Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.55493/5003.v12i4.4656
Vol. 12, No. 4, 269-281.

URL: www.aessweb.com

ENVIRONMENTAL AND HUMAN HEALTH RISKS OF LEAD ACCUMULATION IN SOIL SAMPLES FROM SOLID WASTE DUMPSITES WITHIN ABUJA, NIGERIA

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Article History
Received: 12 September 2022
Revised: 14 October 2022
Accepted: 28 October 2022
Published: 16 November 2022

Keywords
Health risk
Lead
Pollution index
Solid waste dumpsites.

ABSTRACT

The environmental risks associated with heavy metal pollutions are becoming worrisome. Hence, this study evaluated the environmental and human health risks of lead (Pb) accumulation in soil samples from solid waste dumpsites within Abuja, Nigeria. Soil samples (n=72) were collected (0-45 cm depth) from Abaji, Bwari, Gosa, Gwagwalada, Kuje, and Kwali dumpsites and 2 km away (control), and then analyzed for Pb using atomic absorption spectrophotometer. The risks of Pb contaminations were then evaluated in soils and in individuals (Children and Adults) via inhalation and dermal contacts with soil using ecological and health risk equations. Pb concentrations in the dumpsites were below the permissible limits set by environmental protection agencies and were highest in Kuje dumpsite and lowest in Abaji dumpsite. The ecological pollution indices ranged from 'low risks' (at Bwari, Gosa, Gwagwalada dumpsites) to 'very contamination risks' (at Kuje and Kwali dumpsites). Daily dose for Pb via dermal contact pathways were higher and no significant lifetime health (non-carcer and cancer) risks were observed suggesting that inhalation and dermal routes pose very low health risk of Pb poisoning in both children (≤ 15 years) and adults (≤ 70 years). This study suggests that the concentration of Pb in the study dumpsites might cause more ecological risks than health hazards in exposed individuals via inhalation and dermal pathways.

Contribution/ Originality: This study contributes to the existing literature on the potential environmental and health risks associated with lead (Pb) accumulation within the vicinity of solid waste dumpsite in Nigeria. Thus, soils within these dumpsites should be constantly monitored, and managed to avoid the risks associated with exposures to Pb pollution.

1. INTRODUCTION

In some Asian and African countries, incessant solid waste generation, indiscriminate disposal and poor management techniques are widely prevalent [1, 2]. These solid waste materials are dumped at open land spaces for natural degradation to occur especially in most developing nations [3]. The solid wastes are collected by designated waste management agencies for onward disposal at dumpsites/landfills [4]. Apart from lack of proper waste management mechanisms [5], most of the landfills/dumpsites in developing countries including Nigeria are not technically designed and fortified in such a manner that prevents leachates from spreading or percolating to adjacent soils or underground water bodies [6]. Consequently, majority of solid waste dumpsites in these countries therefore serve as reservoirs for direct and indirect pollution of soil, water, air and food and among other threats [1, 5, 7]. One of the major public heath important pollutants of open landfills/dumpsites of solid waste is heavy metal [8].

Heavy metal is a special term broadly use to identify all naturally occurring metallic and metalloids with a density of over 5 g/cm^3 and toxic effects at relatively lower concentrations [9]. These metallic chemical elements occur naturally in the earth crust from where they impact on the environment depending on the rate of anthropogenic activities thereby. Chemists and nutritionists have attempted to group heavy metals based on their physiological essentiality as well as toxicities to living organisms and ecosystem. Naturally occurring chemical elements are loosely classified as essential, non-essential, less toxic and highly toxic metals [9, 10]. Among these groups, the highly toxic metals, particularly mercury (Hg), cadmium (Cd) and lead (Pb) have been the major sources of concern to environmentalists because they seriously impact negatively on the health of humans and other organisms [5, 11]. Generally, heavy metals, irrespective of classification can exert some levels of deleterious effects on plants and animals which are exposed to them via soil, water, air, food, among other sources. For instance in plants, they cause poor build-up of cellular biomass, slow nutrient uptake/assimilation, stunted growth, altered photosynthetic processes, impaired cellular water balance, reduction in crop yields and ultimately death [12-14]. In humans, they cause chronic and acute toxicities and serious health issues, such as tissues, organs and system disorders depending on the metal dosages, routes of exposures and susceptibilities of the individuals involved [1, 15].

