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Indoor Dust-Based Pollution Status and Risk Assessment for a Rural Town, Ebedei in Nigeria Hosting Gas Flare Facility

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Abstract

Recently, there has been series of petitions and protestations from petroleum production gas flare facility host communities in Nigeria about the degradation of their environment. This study was designed to conduct indoor dust related human health risk assessment for Cd, Pb, Mn and Ni. Deposited indoor dust samples were collected from sixteen (16) residential buildings distributed across the four quarters of Ebedei waterside town in Nigeria, within the vicinity of a petroleum production gas flare facility. The samples were digested and analysed for Cd, Pb, Mn and Ni concentrations using inductively coupled plasma mass spectrometry (ICP-MS). Contamination/pollution index (C/PI) and human health risk assessments were conducted. The concentration ranges of 1.2 - 14.9 mg/kg, 44.0 - 161.6 mg/kg and 221.3 - 752.0 mg/kg, and below detection to 29.8 mg/kg were recorded for Cd, Pb, Mn and Ni, respectively. C/PI analyses for metals in the indoor dusts investigated suggested Cd levels to be polluted and Pb levels to be slightly polluted, while Mn and Ni levels indicated contamination. Risk assessment studies indicated that children may be more at risk for all the three exposure pathways. Exposure through the ingestion pathway indicated the highest risk for both the adult and children population.

Keywords

Gas Flare Facility, Ebedei, Risk Assessment, Heavy Metals

1. Introduction

Indoor dust is a conglomerate of particulate matter from several sources in the indoor environments [1] [2]. Most depositions of metals associated with combustion occur in the particulate form [3]. Indoor dust is a source of deposition of heavy metals in potentially harmful quantities to human beings [4]. Concentrations of potentially toxic metals like Pb and Mn in settled house dust correlated significantly with concentrations in re-suspended health relevant fractions [5]. We are most likely to contact indoor dust because a significant proportion of time is spent in the indoors [6]. So, the indoor dust is an important exposure pathway to heavy metals for humans [7].

In the indoor environment, heavy metals are released from consumer products, furniture and building materials and through occupants' activities such as smoking and incense burning [8]. The major migration pathways for inorganic contaminants, such as heavy metals, from the exterior environment to the interior environment are the infiltration of contaminated outdoor air and the track-in of soil adhering to foot and footwear [9].

A good number of researchers have reported in various studies the levels of heavy metals in indoor dust from residential buildings [7] [10] [11] [12], especially in cities and urban centres. In Nigeria, however, only a few studies have been carried out to examine the concentrations of heavy metals in the indoor dust of environment [13]. Ebedei Waterside is a rural community in Delta State of Nigeria and the major economic activity taking place in the community is farming. However, the community is a host to an oil exploration facility which flares gas at a rate that is being feared to be introducing harmful substances at a high level into the community environment.

Metals in the indoor dust can accumulate in the human body through inhalation of re-suspended dust particles, ingestion of dust particles as a result of hand-to-mouth and object-to-mouth actions, and/or through dermal contact absorption of dust particles [14]. An increasing global concern is being given to the contamination of the indoor environment by heavy metals in order to investigate their impact on human health and to minimize health risks [15] [16] [17].

Children have been reported in various studies such as that of to have great susceptibility to the menace of the pollution of the indoor environment by heavy metals [13] [18]. Due to their frequent playing on the ground and mouthing of hand and other objects in the process, children take in more contaminated indoor dust each day as compared to the incidental ingestion of dust particles by adult [19]. Children are very vulnerable to heavy metal poisoning as their organs (the brain for example) are in a period of active growth and differentiation, making them have low tolerance to toxins [20].

The effects of metal contaminated indoor dust on human health is presently well publicized, but there is currently a paucity data on the emissions constituents from petroleum-based gas flare and their possible impact on the environment due to restricted access to the facility [21]. Risk assessment estimates the severity of harm to human and other receptors that may result from exposure to chemicals present in the environment [22]. Human induced enrichment of toxic metals in dust to concentrations beyond "safe" levels is likely to cause harm to human at site of gas flare. Nigeria is currently the second ranking country in volume of gas flared in the world [23]. This study was therefore designed to determine the concentrations of selected heavy metal in indoor dust within the vicinity of a gas flare facility and estimate possible human health risk for a gas flare rural community.

