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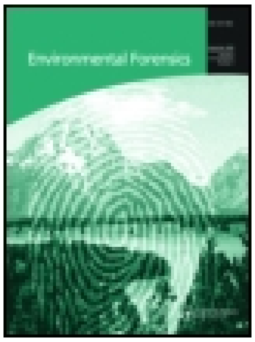

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Source apportionment, health and ecological risk assessments of essential and toxic elements in kerosene-contaminated soils

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ABSTRACT
The levels of essential and toxic elements (Mn, Fe, Cu, Zn, Co, Cr, and Ni) were determined in kerosene-contaminated soils with the aim of identifying their possible sources and associated health and ecological risks. Ni was undetected in the studied soils. Fe had the highest mean concentration (14,172 ± 6110.13 mg/kg) while Co had the least mean concentration (1.42 ± 3.17 mg/kg) in the studied soils. The studied soils showed varying degrees of contamination/pollution based on the results of contamination factor, geoaccumulation index, enrichment factor, modified degree of contamination, and pollution load index. Source apportionment using cluster analysis, principal component analysis, and positive matrix factorization identified vehicular emissions, industrial emissions, biomass/waste incineration, and natural sources as the major contributors to pollution of the soils. Health risk assessment showed that there were no noncarcinogenic risks associated with ingestion, inhalation, and dermal exposure to the studied soils (HI < 1). Ingestion and dermal exposure were identified as the principal exposure pathways to non-carcinogenic health risks. Fe had the highest individual contribution to potential health risks (RR = 57.63%). Ecological risk assessment indicated low ecological risks by the metals in the studied soils (RI < 150).

KEYWORDS
Ecological risk; health risk; kerosene; soils; source apportionment

Introduction

Some metals have known biological roles in living organisms while some do not. The latter represents a group known as “heavy metals.” They are known for their potential toxicity when present in certain doses, forms, or oxidation states. The toxicity of these metals is hinged on their ability to imitate certain essential elements in the body causing the alteration of many metabolic processes. Common examples of these metals include lead, cadmium, chromium, nickel, etc.

The contamination of urban soils by both essential and nonessential metals are predominantly from anthropogenic inputs of vehicular emissions, particulate depositions, domestic and industrial wastes, and combustion of fossil fuels (Facchinelli et al., 2001; Nicholson et al., 2003; Nabulo et al., 2006; Li et al., 2008; Ebong et al., 2015; Ebong and Moses, 2016). Natural soil forming processes such as the weathering of parent rock materials are possible sources of metals in soils, however, they rarely exceed recommended limits (Pierzynski et al., 2000; Kabata-Pendias and Pendias, 2001). The eradication of metals from soils has become problematic due to their nonbiodegradable and persistent nature. Therefore, exposure of human beings and other living organisms to these toxic elements via inhalation, ingestion, or dermal contact has brought about significant health risks as revealed in previous studies (Birke and Rauch, 2000; Grzebisz et al., 2002; Nicholson et al., 2003; Papa et al., 2010; Bukar et al., 2012; Al-Anbari et al., 2015; Ogunbanjo et al., 2016).

Refined crude oil contains several components such as dye additives, corrosion inhibitors, hydrocarbons, antioxidants, and heavy metals (Akakuru et al., 2017). The unprocessed crude oil is relatively less toxic than the refined products as a result of the alteration of the metal species and the addition of new metals in the course of refining (Uzoekwe and Oghosanine, 2011). Kerosene is a colorless, thin liquid generated from fractional distillation of petroleum between 150 °C and 275 °C resulting in a mixture of carbon chains that typically contains 6 and 16 carbon atoms per molecule (Collins, 2007). A common practice in Nigeria is to situate kerosene selling points along roadsides within a metropolis. This is to ensure the