Among the list of commonly encountered heavy metals, lead (Pb) stands out as one of the most abundant, widely distributed and toxic elements of earth crust [12]. Over the years, Pb had been applied as one of the basic raw materials for the production of appliances and lead-products such as batteries, pipes, shields for x-ray among others. From these sources and other industrial and agricultural sources such as smelting, mining, refining, paints, leaded gasoline, pesticides, fertilizers, Pb finds its way into soil, water, air, and food [16]. Soil is considered a natural sink and reservoir of Pb and depending on the levels of anthropogenic activities, its concentration can increase, accumulate and cause environmental toxicity [17]. Pb toxicity, especially in your children, infants and foetus is one of the major concerns associated with Pb polluted food, soil, dust, water and air. Lead (Pb) has been found to seriously affect humans, particularly children whom are exposed through swallowing, inhalation and dermal contact with contaminated soil/dust particles while playing. They influence the normal functioning of the nervous systems, kidneys, bones, teeth, coordination and intellectual developments in exposed individuals [18-20].

Previous studies conducted on the pollution levels of heavy metals, including Pb, have been reported in samples from soil, dust, air, water and crops collected within the vicinity of solid waste dumpsites in Nigeria [21-27] other African [5] and Asian countries [11, 28, 29]. The environmental and health risks of heavy metals in polluted soils at dumpsites have been consider as important indicators for estimating heavy metal contaminations and their health effects on humans who are exposed directly or indirectly to the pollution systems. The ultimate goal of health risk assessment of heavy metal contaminations is to prevent the potential human health risks associated thereby. Considering the toxic effects of elevated concentrations of Pb in soils, waters and crops to the ecosystem and exposed individuals, it is, therefore, pertinent to constantly evaluate the ecological and health toxicity of Pb accumulations in solid waste dumpsites: a major source of heavy metal pollution. Currently, there is paucity of such information from Abuja, the Federal Capital Territory (FCT) of Nigeria where the levels of industrialization and anthropogenic activities have continued to rise to date. Such information will be beneficial to governmental agencies in pinpointing potential environmental risks of lead-contaminated dumpsites with a view to intensifying/proffering substantial management strategies against their environmental and health impacts. This study was aimed at investigating the environmental and human health risks associated with Pb accumulations in soil from major solid waste dumpsites within Abuja, Nigeria.

2. METHODOLOGY

2.1. Study Area

The study was carried out within Abuja (9° 3′ 28.26″ N and 7° 29′ 42.29″ E), the Federal Capital Territory, located in the center of Nigeria, at about 500 m above sea level Figure 1. Abuja land mass covers an area of over 8,000 km^2, with a total population of in. The four major States which surrounds it include Kaduna State (North), Niger State (West), Nasarawa State (East) and Kogi State (South). The current metro area population Abuja is 3,652,000 (2022), a 5.43 % rise from the previous year (2021) [30]. Abuja climate has both wet and dry seasons with a relatively warm temperature of about 26.65 °C and an average precipitation of about 1,200 mm annually. Due to the rapid population growth and industrialization within the FCT, huge amount of heterogeneous solid wastes are generated on daily basis from anthropogenic activities. These municipal and industrial solid wastes are collected and conveyed to designate open spaces scattered all over each local government area councils. For this study, the major dumpsites employed as sampling areas were Gosa, Abaji, Bwari, Gwagwalada, Kuje and Kwali local government areas.

