Potential Health Risk Assessment for Soil Heavy Metal Contamination of Sagamu, South-west Nigeria due to Cement Production

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Abstract

This study was carried out to assess the potential non-carcinogenic health risk of the exposure of children and adults population of Sagamu, southwest Nigeria to heavy metal contamination through soil ingestion pathway. Twenty (20) soil samples were collected randomly between August and October, 2011; wet-digested and analyzed for Pb, Cu, Cr, Cd and Zn by Atomic Absorption Spectrophotometry. Dose intakes through oral ingestion of contaminated soil were calculated using USEPA model for non-carcinogenic risk assessment; chronic reference doses (RfDs) from US RAIS compilation were also adopted. The results of the risk assessment indicated that the highest risks for individual element for both adults and children were largely linked to Cd and Cr. Cumulative hazard quotient index (THI) for the study area showed that the adults and children population were seriously at the risk of chronic non-carcinogenic health problem (THI of 25.739 and 47.995 respectively).

Keywords: daily oral intake, ingestion rate, exposure frequency, systemic toxicity, body weight.

1.0 Introduction

Sagamu, a small town in the southwestern part of Nigeria is located within latitude 6°50' and 7°00' N and longitude 3°45' and 4°00' E (Gbadebo and Bankole, 2007*)*. It is about 63 km southeast of Abeokuta, 72 km southeast of Ibadan, 67 km northwest of Lagos and 32 km west of Ijebu-ode, all in South-west Nigeria. The area stands on a low-lying gently undulating terrain with altitude ranging between 30 and 61 m above sea level. The area is characterized by high annual temperature, high rainfall, high evapo-transpiration and high relative humidity which make it to be classified as humid tropical region (Akanni, 1992). The soil type of Sagamu is ferralitic (Aweto, 1981; Areola, 1982; Adamson, 1996); the climate is classified to be the humid tropical climatic zone (Adamson, 1996) and controlled by the tropical maritime and tropical continental air masses (Aweto, 1981). The monthly relative humidity is at least 70% with temperature ranges between 24^o to 28^o C (Adamson, 1996).

The investigation of the health risk assessment of soil contamination of Sagamu was premised on the previous studies of Gbadebo and Bankole (2007) in which substantial loads of heavy metal were reported in dust and air samples of Sagamu. The contamination of this environment was reported by these authors to be premised on the various activities of Lafarge-WAPCO cement factory located at the southern part of the town. Several methods have been proposed for the assessment of the potential human health risks from toxicants exposure (Storelli, 2008). For instance, the Human Exposure to Soil Pollutant (HESP model) which solely uses data on soil pollution as the input parameter (Veerkamp and ten Berge, 1994; Albering, 1999) to assess cancer and non-cancer risk of exposures. Three major exposure pathways: (1) direct ingestion of soil substrate particles; (2) dermal absorption of heavy metals in particles adhered to exposed skin; and (3) inhalation of suspended particles through the mouth and nose are used to estimate potential health risk (Lai *et al*., 2010). Current non-cancer risk assessment methods are typically based on the use of the target hazard quotient (HQ), a ratio between the estimated dose of a contaminant and the reference dose below which there will not be any appreciable risk (USEPA, 2000). And if such ratio exceeds unity, there may be concern for potential health effects; which have been recognized as a useful index to evaluate the health risk associated with (Rupert *et al*., 2008).

Based on this fore-knowledge that the soil may have been contaminated with heavy metals from various activities of Lafarge-WAPCO cement facility in Sagamu, southwest Nigeria; a study was carried out to assess the potential non-cancer risk of heavy metal exposure to soil heavy metals through oral ingestion route in adult and children populations of the study area.