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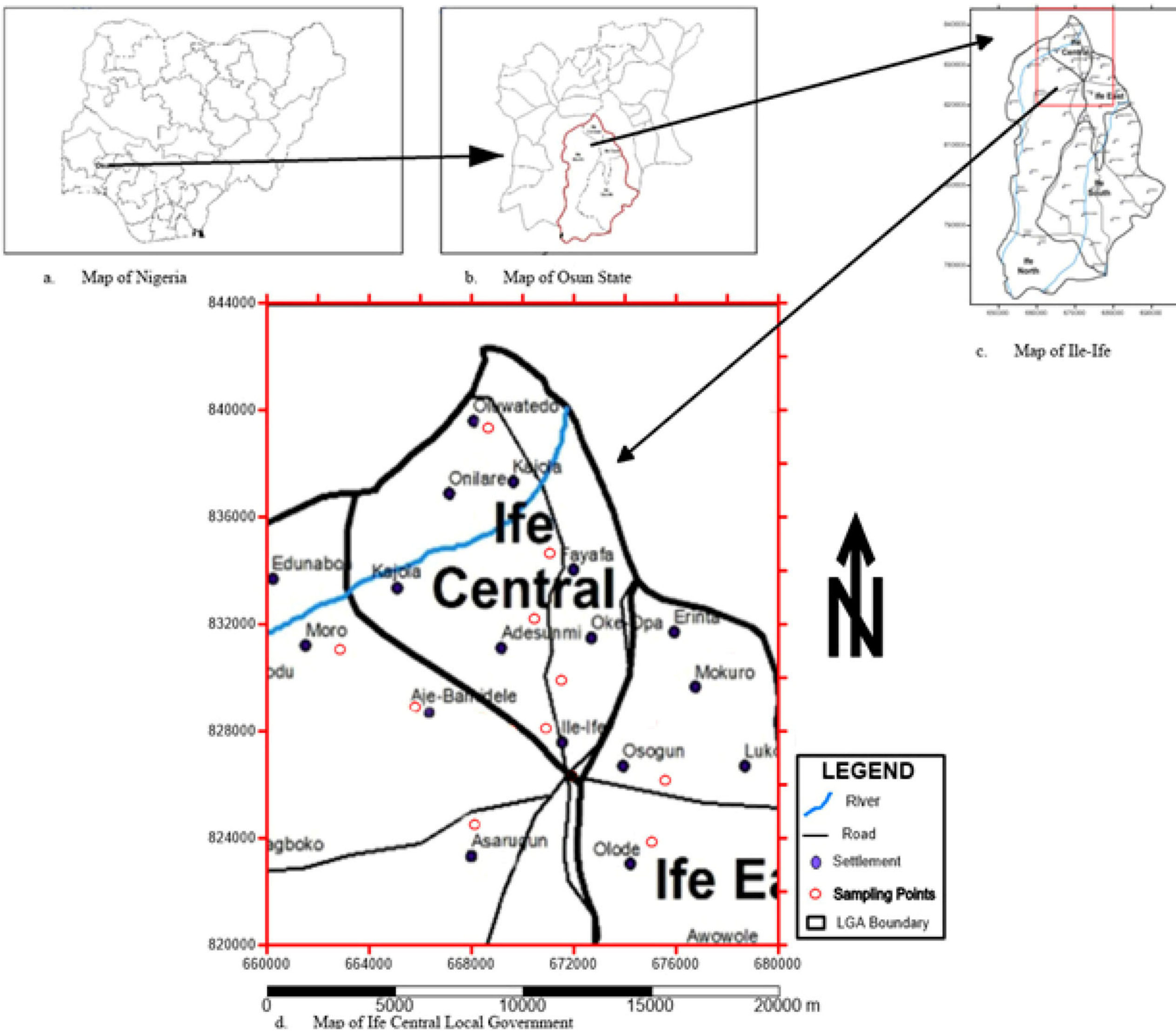

Figure 1. Map of the study area showing sampling locations.

easy accessibility of consumers to the kerosene rather than going to gas stations to obtain the kerosene and other refined petroleum products. In the process of selling, transportation, and storage, the kerosene spills into the surrounding soils, contaminating the soils in the process. Naturally, heavy metals are present in soils in trace amounts. However, anthropogenic inputs emanating from oil spills result in elevating the levels of these metals in soils. Petroleum contamination has been reported to represent a major contributor of toxic metals to the environment (Onojake and Frank, 2013).

Some studies have been carried out on the metal levels of crude oil contaminated soils in Nigeria (Aigberua et al., 2017; Harrison et al., 2018; Aigberua and Inengite, 2019; Onyejekwe et al., 2019; Ikhajiagbe and Ogwu, 2020). Nevertheless, there is rarity of studies focused on the elemental levels of soils contaminated by refined products in Nigeria. During refining, transportation, and storage, more elements are introduced into the refined products, thereby making them more toxic than the crude oils. The need therefore arises to identify the levels of these metals, their sources and potential health and ecological risks associated with different exposure pathways to them by adults and children, hence this study.

Materials and methods

Study area, sampling collection, and preparation

Ile-Ife, the study area, is host to the prestigious Obafemi Awolowo University, Ile-Ife, Nigeria. The map of the study area showing the sampling points is presented in Figure 1. Standard procedure for environmental sampling was adopted for the collection of the samples. Kerosene-contaminated soils were randomly collected from several kerosene-selling points in Ile-Ife, Nigeria in 2019. Surface soils between 0 and 5 cm were collected using hand trowel, stored in hermetically sealed polyethylene bags and transported to the laboratory for analysis. The soil samples were air dried at room temperature and crushed into 2 mm mesh size using agate mortar. The crushed samples were mixed thoroughly by coning and quartering method and used as representative sample for analyses.

Sample digestion and analysis

One gram each of the soil samples was weighed and digested with a mixture of HCl and HNO_3 (aqua regia) in the ratio 1:3 using a temperature-controlled hotplate at 70 °C under a fume cupboard. The heating continued until digestion was completed. The digest was allowed to cool for some minutes and then transferred into 50 mL standard volumetric flask. A blank determination was digested using the same procedure without a sample. The digested samples were taken for elemental analysis using Atomic Absorption Spectrophotometer (Model PG 90) at the Central Science Laboratory, Obafemi Awolowo University, Ile-Ife, Nigeria.

