Soil Contamination and Risk Assessments on Selected Dumpsites within the Basement Complex and Sedimentary Formations of Ogun State, South-western Nigeria

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Abstract

The concentrations of inorganic elements in soils of Saje, Ita-Oshin, Premier, and Oke-Diya dumpsites were determined using an X-Ray Fluorescence spectrometer to assess the soil quality through chronological changes with depths. A soil core sampler collects 56 samples at 20, 40, 60, and 80 cm depths. Saje showed high mean concentrations of Ca, K, Fe, Rb, and Ti at all depths, while Oke-Diya revealed high mean concentrations of Ca, K, Fe, Rb, Ti, Mn, Zn, V, Cr, and Ni at all depths. These concentrations were in a closed range suggesting a build-up of elements in the soil profiles. Oke-Diya had the highest pollution index, followed by Saje, and the contaminations were from anthropogenic and geologic sources. The mean concentrations of Fe, Zn, Ni, Mn, Ti, K, and Ca were high at all depths in Ita-Oshin, and in Premier, the mean concentrations of K and Fe were high at all depths. Premier had the lowest pollution index. Ita-Oshin and Premier enrichment factors showed geologic sources. Saje and Oke-Diya revealed unacceptable non-carcinogenic risks for adults and children, and Ita-Oshin and Premier recorded acceptable limits. Saje and Oke-Diya samples had high carcinogenic risks for adults due to Cr, Pb, and As. Elements Cr and As in Ita-Oshin, and Pb in Premier evinced unacceptable carcinogenic risks for adults. Saje, Oke-Diya, and Premier indicated unacceptable carcinogenic risks for children due to Cr. The study showed toxins build-up in the soil system, and the study areas are not suitable for growing crops and sinking water wells for agricultural and domestic uses.

Keywords: Soil Profile; Depth; Elements; Concentration; X-ray Fluorescence; Health Risk

Introduction

Solid wastes are generated daily from some human actions and activities, and the environment is highly polluted when disposed of on the surface or buried in the subsurface of the Earth. These solid wastes could be waste products from domestic, industrial, and commercial activities, and over time, they have become an increasing problem with human civilization [1–2]. The advancements in tech-

nology have led to an increase in the various solid wastes which contain a high level of toxic elements, and when decomposed after a while, they pose negative consequences on the environment, local economy, and public health [3–6]. Alam et al. [7] highlighted that environmental pollution, especially in the soil systems, is related to human activities, such as waste disposal, agriculture, metallurgy, industry, mining, and burning. Soil contaminations through solid waste disposal are of significant concern to environmental scientists, agriculturalists, and individual citizens [8].

Soil contaminations cause threats to soil and water resources for agricultural activities [9]. Solid waste dumpsites release a substantial amount of hazardous chemicals into the soil system and seep into the surface water and groundwater through leachates [8]. Toxic elements generated through the decomposition of solid wastes were retained in the soil and dissolved into soil solutions through biological and chemical processes. These toxins eventually enter water aquifers through soil pores to pollute the water resources and increase the uptake of elements in vegetation [5, 10–11]. Plant habitually pick up and accumulate heavy metals from soils, groundwater, and air [4, 7, 12]. Toxins have numerous ways of entering the food chain through which they get deposited in humans, and thus, soils' qualitative and quantitative analyses in the vicinity of solid waste dump sites are crucial. Asides from the adverse effects of solid wastes on the soil system and eventually on water resources and vegetation, they also attract numerous vector-borne diseases that could cause various public health hazards [13].

Soils are from parent rocks through weathering and exposed to various contaminants through geologic and anthropogenic activities [1]. Naturally, elements are intrinsic components of the soil, but they become toxic to man when they are available in excess. The dumping of solid wastes is the utmost way heavy metals, metalloids, and radionuclides deposit in the soil system. The decomposed solid wastes had toxic elements in the soil profiles through various reactions and entered the food chain [14–15]. Land for agricultural purposes degrades by the deposition of solid wastes [16]. Elements such as cadmium, chromium, arsenic, uranium, strontium, thorium, radium, thallium, and lead have very high densities, and at low concentrations, they are highly toxic. Some of these elements have unstable nuclei that are radioactive in nature [17], and hence, they could have high negative health consequences on man through irradiation. Generally, the effects of toxic elements on the environment could be assessed by determining the elemental concentrations in the soil. However, this assessment alone is insufficient to provide accurate estimations of the potential adverse effects on man, and hence, soil contamination indices and human health risks assessments are required [3, 5, 10, 16].

The determination of toxins concentrations in groundwater, soil, and plants in the vicinities of open dumpsites in Bangladesh, Sylhet, and Mogla Bazar revealed that the environments were highly polluted and could be dangerous to human beings living close to the dumpsites [7]. Weissmannová and Pavlovský [18] reviewed and classified twenty pollution indices into single and complex indices, and concluded that soils heavy metal concentrations and pollution indices varied distinctly from one region to another. The high concentrations of toxins were from anthropogenic activities. Also, the characterization of contamination indices and children's health risks due to toxic metalloids in school clouds of dust in Lahore, Pakistan, was carried out by Rehmana et al. [19] and concluded that the specks of dust were contaminated and slight children's health risks observed through ingestion. Therefore, this study determined the total elemental concentrations

as well as contents in soils obtained at depths of 20, 40, 60, and 80 cm around some solid waste dumpsites on both basement complex formation of Abeokuta metropolis and sedimentary terrain of Sagamu metropolis in Southwestern region of Nigeria using the energy dispersive X-ray fluorescence analytical technique. Also, the soil contamination indices and human health risks (non-carcinogenic and carcinogenic) were assessed.