2.0 Materials and Methods

2.1 Sampling method

Topsoil samples (0-15 cm) were collected randomly around a mega cement factory (Lafarge WAPCO cement factory) in Sagamu, south-west Nigeria. The factory was operational in 1978 (Ogunkunle and Fatoba, 2013) and as of today, it is working at full capacity of 900,000 tonnes/year. Air pollution control initially employed at the cement factory was electrostatic precipitator (ESP) but in 2011, the air pollution control system was upgraded to Filter bay dust collection system that could reduce dust emissions to less than $10 mg/m^3$ (Lafarge-WAPCO, 2011)

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2.2 Chemical Analysis

Topsoil samples were air-dried for 2 days, homogenized and sieved through a 2-mm mesh. The samples were subjected to wet digestion using Nitric-Perchloric acid method (AOAC, 1990; Hseu, 2004). One (1) gram of the sample was digested in 10 ml of conc. HNO_3 (70%, Sigma-Aldrich Corp.) and 5 ml of $HCLO_4$ (Sigma-Aldrich Corp.) for 30-45 min under gentle heat. The resulting solution was cooled, filtered using Whatman No. 42 filter paper and make up to 25 ml with deionized water in a 50 ml volumetric flask. The digestates were then analyzed for Pb, Cu, Cr, Cd and Zn by Atomic Absorption Spectrophotometer (Buck Scientific 210 VGP). Quality assurance and control were assessed using duplicates and blanks method

2.3 Potential Health Risk Assessment

Potential risk assessment is a multi-step procedure that involves (i) data collection and analyzing the data which are relevant to human health, especially heavy metal in studied medium, (ii) estimation of magnitude of potential human exposures, (iii) toxicity assessment and (iv) characterization of risk (Wcislo, 2006: Grzetic and Ghariani, 2008). Three transmission media have been put forward for calculating the risk assessment of heavy metals, namely soil, groundwater and air (Lai *et al*. 2010) but risk assessment study will be based on the exposure pathway of soil medium by oral intake as determined by USEPA (1989) and HESP model (Veerkamp and ten Berge, 1999). The model estimates exposure to contaminants which is non-carcinogenic thus:

$$\text{Daily oral intake of soil (DI) (mg/kg/day)} = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad \text{(Eq. 1)}$$

Where C = concentration of the contaminant in the medium (mg/kg); IR = ingestion rate (mg/kg); EF = exposure frequency (day/year); ED = exposure period (year); AT = average time for non-carcinogens and BW = body weight (kg) (USEPA, 1989; Grzetic and Ghariani, 2008). This gives the total dose entering the human body through oral ingestion of contaminated soil.

The systemic toxicity or non-carcinogenic hazard for a single element is expressed as the hazard quotient:

Non-cancer Hazard Quotient (HQ) = DI (mg/kg/day)/Rfd (Eq. 2)
where Rfd is chronic reference dose for the element (Table1).

Total chronic hazard index which is the summation of all the individual hazard quotients is represented as below:

$$\text{Total Chronic Hazard Index (THI)} = \sum_{i=1}^{n} HQ \qquad \text{(Eq.3)}$$

The greater is the value of HQ and THI above 1, the greater is the level of concern since the accepted standard is 1.0 at which there will be no significant health hazard (Grzetic and Ghariani, 2008; Lai *et al*., 2010). The probability of experiencing long-term health hazard effects increases with the increasing THI value (Wang *et al*., 2012) and according to Lemly (1996); THI = 1.1-10 refers to moderate hazard while THI >10 refers to high hazard.

3.0 Results

3.1. Heavy metal contents of the surface soil

Total contents of heavy metal in the topsoil of the study area are presented in Table 3. There is presence of high loads of heavy metals in the studied locations. Typical mean Pb content of surface soils worldwide is reported to be 32 mg/kg while Zn naturally content is about 20 mg/kg in crustal rock (Ling *et al*, 2007). Cr (VI) is assumed to be the form of Cr in the topsoil of this study because of the high pH (pH>5) (Table 3) of the soil since it is reported that soils with pH <4 contain predominantly Cr (III) (Wuana and Okieimen, 2011). The predominance of Cr (VI) is related to the redox potential of 400 mV for pH 7.0 to 8.0 which is sufficient for Cr(VI) to dominate any system (Grzetic and Ghariani, 2008). And this finding should raise environmental concerns because Cr (VI) is noted to be more toxic than Cr (III). Cd content of the topsoil appeared to be extremely high when compared with the reported natural average concentration (0.098 mg/kg) in littosphere (Heinrichs *et al*., 1980).