2. Materials and Method

2.1. Description of the Study Area

The study was done in Ebedei Waterside, one of two geographically separated regions of Ebedei community; the other being called Ebedei-Uno. Ebedei Waterside lies between 5˚52'N and 6˚11'E, and 5˚54'N and 6˚13'E along the coast of River Ethiope and it is just around 3 km away from Obiaruku, the Local Government Headquarters. It is divided into four smaller quarters; Obi-Iloh (Umuosele), Obi-Ogene (Umueziogoli), Adonishaka (Ogbe-Uzu) and Ukwuole, with each quarter having four streets. Farming is the common economic activity of the people living in the four quarters. Ebedei Waterside also play host to Platform Petroleum Company—an oil exploration company.

2.2. Sampling

Indoor dust samples were collected from sixteen (16) residential buildings in Ebedei Waterside (**Figure 1**). Four samples from the four streets of each quarter. The collection was done with the aid of a plastic brush and a plastic pan. For every portion of a composite sample, a clean set of plastic brush and plastic pan was used to scoop deposited indoor dust particles from the surfaces of various objects within the residential apartments into a fresh and clean plastic tube. Of the varying surfaces of indoor object from which the deposited dusts were collected, the surfaces of ceiling fans were the most prominent. After the samples from the sixteen sites have been collected into separate plastic tubes, they were all packed together and transferred to the laboratory for subsequent preparations and analysis.

2.3. Sample Digestion and Instrumental Analysis

The collected samples were kept in the sealed plastic tubes in the laboratory until preparation for analysis. In preparation for analysis, a 0.5 g portion of each of the collected samples were measured in duplicates and were all digested with 20 ml *aqua regia* (mixture of HCl and HNO_3 in the ratio of 3:1) by heating them in a solution of the acid mixture for 2 hours. The mixtures were then filtered and the filtrates were diluted to 50 ml with deionized water. The contents of Cd, Pb, Mn and Ni were then determined in all the samples using inductively coupled plasma-mass spectrometry (ICP-MS).

2.4. Contamination/Pollution Index (C/PI)

A comparison between the concentrations of heavy metals in the sampled sites and their reference levels was done to establish a contamination/pollution index

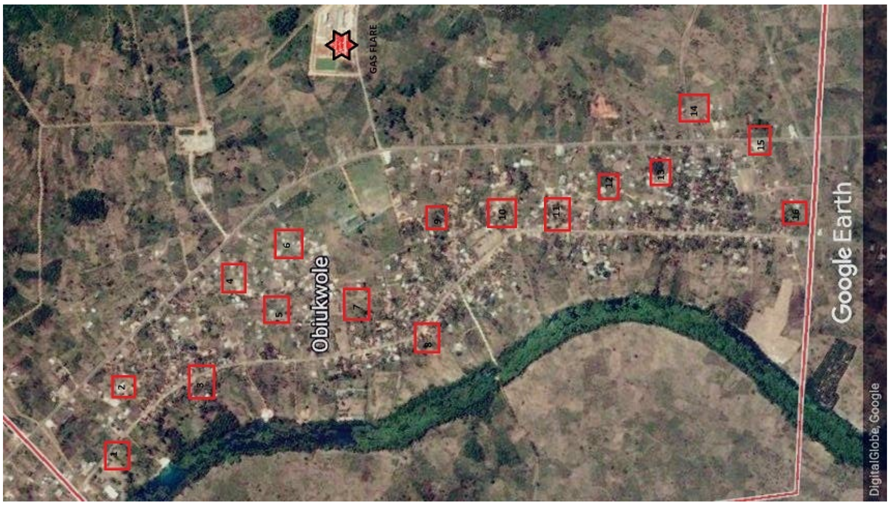

Figure 1. Google map showing the 12 sample locations.

for each of the studied elements in the studied area. This provides adequate information about the significance of the measured concentrations of metals in the indoor dust samples and how the values obtained are related to the maximum allowable limits for the metals [24]. It was derived by employing the contamination/pollution index as previously applied [25].

$$C/PI = \frac{\text{concentration of metal in dust}}{\text{reference value}} \tag{1}$$

No allowable maximum levels of heavy metals have been established for dust samples (indoor or outdoor) by the time of doing this study, hence; the reference values used in this case is the Department of Petroleum Resources of Nigeria maximum allowable levels of metals in soil [26] as stated listed in **Table 1**.

The categorization of degree of contamination/pollution based on this index is as follows: <0.10 = very slight contamination; 0.10 - 0.25 = slight contamination; 0.26 - 0.50 = moderate contamination; 0.51 - 0.75 = severe contamination; 0.76 - 1.00 = very severe contamination; 1.10 - 2.00 = slight pollution; 2.10 - 4.00 = moderate pollution; 4.10 - 8.00 = severe pollution; 8.10 - 16.00 = very severe pollution; >16.00 = excessive pollution.