Quality assurance and quality control

In addition to thorough washing of sample bottles, containers, and glassware, blank determination was carried out as a quality control parameter. All analyses were carried out in triplicates. The analytical procedure adopted in this study was ascertained by recovery analysis. 100 mg/kg metal salts of Mn, Cu, Cr, and Zn were prepared. The resultant solution was then added to the soil samples and analyzed using AAS. The percentage recovery is thus calculated as follows:

$$\%R = \frac{X - X^i}{Y} \times 100 \tag{1}$$

Where X = concentration of toxic metal in the spiked soil sample, X^i = concentration of toxic metal in the unspiked soil sample, and Y = the concentration used for spiking (Adebiyi et al., 2020).

Data analysis

Mean, range, standard deviation, and co-efficient of variation were used to evaluate the distribution patterns of the investigated metals. Hierarchical cluster analysis, principal component analysis, and positive matrix factorization were also used to identify the possible sources of the metals in the studied soils using Statistical Package for Social Scientists (SPSS) version 20 and Environmental Protection Agency Positive Matrix Factorization model 5 software. Human health risk assessment and potential ecological risk assessment were also used to evaluate the risks associated with exposure to the studied soils.

Human health risk assessment

The calculated risk of exposure of adults and children to the elemental concentrations of the soil samples was carried out using USEPA method (USEPA, 1989, 1997, 2001). It was used for the estimation of bioaccessibility of the elements and its impact on humans (Olutona et al., 2017; Tenebe et al., 2019). Chronic daily intake (CDI, mg/kg/day) was used to evaluate exposure to the elemental concentrations of the samples (Hu et al., 2017), calculated as:

$$\mathrm{CDI}\mathit{ingestion} = \frac{\mathrm{Cm} \times \mathrm{R}\mathit{ing} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{ABWXAVT}} \mathrm{x}10-6 \tag{2}$$

$$\mathrm{CDI}\mathit{inhalation} = \frac{\mathrm{Cm} \times \mathrm{R}\mathit{inh} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{ABW} \times \mathrm{AVT} \times \mathrm{PEF}} \tag{3}$$

$$\mathrm{CDI}\mathit{dermal} = \frac{\mathrm{Cm} \times \mathrm{ESSA} \times \mathrm{SAF} \times \mathrm{DAF} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{ABW} \times \mathrm{AVT}} \mathrm{x}10-6 \tag{4}$$

All parameters are as defined by Akhigbe et al. (2019).

Contamination factor (CF)

The contamination factor was calculated using the formula:

$$\mathrm{CF} = \frac{Cm(sample)}{Cm(background)} \tag{5}$$

Geoaccumulation index (I_{geo})

The geoaccumulation index was calculated using the formula (Buccolieri et al., 2006):

$$I_{geo} = log_2 \frac{C_n}{1.5B_n} \tag{6}$$

Enrichment factor (EF)

Enrichment factor (EF) was calculated using the formula (Barbieri, 2016):

$$EF = \frac{\left(\frac{C_n}{C_{ref}}\right) sample}{\left(\frac{B_n}{B_{ref}}\right) crust} \tag{7}$$

Modified degree of contamination (mCd)

The modified degree of contamination by metals in soil was calculated using the formula (Abrahim, 2005):

$$mCd = \frac{\sum CF}{N} \tag{8}$$

Pollution load index (PLI)

The pollution load index was calculated using the formula (Tomlinson et al., 1980):

$$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots \times CF_N)^{1/N} \tag{9}$$

All parameters for contamination factor, index of geoaccumulation, enrichment factor, modified degree of contamination, and pollution load index are as described by Adebiyi and Ore (2021).

Potential ecological risk assessment

The sensitivity of communities inhabited by biological organisms in large areas is determined by the potential ecological risk index (RI). The concentration of the potentially toxic metal, its toxic level, synergy and ecological sensitivity are considered by this method (Singh et al., 2010; Douay et al., 2013) and it is calculated using the formula:

$$RI = \Sigma Er = \Sigma Tr \times CF \tag{10}$$

where Er indicates the potential ecological risk factor of individual metal, Tr indicates the toxicological response factor of each metal (Duodu et al., 2016). CF is the contamination factor of each metal. Endorsed ecological risk indices (Hakanson, 1980) are listed in Table 1.

Results and discussion

Results of recovery analysis

The analytical result for calibration curve and percentage recovery for the analyzed metals in the kerosene-contaminated soils is presented in Table 2. The reliability of the analytical procedures adopted in this study was tested in terms of recovery, accuracy, sensitivity, and precision. The recovery analysis of the soil samples showed percentage recoveries of 93.35%, 92.85%, 94.50%, and 96.75% for Mn, Cu, Cr, and Zn, respectively. The recovery results were adjudged acceptable (70–110%) and reliable to give precise and accurate metal concentrations in the samples.