Plain data on metal content of soil are not always insufficient to describe or evaluate the risk that arises from the exposure of human (adults and children) to different heavy metals in soil (Grzetic and Ghariani, 2008); especially when more concise details on human health risk are required. Given the toxicological profile of the studied heavy metals (USEPA, 2010); it is evident that all the heavy metals have adverse effects on human, even to the level of being carcinogenic above reference dose. The toxicity of these heavy metals is informed by their varying degrees of adsorption in the soil (initial fast reactions which happen within minutes or hours after contact with soil and the slower adsorption reactions that take days or hours), and the redistribution into different chemical forms which created different bioavailability, mobility and toxicity (Shiowatana *et al*. 2001).

3.2. Heavy metal toxicity assessment and risk characterization

The descriptive statistics of daily oral intake (DI) and non-carcinogenic hazard quotient (HQ) for both child and adult in the study area are presented in table 4. The mean values of DI of both the adult and child in thus study are greater than the recommended oral reference dose (RfDs) stipulated except for Zn (USEPA, 2010) (Table 1). Generally, the DI of the investigated heavy metals for child daily ingestion appeared to be higher than that of the adult, meaning that children have higher doses of these heavy metals in soil ingested orally than adults. The sequence of the magnitude of the DOI for child and adult are as stated: Pb>Cu>Cd>Zn>Cr and Cu>Cd>Pb>Cr>Zn respectively.

Characterization of the risk of individual heavy metals showed that Cd, Cr and Cu portend greater toxic hazards of oral exposure of children (Table 4) (HQ= 42, 4 and 1.175 respectively). The hazards for adult in this study pointed that Cd has the highest toxic hazard (HQ=22.5) while Cr rated next with HQ of 4 (Table 4). Generally speaking, the hazardous index (HQ) for the ingestion of soil by children is twice greater in comparison to the corresponding results obtained for adults.

Considering the total chronic hazard quotient index of oral exposure to soil contamination in the study area by the populace, the THI (25.739 and 47.995 for adult and child respectively) which are far above 1, depicted great hazard for both young and old (Table 5). It is also clear from the results that exposure to Cd contamination of soil was the critical factor for the great value of the THI of both the adult and child.

4.0 Discussion

The presence of substantial Pb content in the topsoil cannot be exclusively related to cement production alone, but should also be linked to traffic within and around the town due to the activities of the cement facility. The HQs of Pb exposure through oral ingestion (adults and children) that were less than 1, suggest that the inhabitants of the study area are not exposed to any potential non-carcinogenic risk Pb from oral ingestion of Pb-contaminated soil.

Nevertheless, Inhalation and ingestion are the two routes of exposure to Pb and the effects from both are the same (Wuana and Okieimei, 2011). Pb has been shown to affect almost every organ and system in the human body. Evidence has shown that Pb is a multi-target toxicant which causes effects in the gastro-intestinal tract, cardiovascular system, central and peripheral nervous systems, kidneys, immune system and reproductive system (RAIS, 2008). Children are most prone to the toxic effects of Pb, causing break down of central nervous system (Song *et al*., 2009). Irreversible brain damage is reported to occur when blood Pb level exceed 100 μg/dl in adults and 80-100 μg/dl in children (RAIS, 2008). Adults usually experience decreased reaction time, loss of memory, nausea, insomnia, anorexia, and weakness of the joints when exposed to Pb dose above RfD (NSC, 2009).
Copper usually present in topsoil as Cu(II), though most Cu salts occur in 2 valency states- Cu(I) or Cu(II) ions (Grzetic and Ghariani, 2008), and its bioavailability and toxicity are mostly associated with the divalent state. Children population in this study happened to be prone to health risk from Cu toxicity due to the daily oral ingestion estimate that was greater than oral chronic RfD (0.04 mg/kg/day). This later translated into HQ that was greater than unitary which possess high non-carcinogenic risk when taking into cognizance the acceptable limit . Copper is indeed essential to humans but in high doses especially above RfDs, it can cause anaemia, liver and kidney damage, and stomach and intestinal irritation (Wuana and Okieimei, 2011).

