.26E-03	3.44E-05	9.01E-05
ADI_{inh}(mg/kg/day)	Adult	Mean	9.13E-09	5.09E-11	7.43E-08	1.35E-09	5.63E-09
		Minimum	N/D	3.88E-11	N/D	3.61E-11	6.14E-10
		Maximum	7.39E-08	6.68E-11	4.34E-07	2.83E-09	7.42E-09
	Children	Mean	4.26E-09	2.38E-04	3.47E-08	6.33E-10	2.63E-09
		Minimum	N/D	1.81E-11	N/D	1.69E-11	2.87E-10
		Maximum	3.45E-08	3.12E-11	2.02E-07	1.32E-09	3.46E-09
ADI_{derm}(mg/kg/day)	Adult	Mean	1.40E-05	8.20E-08	1.20E-04	2.18E-06	9.07E-06
		Minimum	N/D	6.25E-08	N/D	5.82E-08	9.89E-07
		Maximum	1.19E-04	1.08E-07	6.98E-04	4.57E-06	1.20E-05
	Children	Mean	1.42E-05	7.92E-08	1.15E-04	2.11E-06	8.75E-06
		Minimum	N/D	6.04E-08	N/D	5.62E-08	9.55E-07
		Maximum	1.15E-04	1.04E-07	6.74E-04	4.41E-06	1.15E-05

N/D means not detected.

Table 3: Descriptive statistics of Average daily intake (ADI) values in mg/kg/day for adults and children in soils from Katsina steel rolling mill dumpsite for carcinogenic risk calculations.

Parameter	Receptor	Statistical parameter	Cancer risk values					Total excess lifetime cancer risk.
			Pb	As	Cd	Cr	Co	
Risk (Ingestion)	Adult	Mean	5.04E-07	4.97E-07	-	9.65E-03	-	9.66E-03
		Minimum	N/D	3.79E-07	-	N/D	-	4.23E-07
		Maximum	4.08E-06	6.52E-07	-	5.63E-02	-	5.63E-02
	Children	Mean	9.41E-07	9.27E-07	-	4.51E-05	-	4.69E-05
		Minimum	N/D	7.07E-07	-	N/D	-	7.89E-07
		Maximum	7.62E-06	1.22E-06	-	2.63E-04	-	2.650E-04
Risk (Inhalation)	Adult	Mean	3.83E-10	7.64E-10	8.55E-09	3.05E-06	5.52E-08	3.11E-06
		Minimum	N/D	7.83E-10	2.28E-10	N/D	6.02E-09	6.571E-08
		Maximum	3.10E-09	1.00E-09	1.79E-08	1.78E-05	7.28E-08	1.78E-05
	Children	Mean	1.79E-10	3.57E-10	2.66E-11	1.42E-06	2.58E-08	1.45E-06
		Minimum	N/D	2.72E-10	7.08E-13	N/D	2.81E-09	2.54E-08
		Maximum	1.45E-09	4.68E-10	5.56E-11	8.30E-06	3.40E-08	8.32E-06
Risk (Dermal)	Adult	Mean	-	1.23E-07	-	-	-	1.23E-07
		Minimum	-	9.39E-08	-	-	-	9.39E-08
		Maximum	-	1.61E-07	-	-	-	1.61E-07
	Children	Mean	-	1.19E-07	-	-	-	1.19E-07
		Minimum	-	9.05E-08	-	-	-	9.05E-08
		Maximum	-	1.56E-07	-	-	-	1.56E-07

Table 4: Descriptive statistics of calculated cancer risk values for adults and children in soils from Katsina steel rolling mill dumpsite.

related problems in the inhabitants around the area. It is therefore recommended that immediate remediation action should be started on the site to bring down the concentrations to the bearable limits and that future steel rolling mill tailings should be properly disposed-off far away from the residential and commercial areas.

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