Levels (mg/kg) of essential and toxic metals in kerosene-contaminated soils

The levels of manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), cobalt (Co), chromium (Cr), and nickel (Ni) in the investigated kerosene-contaminated soils, their mean, range, and co-efficient of variation are presented in Table 3. The mean concentrations of Mn, Fe, Cu, Zn, Co, and Cr in the soils were 1080.20 ± 246.90, $14{,}172 \pm 6110.13$, 12.65 ± 4.18, 66.76 ± 61.44, 1.42 ± 3.17, and 19.67 ± 9.48 mg/kg, respectively. The mean levels of the investigated metals were less than the permissible limits of metals in Nigerian soils (DPR, 2002) except for Mn and Fe. Among the studied metals, Fe had the highest mean level while Co had the least mean concentration.

The contamination/pollution of the studied soils were assessed using various contamination indices such as contamination factor, geo-accumulation index, enrichment factor, modified degree of contamination, and pollution load index, and their results are presented in Table 4. The studied soils exhibited very high contamination by all the investigated metals. The studied soils were strongly to extremely polluted by

Table 1. Indices of corresponding degrees of potential ecological risk (Hakanson 1980).

Er value	Grades of ecological risk of single metal	RI value	Grades of potential ecological risk of the environment
$Er < 40$	Low risk	$RI < 150$	Low risk
$40 \le Er < 80$	Moderate risk	$150 \le RI < 300$	Moderate risk
$80 \le Er < 160$	Considerable risk	$300 \le RI < 600$	Considerable risk
$160 \le Er < 320$	High risk	$RI > 600$	Very high risk
$Er > 320$	Very high risk		

Table 2. Analytical results for calibration curve and percentage recovery (%R) for heavy metals.

Metals	Current (mA)	Wavelength (nm)	Amount spiked (mg/kg)	Amount recovered (mg/kg)	% Recovery
Mn	10	280	100	93.35	93.35
Cu	6	325.1	100	92.85	92.85
Cr	8	228.6	100	94.50	94.50
Zn	8	214.2	100	96.75	96.75

Table 3. Levels (mg/kg) of metals in kerosene-contaminated soils.

Samples	Mn	Fe	Cu	Zn	Co	Cr	Ni
A	1280	11300	18.90	189	ND	27.50	ND
B	1260	8610	18.40	120	ND	22.60	ND
C	1040	22700	14.50	22	ND	24.20	ND
D	930	23700	15.80	18.80	ND	22.50	ND
E	889	6120	9.88	140	ND	19.90	ND
F	535	9920	7.99	24.50	ND	6.20	ND
G	1210	15000	13.90	61	ND	34.40	ND
H	1380	9370	10.00	30	ND	24.20	ND
I	1188	19000	9.15	51.50	9.35	8.35	ND
J	1090	16000	8.00	10.80	4.85	6.85	ND
Range	535 – 1380	6120 – 23700	7.90 – 18.90	10.80 – 189	ND – 9.35	6.20 – 34.40	ND
Mean ± SD	1080.20 ± 246.90	14172 ± 6110.13	12.65 ± 4.18	66.76 ± 61.44	1.42 ± 3.17	19.67 ± 9.48	ND
CV (%)	22.85	43.11	33.04	92.03	223.23	48.19	ND
PL[a]	437	5000	36	140	20	100	35

ND, not detected; PL, permissible limit.
aDepartment of Petroleum Resources (2002).

Table 4. Contamination and ecological risk assessment of metals in kerosene-contaminated soils.

	Mean	IUGS	CF	Igeo	EF	Tr	Er
Mn	1080.20	40	27.00	4.17	89.55	1	27.00
Fe	14172	1600	8.85	2.56	–	–	–
Cu	12.65	0.8	15.81	3.39	52.44	5	79.07
Zn	66.76	3	22.25	3.89	73.80	1	22.25
Co	1.42	NA	NA	NA	NA	–	–
Cr	19.67	3	6.55	2.12	21.74	2	13.11
RI							141.44
PLI			14.07				
mCd			16.09				

CF, contamination factor; Igeo, geo-accumulation index; EF, enrichment factor, Tr, toxicological response factor; Er, ecological risk factor; RI, ecological risk index; PLI, pollution load index; mCd, modified degree of contamination.

Mn, moderately polluted by Fe and Cr, and strongly polluted to Cu and Zn. The studied soils showed severe enrichment for Cr, and extremely severe enrichment for Mn, Cu, and Zn. The modified degree of contamination indicated that the studied soils exhibited an extremely high degree of contamination. The value of the pollution load index (14.07) indicated that the studied soils have deteriorated in quality due to the elevated levels of the investigated metals.