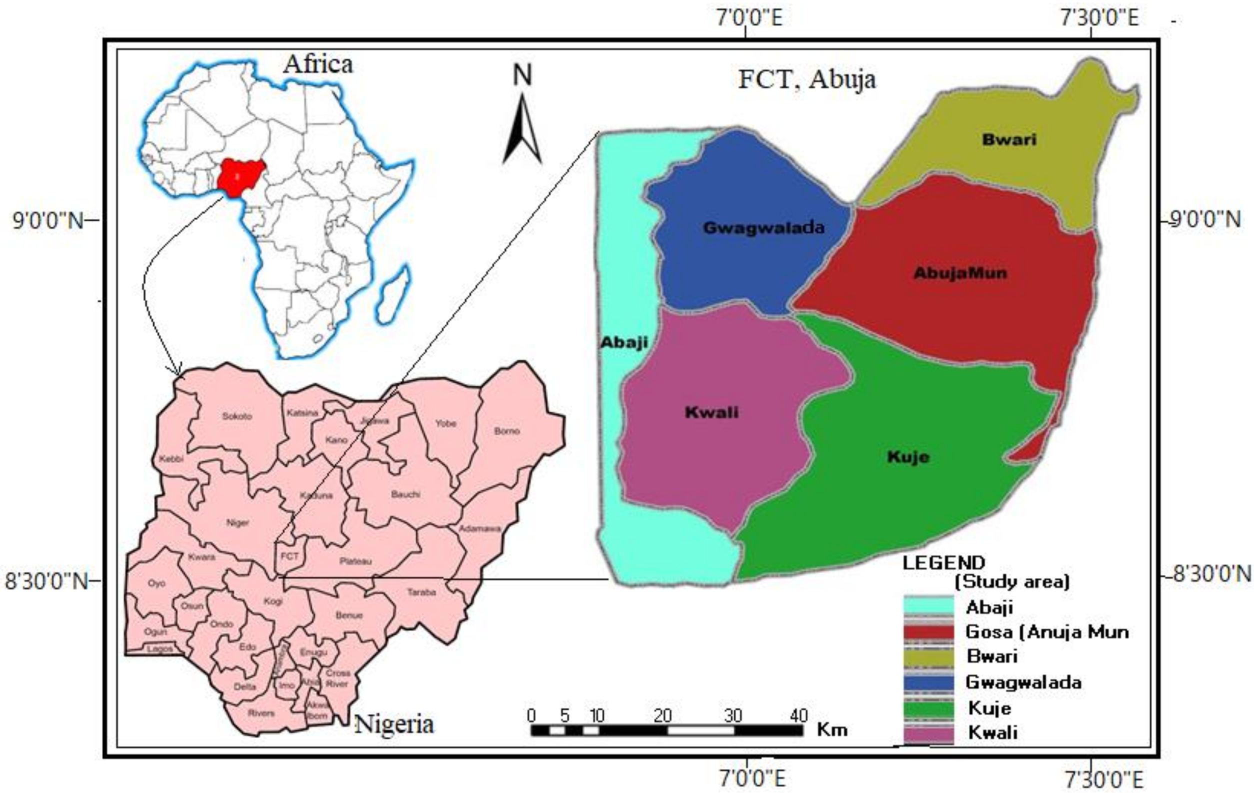

Figure 1. Location map of Abuja showing the study areas.

2.2. Collection of Soil

A total of 72 samples were collected (12 for each location: 3 samples × 4 square zones at10 m apart) from four clearly marked square zones in each of the six area councils (Abaji, Bwari, Gosa, Gwagwalada, Kuje, and Kwali) within the FCT, Abuja using soil auger at a depth of 0-45 cm. The samples were labeled and conveyed in black polyethylene bags to laboratory for further processing. Sampling was done during the dry season to reduce the effect of rainfall and leaching of the inherent metals.

2.3. Preparation, Digestion and Analysis of Metals in Soil Samples

Each of the three replicate soil samples were separately air-dried in the ovun (Jenway) at 35 °C for 3 days, and thereafter, gently crushed with the aid of mortar and pestle before sieving using vibratory electronic sieve shaker to obtained evenly fine soil particles (2 mm). A fixed weight (0.5 g) of the soil samples was obtained and digested in a Teflon test-tube containing 25 mL of the digestion solution (mixture of concentrated HCl, $HClO_4$ and HNO_3 at ratio 3:3:1 v/v/v) [29]. The digestions were done for 4 h at 220 °C. At the end of the process, the digested samples were allowed to cool before filtering using Whatman No 4 filter paper. The volume of the filtrate was leveled up to 50 mL by adding some quantities of HNO_3 (1 % v/v) before analysis of lead (Pb) concentrations using atomic absorption spectrophotometer (AAS Buck Scientific Model 210) by following specifications given by the manufacture.

2.4. Environmental Pollution Risk Assessment

The environmental risk assessment to evaluate the extent of pollution and toxicity of lead (Pb) was done by calculating its geo-accumulation index (I_{geo}) Equation 1, contamination factor (CF) Equation 2, enrichment factor Equation 3 and ecological risk index (ER) Equation 4 [11]. These pollution indices help to simplify the status of environmental pollution/contamination to the general public and policy makers for appropriate mitigation strategies as the case may be. The classification values for geo-accumulation index, contamination factor and potential ecological risk are displayed in Tables 1, 2 and 3 [11] for reference purpose.

2.4.1. Geo-Accumulation Index (I_{geo})

This index was first put forward by a famous scientist known in the year 1969 Muller to generally determine the levels of metal pollutions of aquatic/sediments and terrestrial environments with reference to a background normal levels of the metal [5]. The formula used to calculate I_{geo} is given as shown in Equation 1.

$$(I_{geo}) = \log_2\left(\frac{C_m}{1.5GB_m}\right) \quad (1)$$

Where C_m is the concentration of lead (Pb) in the soil sample, GB_m is the geochemical background value of lead (non-effected reference normal soil) and *1.5* is a constant to minimize variations in background concentration due to lithogenic input.