The toxicological risk of oral exposure of the population (adults and children) to Cr is high in the study. The daily oral intakes of the population (both adults and children) were above RfD (0.003 mg/kg/day; USEPA, 2010) and this calls for greater attention because the predominant Cr specie in the topsoil could be the highly toxic hexavalent Cr [Cr(VI)]. And this hexavalent species of Cr has greater absorption rate of 2-8% when ingested than the trivalent species, though unstable in humans and may later be reduced to Cr(III) by ascorbate and glutathione in the body (IPCS, 2006). Chromium is associated with allergic dermatitis in humans (Scragg, 2006).

There is great risk of complications resulting from Cd toxicity in the exposed population of the inhabitants. The daily oral intake estimates for the population is twice the RfD (0.001 mg/kg/day; USEPA, 2010) which made the HQ to be in the multiples of moderate hazard threshold (Lemly, 1996; Wang *et al*., 2012). This is a serious situation because of the high risk of renal toxicity in the exposed population; renal NOAEL (the dose of chemical at which there were no statistically or biologically significant increase in the frequency or severity of adverse effects seen between the exposed population and an appropriate control) for Cd is 0.0021mg/kg/day (Nogawa *et al*., 1989) which was reported in this study to be far below the daily oral intake of the population. This indicates that the population is exposed to high risk of renal toxicity from Cd oral ingestions. Considering the THI for Cd also calls for serious attention because of the severity of the risk of the population to non-carcinogenic toxicity of Cd.

Zn is an essential element with a recommended daily allowances ranging from 5 mg for infants to 15 mg for adults (RAIS, 2008). It important to note that too little Zn can cause health problems and too much Zn is also harmful; but according to RAIS (2008) harmful effects generally begin at levels in the 100 to 250 mg/day range. The present Zn contents of topsoil in the study area are below any alerting values; hence there is no toxic risk of Zn exposure to the inhabitants.

Conclusion

This study has shown that the impacts of the operations of the cement facility in Sagamu cannot be neglected. The risk assessment for oral exposure of inhabitants in the area indicated that the non-carcinogenic risk tends to become significant for children and adults with exposure duration of 6yrs and 30yrs respectively, mainly for Cd and Cr exposure since the indices exceeded the acceptable limits of non-cancer hazard quotient. The cumulative hazard quotient index (THI) of the study area indicated a serious potential health hazard which Cd was apparently the main critical factor.

Recommendations

It is highly recommended that remediation processes be initiated in the area to reduce level of heavy metals in the topsoil around the Lafarge-WAPCO facility, especially Cd and Cr contents. Remediation goals for heavy metals may be set as total metal concentration or as leachable metal in soil, or as combination.

An assessment of human exposure risks, based on actually measured contaminant concentrations in locally grown vegetables using the standard HESP exposure model should be carried out to assess other routes of exposure apart from soil ingestion. It is also imperative to initiate research into the disease prevalence among the inhabitants to determine if there is any link to heavy metal contamination.

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Table 1. Some toxicological characteristics of the investigated heavy metals (IRIS, 2007)

Characteristics	Pb	Cu	Cr	Cd	Zn
Oral minimal risk level [a]					
MRL (mg/kg/day)	-	0.01	-	0.0002	-
Oral chronic reference dose					
Rfd (mg/kg/day)	0.3	0.04	0.003	0.001	0.02

[a] Minimal risk level (MRL): an estimate of the daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse non-cancer health effects over a specified route and duration of exposure.

Table 2. Risk assessment parameters and values used.

Parameters	Values used
Ingestion rate (IR) (mg/kg)	0.0002 kg/day- child [ab]
	0.0001 kg/day -adult [ab]
Exposure frequency (day/yr)	350 days/year [c]
Exposure duration (yr)	6years - child [b]
	30 years - adult [b]
Average time for non-carcinogens (day/yr)	365 days/year [d]
Body weight (kg)	15 kg - child [ad]
	70 kg –adult [d]

[a] USEPA (1989); [b] Grzetic and Ghariani (2008); [c] Wang *et al*. (2012); [d] USEPA (2000)