Source apportionment of essential and toxic metals in kerosene-contaminated soils

The possible sources of the essential and toxic metals in the kerosene-contaminated soils were identified using hierarchical cluster analysis (HCA), principal component analysis (PCA), and positive matrix factorization (PMF). The dendrogram showing the hierarchical cluster analysis is shown in Figure 2. The cluster analysis indicated that there were two major clusters. The first cluster showed close relationship among Cu, Cr, Co, Zn, and Mn, while the second cluster showed a distant relationship between Zn and Fe. The former indicated that the metals originate from the same source(s).

Principal component analysis is a data reduction technique that creates components that can be meaningfully interpreted. The number of components that should be retained was determined using eigen values and they are presented in Table 5 while the scree plot (showing the eigen values) and a plot of the extracted components are shown in Figures 3 and 4, respectively. Direct oblimin method of rotation was used for the factor analysis and three principal components were identified. The three principal components accounted for 88.036% of the data variance. Factor loadings of 0.5 and above are considered strong and significant (Ravindra et al., 2008). Principal component 1 (which accounted for 46.506% of the total variance) had high factor loadings of 0.902 and 0.857 for Cr and Cu, respectively. This is in consonance with the observed close clustering relationship of the duo in the dendrogram, as also evident in their component plot. In addition to the background levels of these metals in the soils, crude oil contains Cr and Cu as geogenic impurities (Kummer et al., 2009). This might be responsible for the upsurge in their levels in the studied soils. Therefore, it is safe to attribute the levels of Cr and Cu to vehicular emissions and oil spills. Principal component 2 (which accounted for 22.922% of the total variance) had a high factor loading of 0.979 for Fe. This is corroborated by its distant relationship with other investigated metals in the dendrogram. Also, it is far from the other metals in the component plot. Although the levels of Fe in the studied soils are above permissible limits and geochemical background levels as indicated in Tables 3 and 4, they may be due to natural sources controlled by the weathering of parent material (Ma et al., 2016). It is consistent with the assertion that Nigerian soils are rich in Fe. The relatively distant Zn from Fe in the component plot as well as the dendrogram indicated that while Fe levels are probably due to natural

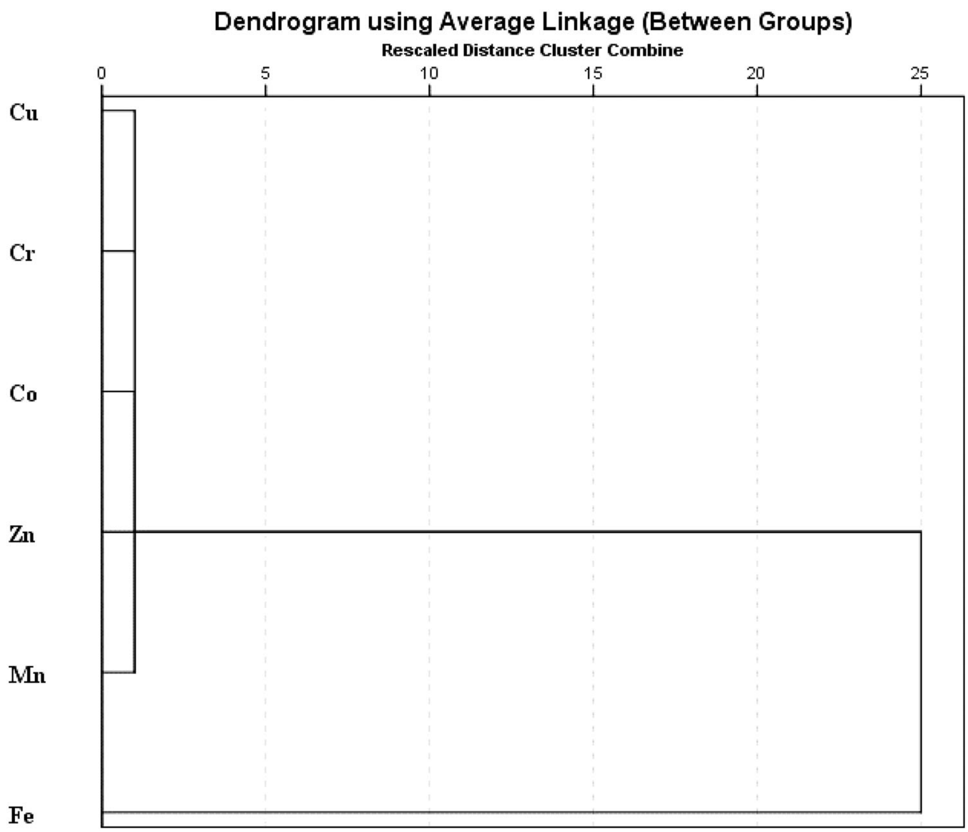

Figure 2. Dendrogram showing the cluster analysis of metals in kerosene-contaminated soils.

Table 5. Principal component analysis of metals in kerosene-contaminated soils.