Table 1. Classification of geo-accumulation index (I_{geo}).

I_{geo} value	Pollution/contamination status [11]
$I_{geo} \leq 0$	Uncontaminated
$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
$1 < I_{geo} < 2$	Moderately contaminated
$2 < I_{geo} < 3$	Moderately to heavily contaminated
$3 < I_{geo} < 4$	Heavily contaminated
$4 < I_{geo} < 5$	Heavily to extremely contaminated
$5 < I_{geo}$	Extremely contaminated

2.4.2. Contamination Factor (CF)

Contamination factor of a given pollutant (metals) in a particular environmental is the index used to evaluate the pollution or contamination status of the metal in soil by comparing its concentration in the samples with that in the background or reference soil. This factor is important in examining the status of environmental pollution or contamination over a given time frame [5]. The formula used to calculate contamination factor is given (Equation 2)

$$(CF) = \frac{C_m}{C_{GB}} \quad (2)$$

Where C_m is the concentration of lead (Pb) the soil sample and C_{GB} is the geochemical background value of lead (non-effected reference normal soil)

Table 2. Classification of contamination factor (CF).

CF value	Pollution/contamination status [11]
CF < 1	Low contamination
1 ≤ CF < 3	Moderate contamination
3 ≤ CF < 6	Considerably contaminated
CF ≥ 6	Very high contamination

2.4.3. Ecological Risk (ER)

Unlike the I_{geo} and CF which illustrations the levels of pollution/contaminations of the environments, ecological risk determines combined impacts/risks of heavy metals with reference to their ecological synergy, toxicities, concentrations and sensitivities [5]. This risk factors help the ecologist/environmentalists to describe the extent of sensitivity or susceptibility of various living organisms and the likelihood experiencing potentials risk from exposure to the heavy metals. This risk could range from very low to very high depending on the synergy, toxicities, concentrations and sensitivities of the metals. ER was calculated as illustrated in Equation 3.

$$\text{ER} = E_r^i = C_r^i \times T_r^i = \left(\frac{C_s^i}{C_n^i}\right) \times E_r^i \qquad (3)$$

Where C_s^i is the concentration of lead (Pb) in the soil sample, C_n^i is the geochemical background value of non-effected reference normal soil and E_r^i is the toxic response factor for lead (Pb = 5) [11]

Table 3. Classification of potential ecological risk (Er) index.

Er value	Potential ecological risk status [11]
Er < 40	Low risk
40 ≤ Er < 80	Moderate risk
80 ≤ Er < 160	Considerably risk
160 ≤ Er < 320	High risk
Er ≥ 320	Very high risk

2.5. Human Health Risk Assessment

The potential health risk of exposure to Pb in soil was estimated by calculating the average daily dose (ADD via inhalation and dermal contact), the non-carcinogenic target hazard quotient (n-CTHQ), hazard index (HI), and lifetime carcinogenic risk (ILCR) coefficients using Equations 4, 5, 6, 7, 8 and 9 [11].

2.5.1. Average Daily Dose (ADD) Via Inhalation

Average daily dose is the concentration of the metal which is present in the food or water during consumption or exposure to it. In this study, two exposure pathways for Pb was considered: the inhation and the demal or skin contact pathways. For inhalation pathway, the individual inhales Pb along with dust or soil particles within the vicinity of Pb contaminated environments [11]. The method commonly used to determine ADD via inhalation of Pb in dust particles is shown in Equation 4.

$$ADD_{inhalation} = C \times \frac{\text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \qquad (4)$$

Where C is the concentration of Pb (mg/kg), EF is the exposure frequency (180 days/year), ED is the exposure duration (6 years for children and 24 years for adults), InhR is the inhalation rate (20 mg/cm^2 for both adult and children) [11] PEF is the particle emission factor (1.36 × 10^9 m^3/kg for both adult and children), BW is the average body weight (child; 15 kg and adult; 70 kg) and AT is the average time (365 × ED).