The study area

Abeokuta and Sagamu are two major cities within Ogun State, Southwestern Nigeria. Saje, Premier, and Ita-Oshin dumpsites are within Abeokuta metropolis on a typical basement complex formation of fine-medium grained biotite, migmatite gneiss, coarse porphyritic

biotite, biotite muscovite granite (Figure 1). Oke-Diya dumpsite is within the Sagamu metropolis on the sedimentary terrain of the Ewekoro formation, underlain by limestone deposits (Figure 1).

Saje dumpsite has been in operation for the past twenty years, and the largest dumpsite in Abeokuta covers an area of about 119,000 m². Ita-Oshin dumpsite has been in operation for the past ten years and has an approximate area of 1,600 m². Also, Premier dumpsite has been in use for about five years and covers approximately 1500 m², and Oke-Diya dumpsite is the largest dumpsite in Sagamu and has been in operation for the past twenty years covering an area of about 60,000 m². Supplementary Material (SM) 1 shows the geo-coordinates of the study locations.
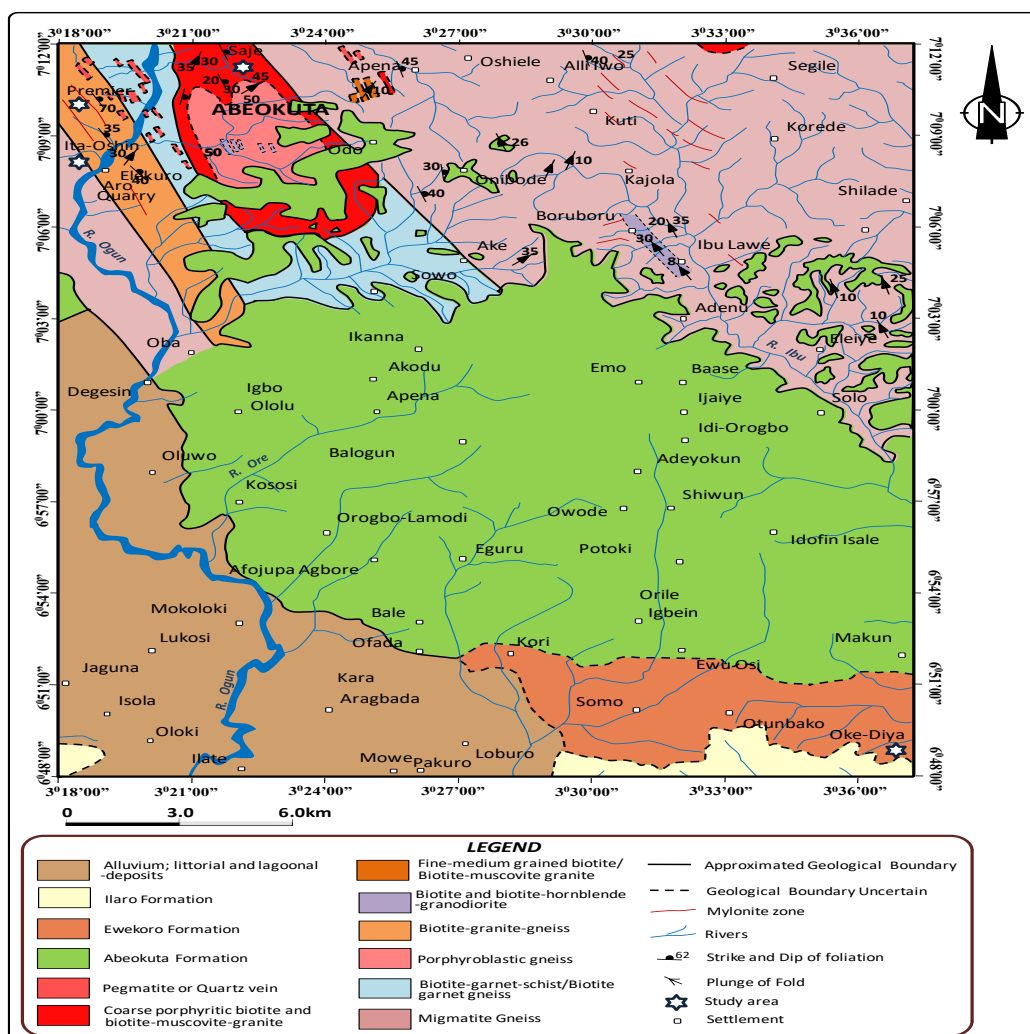

Figure 1 Geological Map of the study areas [20].

Materials and methods

1) Soil samples collection

Samples were collected at every 20 cm depth from the topsoil 0–20 cm [21–22] to a depth of about 80 cm using soil auger boring. The soil depths were measured using meter tape with a reading accuracy of 0.1 cm, and the sampling locations were geo-referenced by Garmin e-Trex global positioning system (SM 1). Due to the inherent variations of soil, samples were obtained at 100 m apart in each of the study areas; three locations each on Saje and Oke-Diya, and two locations each on Premier and Ita-Oshin. The samples were collected in June 2018 during the wet season when the groundwater level is high as solid wastes react with rainwater to produce leachate plumes in large volumes that migrate fast in the subsurface. Figure 2 presents the groundwater flows directions in the basement complex of Saje, Premier, and Ita-Oshin by intrusive investigations. About 200 g of the samples were obtained at each depth into black non-reacting polythene bags and tied immediately to avoid any further interactions with the environment [23].