	Component		
	PC1	PC2	PC3
Cr	0.902*	0.016	0.164
Cu	0.857*	0.049	0.220
Co	−0.827	0.144	0.587*
Fe	0.175	0.979*	0.115
Zn	0.251	−0.753	0.285
Mn	0.188	−0.070	0.879*
Eigen value	2.79	1.37	1.11
% variance	46.506	22.922	18.608
Cumulative %	46.506	69.428	88.036

*Indicates significant factor loadings (>0.5).

sources, Zn levels are due to anthropogenic influences notably car components, tire abrasions, lubricants etc. (Wilcke et al., 1998). Principal component 3 (which accounted for 18.608% of the total variance) had factor loadings of 0.587 and 0.879 for Co and Mn respectively. This is supported by their close clustering relationship in the dendrogram. The elevated levels of Mn in the studied soils above background levels are indicative of anthropogenic influences. Co is a biophilic element (element associated with organic matter). However, its present levels in the studied soils have likely arisen from smelting activities in the study area. It has been reported that increased cobalt concentrations due to anthropogenic influences are mainly from industrial, smelting, and mining activities (Collins and Kinsela, 2010).

Estimations of the source contributions of the total metal burden in the soil samples was carried out by means of Positive matrix factorization (PMF) analysis using EPA PMF 5.0 model. Source profile from the literature was compared with local source markers at the sampling sites to identify the resolved factors. Factor numbers ranging from 3 to 6 were tried in order to choose the *optimal solution*. Fifty runs were made for each factor, and the convergent run with the minimum Qrobust was used for the optimal solutions. The PMF model identified three factors for the soils as shown in Table 6 and Figure 5. The obtained results revealed that Factor 1 was more influenced by high loading of Co (90.0%), Fe (58.2%), and Mn (34.3%). Metals of this kind have previously been associated with industrial production and coke oven emission (Oluyemi et al., 1994). This factor was apportioned to industrial emissions and accounted for 38% of the overall mass load of pollution in the sampling area. Factor 2 showed a significant contribution of Cr (52.6%), Fe (41.8%), and Cu (37.6%). A high fraction of these elements in the second factor are fingerprints emissions from biomass or waste incineration (Ezeh et al., 2017). The contribution of this