2.5.2. Average Daily Dose (ADD) Via Dermal Contact

The dermal contact is another important route through which persons can get exposed to Pb and other metals. An individual, such as children while playing with soil or cleaning the surrounding can become exposed to Pb if present thereby. Skin surfaces, being a very large organ, is on daily basis exposed to pollutants in air and dust particles [11]. Having identified Pb one of the major contaminants of heavy metal polluted environments, the dermal contact was therefore considered along with the inhalation pathways in this study. Equation 5 was used to calculate the ADD via dermal contact exposure to Pb in contaminated soil.

$$ADD_{dermal\ contact} = C \times \frac{SA \times AF \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (5)$$

Where C is the concentration of Pb (mg/kg), SA is the surface area of the exposed skin (2145 cm^2 for adult and 1150 for children) [11], AF is the skin adherence factor for the soil (0.2 mg/cm^2 for adult and 0.07 for children) [11], ABF is the dermal absorption factor (0.001 for Pb) [11], EF is the exposure frequency (180 days/year), ED is the exposure duration (6 years for children and 24 years for adults), BW is the average body weight (child; 15 kg and adult; 70 kg) and AT is the average time (365 × ED).

2.5.3. Non-Carcinogenic Target Hazard Quotient (n-CTHQ)

This health risk factor is used to estimate the potential risk of non-carcinogenic exposure to heavy metals. It is also known as the chronic health risk which does not lead to cancer. The formula used to calculate this risk is given in Equation 6.

$$\text{n-CTHQ} = \left(\frac{ADD_{inhalation}\ \text{or}\ ADD_{dermal\ contact}}{RfD}\right) \quad (6)$$

Where RfD = Reference dose of heavy metal (mg/kg/day).

RfD for Pb is 3.25 × 10^{-3} mg/kg BW/day and 5.25 × 10^{-4} mg/kg BW/day for inhalation and dermal contact, respectively [27]. Value of THQ < 1 indicates no significant health risk to the exposed individuals.

2.5.4. Hazard Index (HI)

Hazard index is the combined effects non-carcinogenic health risk in individuals which are exposed to heavy metals via food. To get the HI, the individual target hazard quotients are summed together in order to estimate the non-carcinogenic risk exposed individuals. It is calculated as shown in Equation 7. After calculating the HI, a value that is equal to or less than one (H ≤1) is considered as 'no significant non-carcinogenic risks. Non-carinogenic risk is indicated by a HI value of greater than one (HI > 1).

$$HI = \sum(n - CHQ) = n - CHQ_{inhalation} + n - CHQ_{dermal\ contact} \quad (7)$$

2.5.5. Lifetime Carcinogenic Risk (LCR) Coefficients

This health risk is very important because it determines the probability that an indivuial who is exposed to heavy metal(s) might experience cancer for a lifetime. It is estimated by multiplying the daily dose and the cancer slope factor (CSF) for the heavy metal (Pb) in questions (Equation 8). Sometimes, the sum of all the pathways of exposure can be determined of their CSF are known by using Equation 9. The value of LCR can be classified as follows: less than 10^{-6} which indicates no carcinogenic risk; greater than 1×10^{-4} which indicates high risk of developing cancer; 1×10^{-6} to 1×10^{-4} which indicates acceptable risk to humans.

$$LCR = ADD_{inhalation} \text{ or } ADD_{dermal\ contact} \times CSF \quad (8)$$

$$\sum LCR = \sum(\text{Cancer risk}) = (\text{Cancer risk}_{inhalation} + \text{Cancer risk}_{dermal\ contact}) \quad (9)$$

Where:
CSF is cancer slope factor for lead (Pb) (0.042 for dermal contact) [27].

2.6. Data Analysis

Data were analyzed in triplicates and presented as mean ± deviation. Descriptive statistics was employed to represent the data in tabular form. The difference in mean of samples were analyzed using analysis of variance (ANOVA) at 5 % level of significance.