2.5. Human Exposures and Risk Assessment

Humans are exposed to these contaminants through three major pathways- inhalation, ingestion and dermal absorption. The intake doses from the respective exposure pathways by the children and adult populations were estimated using Equations (2), (3) and (4) adapted from US EPA [27]. The individual terms and their values inputted into the risk assessment equations are provided in **Table 2**.

$$D_{inh}\left(\text{mg/kg/day}\right) = C\left(\text{mg/kg}\right) \times \frac{inhR \times EF \times ED}{PEF \times ABW \times AT} \tag{2}$$

$$D_{ing}\left(\text{mg/kg/day}\right) = C\left(\text{mg/kg}\right) \times \frac{ingR \times EF \times ED}{ABW \times AT} \times 10^{-6} \tag{3}$$

Table 1. Reference values of heavy metals (mg/kg).

Metal	Reference value
Cd	0.8
Pb	85
Mn	850*
Ni	35

*Derived from the crustal abundance value. Adapted from [26].

Table 2. Description of parameters used in the health risk assessment.

Parameters	Definition	Values		References
		Child	Adult	
C	Metals concentration in dust			
inhR	Inhalation rate	7.6 m^3/day	20 m^3/day	[29]
ingR	Ingestion rate	200 mg/day	100 mg/day	[30]
EF	Exposure frequency	180 days/year		[29]
ED	Exposure duration	6 years	24 years	
AT	Averaging time	ED × 365 days (for non-carcinogenic), 25,550 days (for carcinogenic)		
PEF	Particle emission factor	1.36×10^9 m^3/kg		[31]
SA	Exposed skin area	2800 cm^2	5700 cm^2	
SAF	Skin adherence factor	0.2 mg/cm^2/day	0.07 mg/cm^2/day	
DAF	Dermal absorption factor	0.001		[10]
ABW	Average body weight	15 kg	70 kg	[32]
CR	Contact rate (inhR or ingR or SA × SAF × DAF)			[27]

$$D_{dermal}\left(\text{mg/kg/day}\right) = C\left(\text{mg/kg}\right) \times \frac{SA \times SAF \times DAF \times EF \times ED}{ABW \times AT} \times 10^{-6} \quad (4)$$

The non-carcinogenic and carcinogenic risks as a result of exposures to the metals in the dust samples were considered in this study. The non-carcinogenic risks were estimated using a factor known as the Hazard Quotient (HQ)—the ratio of the intake doses from each of the pathways to the respective reference intake doses (*RfD*) for each metal across each pathway, as shown in Equation (5). The cumulative non-carcinogenic hazard risk from all the exposure pathways was rated as the Hazard Index (HI) for children and adults as calculated using equation provided by US EPA [27].

$$\text{Hazard Quotient}\left(HQ\right) = \frac{D}{RfD} \quad (5)$$

$$\text{Hazard Index}\left(HI\right) = \sum HQ = HQ_{inh} + HQ_{ing} + HQ_{dermal} \quad (6)$$

In the assessment of the carcinogenic risk, the lifetime average daily dose

(*LADD*), a weighted average of the intake doses of a contaminant over a lifetime [28] was calculated for *Cd* and Ni—the two carcinogens considered in this study—through the inhalation route of exposure, as shown in Equation (7) below. To quantitatively estimate the carcinogenic risk (*CR*), the *LADD* was multiplied by the inhalation slope factor (*SF*).

$$LADD\left(\text{mg/kg/day}\right) = \frac{C\left(\text{mg/kg}\right)}{AT} \times \left[\frac{CR_{child} \times ED_{child}}{BW_{child}} + \frac{CR_{adult} \times ED_{adult}}{BW_{adult}}\right] \quad (7)$$

3. Results and Discussion

The concentrations of cadmium, lead, manganese and nickel in four different samples of indoor dust from each of the four quarters of Ebedei and their respective mean values are provided in **Table 3**. All the metals investigated in study have previously been found in suspended particulate matter of the study location [33]. Excluding Mn the other three metals investigated in this study also indicated enrichment factors above 40.