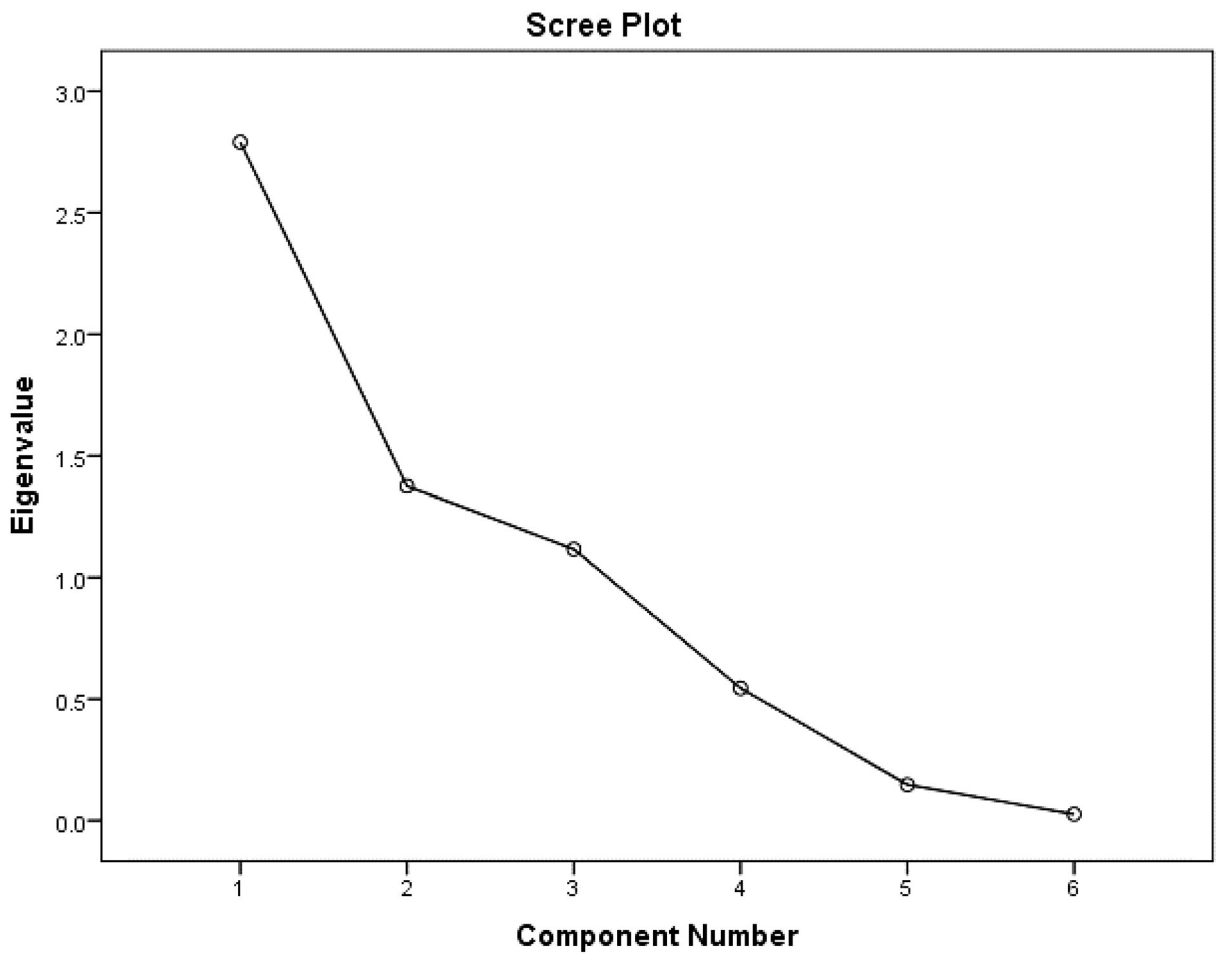

Figure 3. Scree plot showing eigen values of components.

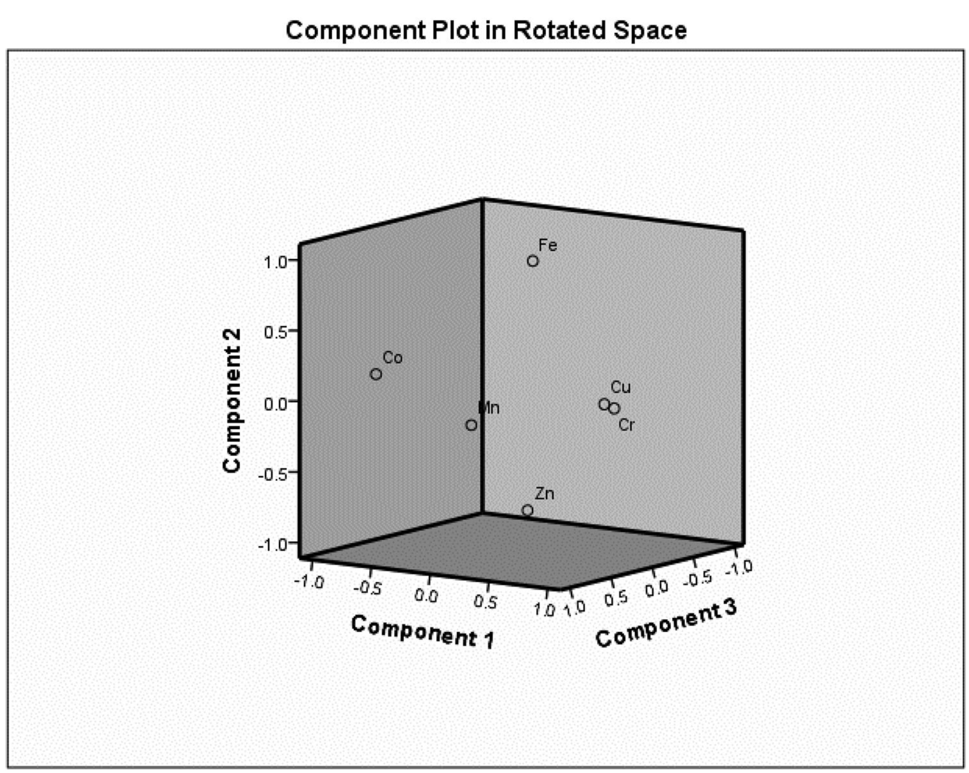

Figure 4. Component plot of Factors 1, 2, and 3.

Table 6. Source profiles of heavy metals in the kerosene-contaminated soils using positive matrix factorization (PMF).

Heavy metal	Factor 1	Factor 2	Factor 3
Mn	**34.30**	37.20	28.50
Fe	**58.20**	**41.80**	0
Cu	28.10	**37.60**	**43.30**
Zn	20.30	0	**79.70**
Co	**90**	10	0
Cr	0.20	**52.60**	**47.20**
Contributions (%)	40	27	33
Source	Industrial emissions	Biomass/waste incineration	Vehicular emission

Bold indicates significant factor loadings.