Table 3. Heavy metal contents (mg/kg) of soils around the mega cement factory

Sample	Co-ordinate	Pb	Cu	Cr	Cd	Zn	pH
1	6°48′57″N 3°36′11″E	712.1	862.2	99.8	764.1	106.2	5.8
2	6°48′50″N 3°36′80″E	688.2	898.8	86.4	692.1	136.4	5.5
3	6°47′01″N 3°34′80″E	712.1	761.1	140.6	811.1	400.2	6.1
4	6°48′77″N 3°36′44″E	709.8	869.2	92.2	601.2	509.2	5.4
5	6°49′84″N 3°37′91″E	742.1	672.2	64.1	422.8	99.8	5.1
5	6°48′24″N 3°35′81″E	800.2	841.2	18.8	962.1	153.1	6.4
6	6°47′31″N 3°37′06″E	99.8	366.4	69.2	638.1	121.1	5.6
7	6°47′77″N 3°34′00″E	299.4	968.8	102.6	692.1	243.2	5.5
8	6°48′34″N 3°36′62″E	686.2	632.1	103.8	504.8	100.6	6.2
9	6°47′97″N 3°38′03″E	985.2	346.2	99.1	609.2	101.1	6.1
10	6°48′11″N 3°36′90″E	298.8	999.2	142.1	700.8	121.1	5.9
11	6°47′29″N 3°38′74″E	867.7	200.4	322.1	342.1	200.8	5.7
12	6°47′11″N 3°38′90″E	699.2	96.2	362.1	806.4	92.1	5.4
13	6°47′65″N 3°38′85″E	804.1	343.8	99.8	79.9	91.1	5.2
14	6°47′69″N 3°38′06″E	863.2	897.2	126.1	96.8	72.1	5.6
15	6°48′05″N 3°36′38″E	992.1	869.4	288.2	642.1	56.1	6.2
16	6°48′42″N 3°38′07″E	968.4	666.6	204.6	538.1	109.6	5.1
17	6°47′30″N 3°38′85″E	906.1	392.2	199.8	466.2	388.1	5.4
18	6°48′35″N 3°38′08″E	489.9	296.1	201.2	492.1	446.2	5.8
19	6°47′69″N 3°38′86″E	398.2	99.9	199.6	604.8	308.8	6.1
20	6°48′26″N 3°38′96″E	266.1	802.4	266.8	39.9	100.9	5.9
	Minimum concentration	99.8	96.2	64.1	39.9	56.1	5.1
	Maximum concentration	985.2	999.2	362.1	811.1	509.2	6.4
	Mean	666.1	613.4	156.6	547.9	188.5	5.71
	±S.D	258.9	300.2	91.7	244.6	137.5	0.38

Table 4. Daily oral intake (DI) and non-carcinogenic hazard quotient (HQ)

Element		Daily Oral Intake (DI) (mg/kg/day)		Non-cancer Hazard Quotient (HQ)	
		Child	Adult	Child	Adult
Pb	Minimum	0.007	0.0041	0.747	0.014
	Maximum	0.076	0.0405	0.253	0.135
	Mean (n=21)	0.036	0.0274	0.120	0.091
Cu	Minimum	0.007	0.0039	0.175	0.097
	Maximum	0.077	0.0411	1.925	1.027
	Mean (n=21)	0.047	0.0252	1.175	0.630
Cr	Minimum	0.005	0.0026	1.667	0.867
	Maximum	0.028	0.0149	9.333	4.967
	Mean (n=21)	0.012	0.0064	4.000	2.133
Cd	Minimum	0.002	0.0016	2.000	1.600
	Maximum	0.062	0.0333	62.000	33.300
	Mean (n=21)	0.042	0.0225	42.000	22.500
Zn	Minimum	0.004	0.0023	0.200	0.115
	Maximum	0.039	0.0209	1.950	1.045
	Mean (n=21)	0.014	0.0077	0.700	0.385

Table 5. Total Chronic Hazard Quotient Index (THI) of heavy metals

	Minimum value		Maximum value		Mean	
	Child	Adult	Child	Adult	Child	Adult
Total Chronic Hazard Quotient Index (THI)	4.789	2.693	75.461	40.474	47.995	25.739