3. RESULTS AND DISCUSSION

3.1. Concentration of Lead (Pb) in Soil Samples

The order lead (Pb) concentrations in the soil samples from the six dumpsites were Kuje dumpsite > Kwali dumpsite > Bwari dumpsite > Gosa dumpsite > Gwagwalada dumpsite > Abaji dumpsite Table 4. Statistical analysis of Pb in all the sampling locations showed that samples collected from dumpsite at Kuje area council had the highest ($p<0.05$) concentrations of Pb. The levels of Pb were not different ($p<0.05$) at Abaji, Kwali, Bwari and Gosa dumpsites. Compared with the control samples (non-effected reference soil samples, 2 km away from each dumpsite), Pb concentrations were significantly ($p<0.05$) elevated at Abaji, Kwali, Gwagalada and Gosa dumpsites than at the control locations Table 4. This indicates that the solid waste dumpsites had higher heavy metal generating materials than the control sites. Previous studies [22, 31-33] on solid waste dumpsites had similar observations and are in agreement with our study. The concentrations of Pb (mg/kg) were 14.21 (Abaji dumpsite), 19.63 (Bwari dumpsite), 16.12 (Gosa dumpsite), 14.52 (Gwagwalada dumpsite) 31.94 (Kuje dumpsite) and 23.50 (Bwari dumpsite). The mean concentrations of Pb in all the dumpsites were within the permissible limit of 50 mg/kg set by Food and Agricultural Organization/World Health Organization (FAO/WHO [34], 70 mg/kg set by Alberta Emmanuel and Parks (AEP) [35] and 164 mg/kg set by National Environmental Standards and Regulations Enforcement Agency (NESREA) [36] for Nigerian soils. Finding from this study suggests that the each dumpsites were not substantially polluted and thus poses relatively low pollution problem. However, Pb concentrations in soil samples from the different dumpsites studies were higher than lowest limits (2-200 mg/kg) for normal soil reported by Bowen [37]. Although, the levels of Pb were lower than most permissible limits for normal soil, it is important to point out that continuous use of such soil within and around as dumpsites for cultivation of crops could potent portend potential health implications. Pb are mobile, abundant in soil, dusts and sediments if their sources are not well managed, could accumulate and enter food chain. There is need to intensify the monitoring of heavy metals in the study locations to reduce their bioaccumulation and potential and toxicity of the ecosystem. This finding is in agreement with earlier report on the impact of continuous cropping on heavy metal contaminated soil [38]. The concentrations of Pb in this study were higher than 1.8-3.7 mg/kg solid waste in Uyo, Akwa Ibom, Nigeria [39], 0.31-0.54 mg/kg from municipal waste dumpsite in Ghana [40] 10.09 to 13.86 mg/kg from old landfill in Bayelsa state, Nigeria [41]. However, significantly higher Pb concentrations of 94.01 mg/kg 12.90 to19.95 mg/kg, 20.825 to 62.501 mg/kg and 262.536 mg/kg were reported from soils around a rare earth mine in Gannan, China [28], dumpsites in Abakakili, Enugu State, Nigeria [33], abandoned urban open waste dumpsite along Enugu/Port Harcourt road, Enugu State (Ugwuaji dumpsite) [32], municipal solid waste dumpsite in Potiskum, Yobe State, Nigeria [42].

Table 4. Mean concentration of Pb (mg/kg) in soils from dumpsites and control site in Abuja, Nigeria.

Sampling location	Dumpsite soil					Control soil
	Min.	Max.	Med.	Mean	SD	
Abaji area council	9.23	23.72	14.76	14.21[c]	6.98	1.10 ± 2.05
Bwari area council	13.28	29.09	20.21	19.63[bc]	4.36	12.30 ± 2.17
Gosa area council	7.67	27.16	15.78	16.12[bc]	4.30	5.29 ± 3.12
Gwagwalada area council	8.66	21.19	14.56	14.52[c]	4.20	10.94 ± 2.86
Kuje area council	15.54	65.11	32.07	31.94[a]	12.01	1.03 ± 0.32
Kwali area council	18.23	27.91	22.08	23.50[b]	2.61	1.11 ± 4.13

Note: Mean values similar alphabets as superscripts are not significantly different (p=0.05).

3.2. Environmental Pollution Risk Assessment

Table 5 shows the pollution indices for geo-accumulation (I_{geo}), contamination factor (CF) and potential ecological risk (PERI) of lead in soil samples from the six dumpsites within Abuja, Nigeria. These indices were determined to evaluate pollution status, pattern of contamination and potential environmental risks associated with exposure to elevated levels of Pb in soil. Values from $I_{geo,}$ as indicated in Table 5 revealed that the concentrations Pb in soil samples from the dumpsites were uncontaminated (at Bwari and Gwagwalada dumpsites), moderately contaminated (at Gosa dumpsite), heavily contaminated (at Abaji and Kwali dumpsites) and heavily to extremely contaminated (at Kuje dumpsite). The contamination factor (CF) showed moderate (at Bwari and Gwagwalada dumpsites), considerably and (at Gosa dumpsite), very high contamination (at Abaji, Kwali dumpsites and Kuje dumpsites). The ecological risk associated with the contamination Pb at the study location revealed low risks (at Bwari, Gosa and Gwagwalada dumpsites), moderate risk (at Abaji dumpsite) and considerably risks (at Kuje and Kwali dumpsites). The high contamination factors and ecological risks of Pb in some of the dumpsites suggest that constant and consistent exposure to Pb could exert negative effects on the ecological and human health. The commonest effects of elevated levels of Pb in soil include poor growth and cellular developments in plants as a result of altered photosynthetic process, reduction in nutrient uptake/assimilation and destabilization of cellular water balance [12-14].