The control samples were collected at a location close to each study area within the same geology at depths of 20, 40, 60, and 80 m and distances ranging from 800–1000 m. The control locations were unpolluted, and the chances of traffic (road and railroad tracks) and industrial and agricultural activities were minimal. In all, fifty-six (56) soil samples were obtained and air-dried in an environment free of dust [24] and other contaminants [25]. The soil samples were sieved in a 2 mm sieve and stored in neat plastic containers [7, 16], and the analyses were done by the Energy Dispersive X-Ray Fluorescence (EDXRF) spectrometer at the Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria.

2) Samples preparations and EDXRF elemental analyses

Sample preparation is highly variable depending on the matrix of samples, the goal of the analysis, and the nature of the X-ray beam relative to the soil sample [25–26]. Materials such as metal, ceramics, and obsidian do not require preparations. Soils require preparation to determine the total elemental concentrations, and about 5 g of sieved air-dried fresh soil samples were pulverized into powdery grain size of less than 125 nm using a small agate mortar. Three drops of binder (toluene acid) were added to the sample and mixed until the mixture becomes fine-powered particles [27–30]. The fine particles were sieved in a 100 μm stainless-steel mesh and were made into pellets using a hydraulic pelletizing system (model Carver) operated at a pressure of 6–8 mmHg [21]. The pellets were labelled appropriately, covered with Mila, and stored in plastic containers for analysis.
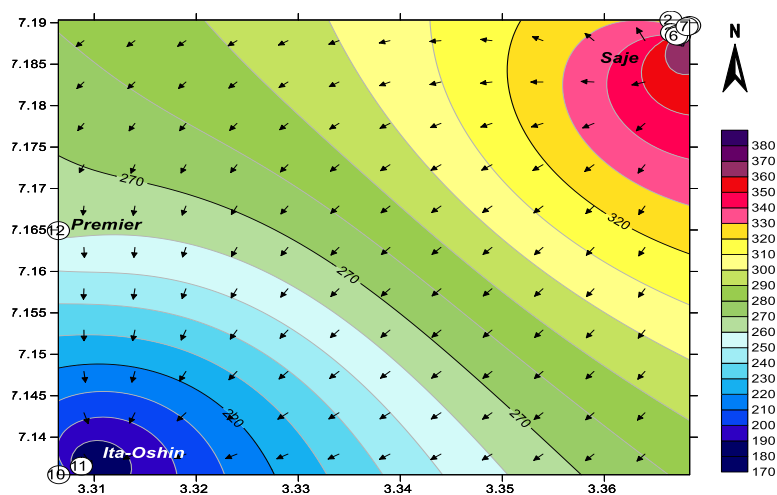
Figure 2 Piezometric map of groundwater flow across Saje, Premier and Ita-Oshin [8].

The EDXRF spectrometer (XR-100CR AMPTEK) was used to analyze K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, and Pb in prepared soil samples. The pellets were placed in the sample holder of the spectrometer and bombarded with the X-ray fluorescence generated from an X-ray tube with an argon anode operating at a current of 50 µA and voltage of 25 kV for 18 minutes or 1200 counts in a chamber set up externally. The counting rate was the time set for all detectable elements in a particular sample [31–32]. The number of gamma rays or photons detected for different X-ray energy lines was recorded. Therefore, to quantitatively measure the elemental compositions and quantitatively establish the elemental concentrations of the samples, the energy of X-ray peaks in a sample spectrum and the count rate of various elemental peaks were determined [11, 33–35].

The source from the spectrometer irradiates the pellets, and the solid-state Si-pin detector system (XR-100CR) measures the irradiations emitting from the samples. The detector can measure different energies of the characteristic X-ray rays from the pellets. The intensities of the energies were determined by the area of the energy peaks on the spectrum which were analyzed into concentrations by ADMCAR plus Fundamental Parameters (FP-CROSS) software.

3) Soil contamination index

The contamination index comprises contamination and enrichment factors, as well as the pollution index quantifies the degree of contaminant depositions in the soils [16, 36]. The contamination factor is the pollution index for each element and is derived using Eq. 1 [3, 37].

$$C_f = \frac{C}{C_{ctr}} \quad \text{(Eq. 1)}$$

where C is the concentration of element, C_{ctr} is the control elemental concentration (background), and C_f is the contamination factor. The classifications are; $C_f > 6$ (high contamination), $3 < C_f < 6$ (considerable contamination), $1 \leq C_f < 3$ (moderate contamination), and $C_f < 1$ (low contamination).

Previous studies had shown that the background elemental concentrations were determined from samples obtained in locations with low or no contaminants and served as the basis for the determining study samples pollutions [38–39]. In this study, the direct method of determining background concentrations involving geochemical analyses of the control samples was adopted instead of the commonly used statistical method [1–3, 40–41]. The statistical data are mainly secondary data that could be misinterpreted.

The pollution load index (PI) assesses the collective pollution by all the soil samples using Eq. 2 [3]. The PI is classified as PI>3 (severely contaminated), 2<PI≤3 (moderately contaminated), 1<PI≤2 (slightly contaminated), and PI≤1 (uncontaminated). Where n is the total number of elements.

$$PI = \left(C_{f1} \times C_{f2} \times C_{f3} \times C_{f4} \times ... \times C_{fn} \right)^{\frac{1}{n}} \quad \text{(Eq. 2)}$$

The enrichment factor (*EF*) revealed the vastness of the contaminants in the soil samples using Eq. 3 [16, 42–43].

$$EF = \left(\frac{C/C_{Fe}}{C_{ctr}/C_{ctr(Fe)}} \right) \quad \text{(Eq. 3)}$$

Where C_{Fe} is the concentration of Fe in the sample, and $C_{ctr(Fe)}$ is the concentration of Fe in the control sample. Fe had the highest concentrations in the analyzed soil samples, and it was used as the reference element to normalize the concentrations to achieve accurate enrichment factors. The contaminants had geologic origin if *EF* < 2, and anthropogenic origin if *EF* > 2. Enrichment factor is based on the differences between the elements ori-

ginating from natural sources and human activities [44].