The mean concentrations of cadmium in the indoor dust of Obi-Iloh, Obi-Ogene, Adonishaka and Ukwuole were 6.2 mg/kg, 4.8 mg/kg, 5.2 mg/kg and 3.0 mg/kg respectively (**Table 3**). All means recorded for the four quarters were above the 0.8 mg/kg permissible value set by the Nigerian Department of Petroleum Resources for soil matrix [26]. The range of means of the concentrations observed for Cd in four quarter of the study area 3.0 - 6.2 mg/kg, 4.8 mg/kg is above the range of <0.05 mg/kg previously reported by Asia *et al.* (2007) [34] for surface soil at flare site in Nigeria. The range of Cd, 1.2 mg/kg and 14.9 mg/kg obtained in this study consistent with the range of 0.2 mg/kg to 20 mg/kg reported for Cd in the city of Instabul, Turkey [10].

The mean concentrations of lead in the samples from Obi-Iloh, Obi-Ogene, Adonishaka and Ukwuole were 98.9 mg/kg, 132.4 mg/kg, 79.0 mg/kg and 79.5 mg/kg respectively (**Table 3**). Mean values recorded for Obi-Iloh and Obi-Ogene were both above the 85.0 mg/kg reference value set by the Nigerian Department of Petroleum Resources for soil matrix [26], while those recorded for Adonishaka and Ukwuole were below the set reference value. The mean concentrations of the four quarters, 98.9 mg/kg, 132.4 mg/kg, 79.0 mg/kg and 79.5 mg/kg are consistent with the concentration, 99.4 mg/kg reported previously [33] for surface soil at a gas flare facility in Niger delta, Nigeria. Also the range of means (79.0 - 132.4 mg/kg) recorded in this study is consistent with 60.1 - 388 mg/kg [34] and 3 - 230 mg/kg [10] reported for indoor dust in other parts of the world.

The mean concentrations of manganese in the indoor dusts of Obi-Iloh, Obi-Ogene, Adonishaka and Ukwuole were 386.9 mg/kg, 604.9 mg/kg, 406.7 mg/kg and 282.7 mg/kg respectively (**Table 3**). All the recorded mean values for the four quarters were below the 650.0 mg/kg reference value set by the Nigerian Department of Petroleum Resources for soil matrix [26].

In the case of nickel, the recorded mean concentrations in Obi-Iloh, Obi-Ogene, Adonishaka and Ukwuole were 23.0 mg/kg, 19.9 mg/kg, 17.0 mg/kg

Table 3. Concentrations of cadmium, lead, manganese and nickel in the four quarters of Ebedei.

Quarter	Sample code	Cadmium	Lead	Manganese	Nickel
			mg/kg		
Obi-Iloh	1	14.9	153.8	483.0	24.5
	2	4.3	88.0	333.9	17.0
	3	2.8	44.0	283.0	26.6
	4	2.8	109.8	447.5	24.5
	Mean	**6.2**	**98.9**	**386.9**	**23.0**
Obi-Ogene	5	3.3	109.6	544.0	22.3
	6	2.3	107.6	501.3	27.6
	7	6.2	150.8	622.4	29.8
	8	7.2	161.6	752.0	b.d
	Mean	**4.8**	**132.4**	**604.9**	**19.9**
Adonishaka	9	5.6	140.0	617.2	1.1
	10	6.2	53.8	361.3	23.4
	11	4.0	55.5	271.5	24.6
	12	5.0	66.6	376.9	19.1
	Mean	**5.2**	**79.0**	**406.7**	**17.0**
Ukwuole	13	2.8	77.7	221.3	19.2
	14	5.0	76.6	224.7	19.1
	15	2.8	66.6	356.1	22.3
	16	1.2	96.9	328.7	25.6
	Mean	**3.0**	**79.5**	**282.7**	**21.6**
Reference (DPR, 2002)		**0.8**	**85.0**	**850.0**	**35.0**

and 21.6 mg/kg respectively (**Table 3**). All of which values were below the set reference value of 35.0 mg/kg for nickel in soil matrix by the Nigerian Department of Petroleum Resources [26]. The mean concentrations, 23.0 mg/kg, 19.9 mg/kg, 17.0 mg/kg and 21.6 mg/kg are above the concentration, 6.7 mg/kg reported previously [33] for surface soils around the vicinity of a gas flare facility in Nigeria. The means obtained for the four quarters of Ebedei in this study, 23.0 mg/kg, 19.9 mg/kg, 17.0 mg/kg and 21.6 mg/kg are consistent with range of concentration mean, 17.1 - 53.6 mg/kg obtained for 12 rural cities in China [35].