Table 5. Geo-accumulation index (I_{geo}), contamination factor (CF) and potential ecological risk index (PERI) of Pb in soil samples from dumpsites in Abuja, Nigeria.

Sampling area	Pollution index	Pollution values	Pollution status
Abaji area council	I_{geo}	3.69	Heavily contaminated
	CF	12.92	Very high contamination
	ER	64.6	Moderate risk
Bwari area council	I_{geo}	0.09	Uncontaminated
	CF	1.60	Moderate contamination
	ER	8.00	Low risk
Gosa area council	I_{geo}	1.02	Moderately contaminated
	CF	3.05	Considerably contaminated
	ER	15.25	Low risk
Gwagwalada area council	I_{geo}	-0.18	Uncontaminated
	CF	1.33	Moderate contamination
	ER	6.65	Low risk
Kuje area council	I_{geo}	4.37	Heavily to extremely contaminated
	CF	31.01	Very high contamination
	PERI	155.05	Considerably risk
Kwali area council	I_{geo}	3.82	Heavily contaminated
	CF	21.17	Very high contamination
	ER	105.85	Considerably risk

Note: $I_{geo;}$ Geo-accumulation index, CF; contamination factor, ER; potential ecological risk index.

The major sources of Pb contamination and enrichment in soil sources included dumping of wastes from batteries, smelting, mining, refining, paints, leaded gasoline, pesticides, and fertilizers, without appropriate managements. Thus, the higher ecological risks observed in this study corroborates earlier reports that solid waste dumpsites contributes immensely to the contamination and ecological risks associated of Pb, including other heavy metals pollution unlike to those areas with less anthropogenic inputs.

3.3. Human Health Risk Assessment

The potential human health risk of exposure to Pb in soil was estimated by via through two major pathways. These are the dermal or skin contact and the inhalation routes of exposure to Pb contaminated soil. As presented in Table 6, the ranges of average daily dose (ADD) through the dermal contact pathways for Pb were 3.761×10^{-8} (Abaji) to 8.453×10^{-8} (Kuje) for children and 4.295×10^{-8} (Abaji) to 9.653×10^{-8} (Kuje). The inhalation pathway had a range of 1.136×10^{-8} (Kwali) to 9.491×10^{-9}(Bwari) and 1.472×10^{-9} (Abaji) to 3.309×10^{-9} (Kuje).

Table 6. ADD values of Pb in soil (via inhalation/dermal contact) for adults and children.

Sampling area	Individual	ADD inhalation	ADD dermal contact
Abaji area council	Children	6.870×10^{-9}	3.761×10^{-8}
	Adult	1.472×10^{-9}	4.295×10^{-8}
Bwari area council	Children	9.491×10^{-9}	5.195×10^{-8}
	Adult	2.033×10^{-9}	5.933×10^{-8}
Gosa area council	Children	7.794×10^{-9}	4.266×10^{-8}
	Adult	1.670×10^{-9}	4.872×10^{-8}
Gwagwalada area council	Children	7.020×10^{-9}	3.843×10^{-8}
	Adult	1.504×10^{-9}	4.388×10^{-8}
Kuje area council	Children	1.544×10^{-8}	8.453×10^{-8}
	Adult	3.309×10^{-9}	9.653×10^{-8}
Kwali area council	Children	1.136×10^{-8}	6.219×10^{-8}
	Adult	2.435×10^{-9}	7.102×10^{-8}

In general, average daily dose (ADD) through the dermal contacts and were higher than the inhalations of Pb for both children (≤ 15 years) and adults (≤ 70 years). This suggest that human health risk associated with Pb pollution will be more pronounced via the dermal route than the inhalation pathways. Similar findings were reported by Ahmad, et al. [11] who observed that Pb and other toxic heavy metals demonstrated higher risks via dermal routes than their inhalation counterparts. In the same vein, it was observed that that the non-carcinogenic target quotient through the dermal contacts and were also higher than the inhalations of Pb for both children (≤ 15 years) and adults (≤ 70 years) (From Table 7).

Table 7. n-CTQ and HI values of Pb in soil (via inhalation/dermal contact) for adults and children.