4) Health risk assessments

The risk assessments involved the evaluation and estimation of adverse effects due to human exposure to some toxic elements [16]. This process was comprised of the identification of toxins, level of exposure, elemental toxicity, and risk characterization. The toxins identified were by the spatial distributions and concentrations of the elements available in the soil samples; K, Cu, Rb, Ti, Pb, Sr, V, Fe, As, Ca, Cr, Mn, Zn, and Ni. The exposure assessments quantify the potency and frequency of human vulnerability to these toxins, and it was determined by the average daily dose intake (ADDI) of the elements measured in mg kg^{-1} d^{-1} for children and adults (Eq. 4).

$$ADDI = \frac{C \times CF \times RI \times DE \times EF}{AT \times BW} \qquad \text{(Eq. 4)}$$

where C is the elemental concentrations in mg kg^{-1}, RI is the rate of ingestion per day in mg d^{-1}, CF is the conversion factor in kg mg^{-1}, DE is the duration of exposures in years, AT refers to the average time in days, BW represents the body weight in kg, and EF is the exposure frequency in d a^{-1} as presented in Table 2.

The toxicity evaluations were determined by a non-carcinogenic threshold, oral reference dose (RfD), and also by carcinogenic factor, cancer slope factor (CSF) are shown in Table

3. Health risks characterization for children and adults were determined by the carcinogenic and non-carcinogenic hazard indices.

Table 2 Exposure parameters used for the human health risk assessment [20]

Parameters	Children	Adult
RI (mg d^{-1})	200	100
EF (d a^{-1})	350	350
DE (a)	6	30
CF (kg mg^{-1})	10^{-3}	10^{-3}
BW (kg)	15	70
AT (d)	25550	25550

4.1) Non-carcinogenic risks assessment

Non-carcinogenic risks were derived by harmonizing the information gathered to quantitatively estimate the health hazard indices through Hazard quotient (HQ) and hazard index (HI) [45]. The HQ estimated the risk involved in being exposed to the toxic elements (Eq. 5). The summation of HQ resulted in HI estimates (Eq. 6) for a particular study area. There are no associated non-carcinogenic health risks if the values of HQ and HI are less than one, otherwise, there may be a need for concerns [20, 48–49].

$$HQ = \frac{ADDI}{RfD} \qquad \text{(Eq. 5)}$$

$$HI = \sum HQ \qquad \text{(Eq. 6)}$$

Table 3 Oral RfD (mg kg^{-1}d^{-1}) and CSF values for the toxic metals [20, 45–47]

	Ni	Zn	Fe	Cu	As	Cr	Mn	V	Ti	Sr	Pb
Oral RfD	0.02	0.3	0.7	0.04	0.0003	0.003	0.014	0.005	3	0.6	0.0035
Oral CSF	-	-	-	-	1.5	0.5	-	-	-	-	0.0085

4.2) Assessment of carcinogenic health risks

The carcinogenic risk (CR) derivation shown in Eq. 7 estimated the cumulative likelihood of a person developing cancer by living around the study areas over a lifespan due to oral openness to a possible carcinogen.

$$CR = \sum ADDI \times CSF \qquad \text{(Eq. 7)}$$

The CSF transmutes the estimated ADDI estimates over a lifespan of direct exposure to carcinogens which increases the risk that an individual will develop cancer [49]. The carcinogenic and non-carcinogenic hazard indices were used for the characterization of health risks for both the children and adults living around the study areas.

5) Statistical analysis

Environmental data such as the soil elemental concentrations are strongly distinguished by their intrinsic variability, which could not be described only by geochemical analyses [4, 50–51]. Hence, there is a need for a statistical technique. Descriptive analyses of the elemental concentration (mean and standard deviation), Pearson's correlation analyses (SPSS version 20), Shapiro-Wilk and Kolmogorov-Smirnov normality tests, and analysis of variance (ANOVA) were employed. The Pearson's correlation analyses for the consistent elements at all depths revealed the relationships between the toxins.

Results and discussion

The XRF results revealed elements with atomic numbers 19 and above, and this discrepancy was due to the limitations imposed by the EDXRF spectrometer. Tables 4-7 showed the mean elemental concentrations of the study and control samples through elements' chronological changes with depths (20, 40, 60, and 80 cm) to assess the quality of the soils. SM 2 presented the mean elemental concentrations

of the topsoil (0–20 cm) and subsoil (20–80 cm) for both the study and control samples. The selection of contamination indices for elemental assessments depends on variables, such as element sources, degree of contamination, and potential adverse health risks [44, 52–55]. The classifications of soil contamination indices generally revealed the degree of soil pollution.

1) Saje dumpsite

The samples indicated high mean concentrations of Ca, K, Fe, Rb, and Ti to a depth of 80 cm (Table 4). The mean concentrations of Fe, Ba, Pb, and Cr increased with depth, while that of K, Ca, Cu, Mn and Rb decreased with depth (SM 2). In general, the elemental concentrations in the study samples surpassed that of the control samples indicating the elemental enrichments of the subsoil (20–80 cm). In similar studies, Cd, Cr, Cu, Pb, and Zn concentrations were much more than the background concentrations [19]. As Baranowski et al. [24] reported, high concentrations of Rb, Pb, Zn, Mn, and Fe could lead to bioaccumulation in crops. High concentrations of Zn in soils are mostly from anthropogenic impacts and could lead to cancer due to brain, gastrointestinal and respiratory tract infections [19, 52]. The topsoil (0–20 cm) and subsoil (20–80 cm) had high mean concentrations of Fe, K, Ca, Ti, and Mn (SM 2).