4. Contamination/Pollution Index (C/PI)

The index values presented in **Table 4** show that Cd levels in the studied area are within the range of moderate to severe pollution. The Pb levels range between severe contaminations to slight pollution for the four quarters. Mn concentrations ranged between moderate to severe contaminations in the four quarters

Table 4. Contamination/pollution index of Cd, Pb, Mn and Ni for deposited indoor dust.

Quarter	Cd	Pb	Mn	Ni
Obi-Iloh	7.75	1.16	0.46	0.66
Obi-Ogene	6.00	1.56	0.71	0.57
Adonishaka	6.50	0.93	0.48	0.49
Ukwuole	3.75	0.94	0.33	0.62

<0.10 = very slight contamination; 0.10 - 0.25 = slight contamination; 0.26 - 0.50 = moderate contamination; 0.51 - 0.75 = severe contamination; 0.76 - 1.00 = very severe contamination; 1.10 - 2.00 = slight pollution; 2.10 - 4.00 = moderate pollution; 4.10 - 8.00 = severe pollution; 8.10-16.00 = very severe pollution; >16.00 = excessive pollution.

studied. Ni concentration levels suggest that the town is contaminated severely.

5. Health Risk Assessment

Predicted daily intake doses for the oral pathway is higher than those obtained for the dermal and inhalation exposures for all population types considered (Table 5). Hazard quotient values followed the same sequence; suggesting that humans are more at risk of non-carcinogenic effect when exposed to these heavy metals through the ingestion mode than the other two modes of exposure as greater percentage of the HI values of the studied metals is contributed by the HQ_{ing}. This is consistent with several reports elsewhere [28] [34] [36]. Also the daily intake doses predicted for children are above those for adults irrespective of the pathway.

For Cd in samples the estimated daily intake dose ranges are (3.2E−05 - 8.8E−10 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) and (3.2E−06 - 5.0E−10 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) for children and adults, respectively for all three pathways (Table 5). The daily intake doses predicted for both children and adults in Ebedei are below the known reference doses of 1.0E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$, 1.0E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ and 5.05E−05 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ for ingestion, inhalation and dermal, respectively. For Pb in samples the estimated daily intake dose ranges are (6.4E−04 - 1.0E−08 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) and (6.9E−05 - 1.0E−08 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) for children and adults, respectively for all three pathways (Table 5). The daily intake doses predicted for both children and adults in Ebedei are below the known reference doses of 3.5E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$, 3.52E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ and 5.25E−04 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ for ingestion, inhalation and dermal, respectively.

For Mn in samples the estimated daily intake dose ranges are (2.8E−03 - 7.7E−08 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) and (3.0E−04 - 4.4E−08 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) for children and adults, respectively for all three pathways (Table 5). The daily intake doses predicted for both children and adults in Ebedei are below the known reference doses of 4.6E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$, 1.43E−05 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ and 1.84E−03 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ for ingestion, inhalation and dermal, respectively. For Ni in samples the estimated daily intake dose ranges are (1.3E−04 - 3.7E−09 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$)

Table 5. Health risk assessment from exposures to heavy metals.

Element	RfD_{ing}	RfD_{inh}	RfD_{derm}	Inh SF		DI		HQ		HI		LADD	CR
						$(\mu g \cdot kg_{BW}^{-1} \cdot d^{-1})$							
						Children	Adult	Children	Adult	Children	Adult		
					Ingestion	3.2E−05	3.4E−06	3.2E−02	3.4E−03				
$Cd_{non\text{-}cancer}$	1.0E−03	1.0E−03	5.0E−05		Inhalation	8.8E−10	5.0E−10	8.8E−07	5.0E−07	0.034	0.004		
					Dermal	8.8E−08	1.3E−08	1.8E−03	2.6E−04				
Cd_{cancer}				6.2								2.5E−10	1.6E−09
					Ingestion	6.4E−04	6.9E−05	1.8E−01	1.9E−02				
Pb	3.5E−03	3.52E−03	5.25E−04		Inhalation	1.8E−08	1.0E−08	5.1E−06	3.0E−06	0.184	0.020		
					Dermal	1.8E−06	2.7E−07	3.5E−03	5.1E−04				
					Ingestion	2.8E−03	3.0E−04	6.1E−02	6.5E−03				
Mn	4.6E−02	1.43E−05	1.84E−03		Inhalation	7.7E−08	4.4E−08	5.4E−03	3.1E−03	0.071	0.010		
					Dermal	7.7E−06	1.2E−06	4.2E−03	6.5E−04				
					Ingestion	1.3E−04	1.4E−05	6.5E−03	7.0E−04				
$Ni_{non\text{-}cancer}$	2.0E−02	2.06E−02	5.4E−03		Inhalation	3.7E−09	2.1E−09	1.8E−07	1.0E−07	0.007	0.001		
					Dermal	3.8E−07	5.7E−08	7.0E−05	1.1E−05				
Ni_{cancer}				0.84								1.0E−09	8.9E−11