Location	Individual	n-CTHQ $_{inh}$	n-CTHQ $_{derm}$	HI	Interpretation
Abaji area council	Children	2.114×10^{-6}	7.163×10^{-5}	7.374×10^{-5}	No significant risk
	Adult	4.529×10^{-7}	8.181×10^{-5}	8.226×10^{-5}	No significant risk
Bwari area council	Children	2.920×10^{-6}	9.895×10^{-5}	1.019×10^{-4}	No significant risk
	Adult	6.255×10^{-7}	1.130×10^{-4}	1.136×10^{-4}	No significant risk
Gosa area council	Children	2.398×10^{-6}	8.126×10^{-5}	8.150×10^{-5}	No significant risk
	Adult	5.138×10^{-7}	9.280×10^{-5}	9.331×10^{-5}	No significant risk
Gwagwalada area council	Children	2.160×10^{-6}	7.320×10^{-5}	7.536×10^{-5}	No significant risk
	Adult	4.627×10^{-7}	8.358×10^{-5}	8.404×10^{-5}	No significant risk
Kuje area council	Children	4.751×10^{-7}	1.610×10^{-4}	1.615×10^{-4}	No significant risk
	Adult	1.018×10^{-6}	1.839×10^{-4}	1.849×10^{-4}	No significant risk
Kwali area council	Children	3.495×10^{-7}	1.185×10^{-4}	1.188×10^{-4}	No significant risk
	Adult	7.492×10^{-7}	1.353×10^{-4}	1.360×10^{-4}	No significant risk

Although, the non- carcinogenic target quotient (n-CTQ) for Pb at each dumpsite were higher among the children, the corresponding HI were generally lower than 1, which in accordance with the guidelines set by USEPA [43] for no-carcinogenic metals. This is an indication that is no significant carcinogenic risks via the two major studied pathways of exposures for both children and adults to Pb.

Analysis of incremental lifetime cancer risk (ILCR) of exposed individuals, as presented in Table 8, revealed that all the sites had ILCR values of $< 10^{-6}$, which indicates no carcinogenic risk over a lifetime exposure to Pb in both adults and children via dermal contact. This finding is in concordance with an earlier study [29] who observed no carcinogenic risks for Pb in exposed individuals. Although there was no observed carcinogenic risks in this study, however, stringent measures should be put in place or intensified with a view to preventing further metal contaminations of soils and farmlands within and around solid waste dumpsites.

Table 8. ILCR values of Pb in soil for adults and children.

Sampling area	Individual	LCR	Interpretation
Abaji area council	Children	1.580×10^{-9}	No carcinogenic risk
	Adult	1.803×10^{-9}	No carcinogenic risk
Bwari area council	Children	2.181×10^{-9}	No carcinogenic risk
	Adult	2.492×10^{-9}	No carcinogenic risk
Gosa area council	Children	1.792×10^{-9}	No carcinogenic risk
	Adult	2.046×10^{-9}	No carcinogenic risk
Gwagwalada area council	Children	1.614×10^{-9}	No carcinogenic risk
	Adult	1.843×10^{-9}	No carcinogenic risk
Kuje area council	Children	3.550×10^{-9}	No carcinogenic risk
	Adult	4.054×10^{-9}	No carcinogenic risk
Kwali area council	Children	2.612×10^{-9}	No carcinogenic risk
	Adult	2.982×10^{-9}	No carcinogenic risk

4. CONCLUSION AND RECOMMENDATION

In this study, the concentration of Pb and associated ecological and human health risk in soil samples from some solid waste dumpsites within Abuja, Nigeria, were evaluated using standard techniques. Pb concentration was found in following sequence Kuje dumpsite > Kwali dumpsite > Bwari dumpsite > Gosa dumpsite > Gwagwalada dumpsite > Abaji dumpsite. The mean concentrations of Pb in all the dumpsites were within the permissible limits set by NESREA and FAO/WHO. The pollution indices suggest heavy contamination and risks in soil at especially Kuje and Kwali dumpsites. No substantial risks for non-carcinogenic and life time cancer risk were observed indicating both evaluated pathways (inhalation and dermal routes) pose very low health risk of Pb poisoning in both children (≤ 15 years) and adults (≤ 70 years). This study has shown that the concentration of Pb in the study dumpsites poses more ecological risks in some of the dumpsites soil than health risks in exposed individuals via inhalation and dermal routes pathways. Important protective strategies that can extract or contain this heavy metal from leaching deep into surrounding soils and water bodies should be considered. Moreover, further study on the impact of Pb on surfaces and underground water bodies and farm lands close to the dumpsites is recommended.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study.

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