The topsoil had high contamination factors of Rb, Mn, Cr, Ca, K, and Ti, and Ca, Cr, Mn, and Rb in the subsoil (SM 3). The Sr in the topsoil, and K, Fe, Zn, and Sr in the subsoil had considerable contaminations, while V, Zn, Cu, Ni, and Fe in the topsoil, and V, Cu, Ni, and Ti in the subsoil revealed moderate contaminations. The topsoil was highly polluted, and the mean contamination factors indicated high elemental contaminations except for V, Zn, Cu, Ni, Fe, and Sr, which showed considerable and moderate contaminations. High soil contamination factors were reported in similar studies by

Kowalska et al. [44] and Nwankwoala and Ememu [56]. The pollution load index (SM 4) revealed severe elemental contaminations in topsoil (11.21) and subsoil (6.70). The enrichment factors indicated that in the topsoil, anthropogenic sources contributed to high concentrations of Rb, Mn, Cr, Ca, K, and Ti, while V, As, Zn, Cu, Ni, Fe, and Sr were from geologic sources. The subsoil revealed that Rb, Mn, Cr, Ca, and As originated from anthropogenic sources, while V, Zn, Cu, Ni, Fe, Ti, K, and Sr were from geologic sources. The correlation analysis (SM 5) showed strong positive correlations between K & V at $\rho=0.01$ and K & Zn at $\rho=0.05$. These suggested that these elements were mainly from anthropogenic sources and partly from the basement complex formation. The elemental concentrations increased at almost the same rate.

2) Ita-Oshin dumpsite

The mean concentrations of Fe, Zn, Ni, Mn, Ti, K, and Ca were high to 80 cm in depth at Ita-Oshin (Table 5). The topsoil had high mean concentrations of V, Sr, and Rb, and the mean concentrations of Sr, Rb, Ni, Zn, and Mn were in the same range as the control sample (SM 2). Elements Sr, Cr, Mn, Fe, and Cu, were in the same range as the control sample in the subsoil. The mean concentrations of Ni, V, Sr, Rb, Zn, Mn, Pb, and Cu decreased with depth. The topsoil was more polluted than the subsoil, as reported by Mukhopadhyay et al. [16]. The low concentrations observed in the subsoil may be due to the infiltrations aided by some activities of the waste management authorities.

Ita-Oshin samples had high contaminations of K, V, Cr, and Fe in the topsoil, and K, V, Ca, Ti, and Fe in the subsoil (SM 3). The Ca and Ti in topsoil and Ni in subsoil had considerable contaminations, while Mn, Ni, Zn, Rb, and Sr in topsoil, and Cr, Mn, Cu, Zn, Rb, and Sr in subsoil had moderate contaminations. The mean contamination factors for K, Ca, Ti, V and Fe indicated high pollution. The pollution load revealed severe elemental contaminations for the topsoil (3.34) and subsoil (3.84). Ita-Oshin analysis (SM 6) showed strong positive correlations between Ti & V, Mn & Fe, and Cu & Zn at $\rho=0.01$. These elements were from the same sources and were mainly geologic; this confirms the estimated enrichment factors. Ita-Oshin showed a negative correlation between K & Cr at $\rho=0.05$.

3) Premier dumpsite

The mean concentrations of K and Fe were high to a depth of 80 cm in the samples (Table 6). The elemental concentrations were low compared to other study areas, as observed in Liu et al. [53]. The topsoil (0–20 cm) revealed high mean concentrations of Fe, Ti, V, K, Ca, Mn, Cr, Cu, Ni, Sr, As, Rb, and Pb (SM 2). Elements Ni, As, and Pb concentrations were in a closed range with the control samples, and Mn, Ti, V, and Ba were not in the control samples. Generally, the concentrations of Ba, Th, Cu, Pb, Ni, Fe, and As increased with depth. The control samples had low concentrations at all depths and indicated elemental pollution in both the topsoil and subsoil.

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Table 4 Mean elemental concentrations (ppm) with depths in the soil samples of Saje

Elements	20 cm		40 cm		60 cm		80 cm	
	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD
K	24,880±612	281±49.5	1,945±603	627±18	29,108±799	5,269±239.1	34,233.1 ± 941	8,843±450
Ca	36,733±734	548±67	9,713±522	374±52	13,213±368	323.8±59.6	8,264±627.67	578±71
Ti	5,796±130	105.1±5.5	5,464.5±94.5	167.1±6.9	3,493.33±85.67	3,426±89	5,892.5±123.5	3,798±24.6
V	77.5±4.5	28±3	70.5±4	23±2	53.67±3.33	44±3.1	78±4.2	58.85±8.3
Cr	1,267.67±150.6	33±3	934±73.67	27±3	2,411.67±322.67	69.7±9.3	1,159±50.67	41.1±5.6
Mn	21,238±616.67	118±5	30,260±530	60±4	19,926.1±97.03	804.10±16.9	339.3±11.6	271.9±14.5
Fe	19,005±119	6,452±616	23,416±125	3,575±50	24,306.1±11.67	7,924.00±66	40,903± 60	7,793±74
Ni	19±2	16±1	13±1.67	1.34±7	25±1.67	14.00±1	26± 2	14.32±10.5
Cu	40±2.3	24±3	38±3.67	24.86±4.62	16.67±2	44.00±4	27±2.33	7.80±0.78
Zn	302.66±4.7	259.3±2.2	594.67±3.4	89.15±6.26	382.33±19.33	21.00±1.1	554±31	151±13
As	5.5±1.5	ND	13±1	ND	ND	ND	6±1	ND
Rb	6,527.6 ±463	106.5±15.1	3,725±28.5	80.43±1	8,131.7±89.75	690.25±1.13	92.85±8.66	42.6±5.7
Sr	51.67±4.67	11.9±2.5	14.6±2.23	3.44±0.14	49,793.3±207.57	1,816±38	36,996.67±502.33	2,258±45
Pb	ND	ND	12±4	ND	ND	ND	27±8	ND