and (1.4E−05 - 2.1E−109 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$) for children and adults, respectively for all three pathways (Table 5). The daily intake doses predicted for both children and adults in Ebedei are below the known reference doses of 2.0E−02 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$, 2.06E−02 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ and 5.4E−04 $\mu g \cdot kg_{BW}^{-1} \cdot d^{-1}$ for ingestion, inhalation and dermal, respectively.

Therefore exposures to the individual metals pose no significant risk of non-carcinogenic effects based on the fact that the HI values for the individual metals fell below the threshold value of 1. The higher HI values recorded for the children population in this study suggest that children are more at risk of non-carcinogenic at Ebedei following exposure to the dust in their environment. Pb indicated greater percentage of the minimal risk of non-carcinogenic effects that may be observed among the children and the adult populations, followed, by Mn and Cd, and Ni.

The assessments of the risk of carcinogenic effects were conducted for Cd and Ni, and the assessment was done for exposures through the inhalation pathway alone. The cancer risk estimated for Cd and Ni were 1.6×10^{-9} and 8.9×10^{-11}, respectively. The cumulatively risk factor, (1.7×10^{-9}), the estimated cancer risk values in this study are below regulatory range of 10^{-6} - 10^{-4}. Hence, there is a very low tendency for individuals to be at risk of any carcinogenic effect.

5. Conclusion

In this study, concentration ranges of 1.2 - 14.9 mg/kg, 44.0 - 161.6 mg/kg and 221.3 - 752.0 mg/kg, and below detection to 29.8 mg/kg were recorded for Cd, Pb, Mn and Ni, respectively. Resultantly, C/PI values of 6, 1.1, 0.5 and 0.6 were recorded for Cd, Pb, Mn and Ni, respectively. The cumulative HI values indicated potential carcinogenic risks for both the children and adult populations were 0.296 and 0.035, respectively while an estimate of the possible total cancer risk for an individual living within Ebedei Waterside throughout a lifetime gave a cancer risk value of 1.7×10^{-9}. Although carcinogenic and non-carcinogenic risks for this study were below threshold values, there is an indication that human population from Ebedei may be exposed to elevated doses of potentially toxic metals in indoor environments.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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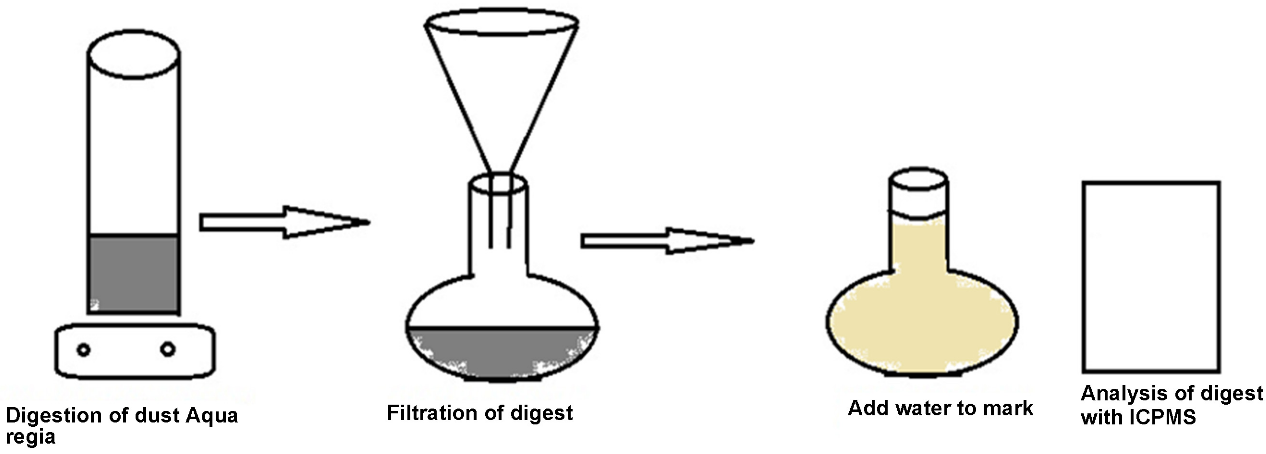

Flowchart of experimental procedure.