Remark: ND: Not detected, Ctr.: Control, Con.: Concentration, SD: Standard deviation

Table 5 Mean elemental concentrations (ppm) with depths in the soil samples of Ita-Oshin

Elements	20 cm		40 cm		60 cm		80 cm	
	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD
K	22,595±163	2,464±32.9	19,985±22.35	2,441±29.1	27,825±25	1,597±138	32,745±163	257±32
Ca	3,476.5±116.5	1,238±144	1,576±115	761±10	5,936±40.6	502.±4.5	7,109.8±98.5	9±1
Ti	3,612.±99	640±21.9	3,369.5±13.4	587±17.5	5,488±17.35	486.90±11.3	4,549±12	197.1±10
V	799.5±46.5	68.2±7.4	588±56	83.8±7.5	418±39	69.90±4.3	378±24.5	73.62±7.14
Cr	508.5±37.5	63.7±7.1	955±53.5	730±70	252±30.5	230±37	303±23	20±2
Mn	2,455.5±82.5	2,032±14.2	1,675.5±94.5	1,387±12.6	896±56.5	985±72	894±38.5	568±31
Fe	43,700±521	4,660±78.6	44,900±663	3,945±74.5	37,788±421.5	2,409±47	41,247±302	3,503±29.3
Ni	1,406±62.5	1,075±12.5	990.5±53	627±65.2	764±52	101.8±52	757.5±34.5	37±4
Cu	362±31.5	116±64	335.5±42.5	386±51	380.5±38	252±26.2	220±22.5	5±1

Table 5 Mean elemental concentrations (ppm) with depths in the soil samples of Ita-Oshin (*continued*)

Elements	20 cm		40 cm		60 cm		80 cm	
	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD
Zn	2,774±86	2,025±127	2,515.5±104	811±74	1,230±65.5	796±45.5	664.5± 31	17±2
As	ND	ND	ND	ND	4±1	ND	ND	ND
Rb	441±19.5	292±49	243±35.5	128±29	125.5±21	129.2±18	100±12.5	18±4
Sr	779.5±15	520±88	133.5±32	175±45	133±27	99.3±15.5	107.5±13.5	29±7
Pb	ND	ND	ND	ND	ND	ND	ND	ND

Remark: ND: Not detected, Ctr.: Control, Con.: Concentration, SD: Standard deviation

Table 6 Mean elemental concentrations (ppm) with depths in the soil samples of Premier

Elements	20 cm		40 cm		60 cm		80 cm	
	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD
K	3,499.5±189.5	674± 7.5	1,741.5±117.5	119.58±10.18	9,879±504	757.4±66.5	2,550.5±201.5	339.8±18.8
Ca	1,582.5±76	1,514±11.4	1,000±33	138.6±21.6	988±65.5	110.3±15.7	2,214.5±122.5	551.1±44
Ti	9,910±28.7	ND	848±73.1	431.7±26.4	4,068±461	301.7±17.8	848±73	114.8±37.2
V	4,552.63±556.2	ND	157±2.4	14±1.3	109.54±8.13	10.2±8	288.00±40	29.9±1.8
Cr	107±8.5	19.9±1.5	107±17.5	81±10	108.5±8	10.9±7	185.5±23.5	30.1±1.8
Mn	636±29	ND	959.5±53.1	43.26±2.32	3,533±76	48.15±2.12	1768±66	320.1±6
Fe	32,396±26	4,971.1±83	40,751±400	6219.1±87.9	31,022.25±520.1	721.72±8.2	44,753±504.1	668±31
Ni	60.5±4	23±1.1	1,777±71.5	43.3±2.3	72.10±4	20.9±1.4	3,473±140	532.1±24
Cu	90±1	11±1.11	179.1±23	12.2±1.8	66.00±1	78.7±8.6	259.5± 27	152.1±13
Zn	50±3	36±2	339.2±31	29.8±1.9	38.00±2.5	18.31±1.31	358±32	33.4±1.9
As	44±6	29±2	123.99±14.75	ND	19.00±2	ND	6±1	ND
Rb	40±6.5	40±5	131.5±2.4	57.7±9.9	30.10±4.5	56±7.9	124±21.5	53±8.1
Sr	59.5±10	24±5	202±4	11.93±1.89	26.00±6.1	56.9±1.07	351±66	37±6.1
Pb	5±1	9±1	19±2	ND	9.5±1.1	ND	5±1	ND

Remark: ND: Not detected, Ctr.: Control, Con.: Concentration, SD: Standard deviation

Table 7 Mean elemental concentrations (ppm) with depths in the soil samples of Oke-Diya

Elements	20 cm		40 cm		60 cm		80 cm	
	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD	Mean Con.±SD	Ctr. Con.±SD
K	22,477±677	1,155±127	21,902±657	1,065±874	23,191±229	1,606±136	23,562±259	2,057±168
Ca	14,918±254	1,044±94	13,257±264	2,140±73.1	9,609.67±195	282±33	13,959.67±224.33	290±37
Ti	29,270±705.33	ND	22,410±865	ND	16,315.3±169	726±10	25,405±185	4,825±125
V	5,293.3±127.67	ND	5,302±302	ND	5,228±255	84±43	5,393.5±135	702±48
Cr	1,330.33±30	175±14	1,312±126.3	151±26	1,362±276.5	105±35	1,472.33±336.7	461±39
Mn	31,485±63.67	361±17	31,087±352	204±14	32,903±767	1,848±66	31,752.33±602	1,957.3±80
Fe	49,015.7±434	2,299±131	46,623±363.33	2,708±719	44,708±343	5,101±451	40,056.7±340.67	8,550±122
Ni	1,267.1±26.67	19±1	1,278.67±205	79±3	1,296±129	98±8	1,355±335	1,027.3±58
Cu	1,239.67±56.67	52±4	915.67±46	269±2.2	593.33±34.67	194±21	671 ± 41.33	426±37.3
Zn	3,822.67±101.67	35±2	7,177±118	1,950±217	6,247.67±11.1	638±39	5,024± 99.67	864±53.3
As	896.5±42	14±1	1081±49	115±18	362.5±22	ND	315.5±25	ND
Rb	4,157.33±11.67	20±4	4,171±13.3	37±1.2	4,145.67±96.7	109±16	4,152.33±100	184±24.1
Sr	122.67±17.67	22±5	123.3±17	68±10	105.67±15.3	102±21	123±17	131.1±27.1
Pb	ND	ND	307±31.3	ND	411±12	ND	406±12	ND

Remark: ND: Not detected, Ctr.: Control, Con.: Concentration, SD: Standard deviation

In Premier samples, Fe and Cu in the topsoil, and K, Zn, Ni, Fe, Mn, V, and Ti in the subsoil had high contamination factors (SM 3). Elements K, Mn, and Cr (topsoil), and Ca, Sr, Pb, and Cr (subsoil) showed considerable contaminations. Moderate contaminations were indicated by Ca, Ni, Zn, As, Rb, and Sr in the topsoil and Cu and Rb in the subsoil. The mean contamination factors showed high values of V, Fe, Mn, V, Ti, and K in the subsurface. The pollution index (SM 4) revealed moderate contamination in the topsoil (2.37) and severe contamination in the subsoil (6.37). The subsoil of Ita-Oshin and Premier had higher pollution loads than the topsoil. The soil analysis (SM 7) showed strong positive correlations between Ti & V and Cu & Zn at $\rho=0.01$. These elements had similar sources (geologic), and this validates the estimated enrichment factor. Premier showed a negative correlation between K & Cr at $\rho=0.05$.

4) Oke-Diya Dumpsite

High mean concentrations of Fe, Mn, Ti, K, Ca, Zn, V, Rb, Cr, and Ni were in the samples to a depth of 80 cm (Table 7). The elemental concentrations in the soil profiles were in the closed range, suggesting the build-up of elements in the subsurface. High mean concentrations of potential contaminants (Zn, Cu, Cd, and Pb) in the subsoil as also reported by Lamine et al. [4]. Oke-Diya samples had the highest elemental contaminations that indicated anthropogenic and hydro-geologic sources. Moreover, the sedimentary formation and the nature of wastes contributed to the high elemental depositions in the study area. In the topsoil, Pb, Ti, V, and Th were not detected in the control samples, while in the subsoil, Pb and As were not in the control samples (SM 2). In a similar study, Shaheen et al. [3] showed high elemental concentrations in the topsoil and subsoil, which were generally lower than the concentrations obtained in this study. Also,

the patterns of the elemental pollutions were in agreement with the study of de Borba et al. [1], which shows distinct changes in the concentrations of toxic elements in soil profiles and depths around dumpsites in Brazil using the X-ray fluorescence technique.

Oke-Diya samples revealed high contaminations of Fe, Mn, K, Ca, Zn, Rb, Cr, Ni, and As in the topsoil, and Fe, Mn, K, Ca, Rb, V, and Ti in the subsoil (SM 3). Elements such as Sr (topsoil) and Cr, Ni, and Zn (subsoil) showed considerable soil contaminations. The subsoil revealed moderate contaminations of Cu and Sr. The soils were highly polluted; all the elements indicated high mean contamination factors except Sr. The pollution load index (SM 4) showed severe contaminations for the topsoil (33.01) and subsoil (9.16). The enrichment factors of Oke-Diya samples revealed that the abundance of Rb, Mn, Zn, Rb, and As in the topsoil was from anthropogenic sources, while other elements indicated geologic sources. Also, in the subsoil, only Ti and Rb revealed anthropogenic sources. Oke-Diya correlation analysis (SM 8) revealed strong positive correlations at $\rho=0.01$ between V & Ca, Mn & V, Fe & Ti, Fe & Mn, Ni & Ca, Ni & V, Ni & Mn, Zn & Mn, and Zn & Ni. At $\rho=0.05$, correlation exists between Mn & Ca, Mn & Ti, Fe & V, Zn & V, and Zn & Fe. These suggested that the same factor(s) or sources were responsible for the concentration of these elements, which were majorly anthropogenic and partly geologic through the sedimentary terrain of the study area.

5) Contaminations from dumpsites

The study samples were more contaminated than the control samples. Ita-Oshin and Premier enrichment factors (SM 9) showed that elemental pollutions were mainly from geological sources. Oke-Diya had the highest pollution index, followed by Saje with highly contaminated topsoil, and these pollutions could be

from several sources depending on the nature of the solid wastes [3, 36]. Saje and Oke-Diya enrichment factors (SM 9) revealed that anthropogenic and geologic sources contributed to the abundance of toxic elements in the subsurface of these study areas; the toxins in the topsoil were mainly from anthropogenic sources. The anthropogenic enrichments of Saje and Oke-Diya soil samples may result from domestic, commercial, and industrial activities [16, 44, 55]. The water aquifers could get polluted if the toxins percolate into deep soil layers, and the improper use of soil systems could lead to serious environmental threats.

The Kolmogorov-Smirnov and Shapiro-Wilk normality tests (SM 10) showed that the data were not normally distributed (since $\rho >$ 0.05), and one-way ANOVA involving Kruskal-Wallis tests for the study areas and soil profile depths were considered (SM 11). The one-way ANOVA (SM 12) across the study areas revealed that the mean elemental concentration ranks were significantly different, except for K, Fe, Sr, and Ba, whose mean concentration ranks were not contrasting. Also, the mean elemental concentration ranks across the depths were not significantly divergent.

Addressing soil contaminations would reduce the adverse effects these toxins could pose on plants, animals, and humans, and the continual proceeding with these toxins without adopting remediation strategies to bring these levels of contamination to the minimum or within the international regulatory standards could pose more threats to the soil, surface water, and groundwater. These increasing accumulations of toxic metals were mainly by anthropogenic sources through the uncontrollable deposition of different kinds of waste materials and a lack of knowledge, policies, and regulations guiding the dumping of wastes and their implementations by the government [57]. To avoid further environmental pollution due to toxic element infiltrations from dumpsites, the government needs to start constructing a modern (engineered) landfill system with liners that prevent easy percolations of toxins into the environment [58]. Also, the integrations of individual treatment methods, such as biological, chemical, and physical techniques, could reduce the concentrations of toxic elements in the environment. The combinations of these remediation techniques are economically feasible, eco-friendly, effective, and versatile [59–60].

6) Human health risk assessments

The ADDI for children and adults are different (SM 13–16) due to their differences in behaviour, physiology, immune system, and body metabolism [19]. The exposure parameters used in this study are not localized to Nigeria but used in other regions. The HQ and HI values in SM 17 revealed that for Saje, Mn was above a unit for children, and all the elements had values below one for adults. In 2020, Shaheen et al. [3] reported lower HQ values for adults than children. The HI for both the children (1.13) and adults (2.07) in Saje were due to Cr and Mn, and these values indicated that the overall health risks of the children and adults inhabiting the study area should be of concern as these could lead to neurological and developmental health effects, especially, in children [5, 19]. The HQ and HI values for Ita-Oshin and Premier were below one. The children and adults around these study areas were safe from non-carcinogenic risks. The HQ for Oke-Diya revealed that V, As, and Mn had more values than one for children, and for adults, As and Mn were above one. The HI for children (6.76) and adults (3.85) indicated high elemental pollution, which could give rise to non-cancerous risks for children and adults around the study area. In 2020, Mensah et al. [37] showed high health risks due to As in children around a gold mining site.

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The estimated carcinogenic risks for children and adults due to high concentrations of Cr, As, and Pb in the soil samples are in SM 18. For regulatory basis, US Environmental Protection Agency gave $1 \times 10^{-6} – 1 \times 10^{-4}$ as the acceptable range for carcinogenic risks [49]. The cancer-related risks for adults in Saje and Oke-Diya were negligible as the values of Cr, As, and Pb were within the acceptable range. For children, the carcinogenic risk due to Cr was not within the acceptable range, while for Pb and As, the risks were within the range. Ita-Oshin Cr and As revealed unacceptable risk for adults and for children, and Cr and As indicated acceptable risk and unacceptable risk, respectively. Premier Cr and As were within the permissible range for adults, and Pb was not within range. In recent studies, the carcinogens were of the same trends for adults and children in Rehman et al. [19] and Olujimi et al. [61].

Conclusion

The soil elemental concentrations analyses with depths around selected dumpsites within Abeokuta and Sagamu metropolises were determined to access soil contaminations and risks associated with human health. The results indicated soil contaminations that could have adverse consequences on humans, plants, and animals, even at very minute concentrations. The contamination indices were generally high, most especially in the topsoil. Oke-Diya samples had the highest mean elemental concentrations in the soil profiles, followed by Saje samples and Ita-Oshin samples, while Premier samples had the lowest elemental concentrations. The high concentrations in Oke-Diya and Saje samples could be due to the age of the dumpsites, the nature and quantity of solid wastes dumped daily, and their geology. The highest concentrations revealed by Oke-Diya were due to its sedimentary geology. The enrichment factors of Ita-Oshin and Premier indicated that

the elements were mainly from geologic sources, while Saje and Oke-Diya enrichment factors showed that both anthropogenic and geologic sources contributed to the high elemental concentrations. The human health risks were high for both children and adults, and these risks could be through direct ingestion of the soil through specks of dust, contact with the polluted soil, use of land for agricultural purposes, drinking of contaminated water from hand-dug well, or boreholes nearby the study areas, contaminated groundwater for irrigation purposes, and other domestic uses of surface water. The study areas should not be used for any agricultural activities now or in the nearest future. Also, hand-dug wells and boreholes should not be near the study areas to avoid water contamination through the soil pores as the degree of soil pollution will increase as the dumpsites age.

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