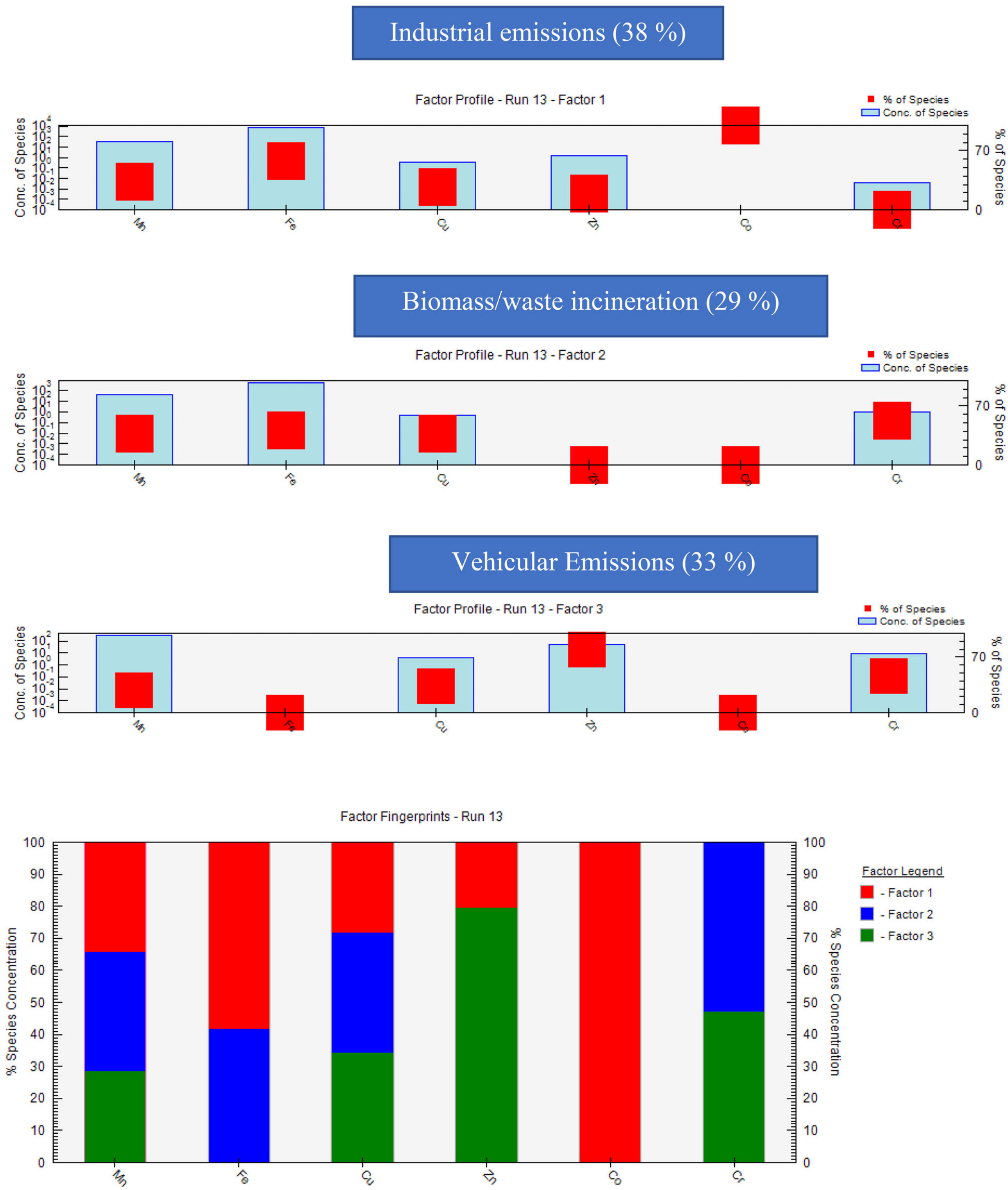

Figure 5. Factor profiles and contributions of Factors 1, 2, and 3 using PMF.

Table 7. Health risk assessment of metals in kerosene-contaminated soils by children and adults from ingestion, inhalation and dermal exposure.

Metals		$CDI_{(ing)}$	$CDI_{(inh)}$	$CDI_{(derm)}$	$RfD_{(ing)}$	$RfD_{(inh)}$	$RfD_{(derm)}$	$HQ_{(ing)}$	$HQ_{(inh)}$	$HQ_{(derm)}$	HI	RR (%)
Mn	Children	1.38E-01	3.87E-07	3.86E-04	1.40E-01	5.00E-05	1.84E-03	9.86E-01	7.74E-03	2.10E-01	1.20E + 00	21.96
	Adults	6.34E-03	5.96E-08	2.53E-04				4.52E-02	1.19E-03	1.37E-01	1.84E-01	
Fe	Children	1.81E + 00	5.08E-06	5.07E-03	3.00E-01	NA	1.40E-01	2.58E + 00	NA	3.62E-02	2.62E + 00	57.63
	Adults	8.32E-02	7.83E-07	3.31E-03				1.18E-01	NA	2.37E-02	1.42E-01	
Cu	Children	1.61E-03	4.53E-09	4.52E-06	4.00E-02	4.02E-02	2.40E-02	4.04E-02	1.13E-07	1.89E-04	4.06E-02	0.90
	Adults	7.42E-05	6.99E-10	2.96E-06				1.85E-03	1.74E-08	1.23E-04	1.98E-03	
Zn	Children	8.53E-03	2.39E-08	2.38E-05	3.00E-01	3.00E-01	7.50E-02	2.84E-02	7.98E-08	3.19E-04	2.87E-02	0.63
	Adults	3.91E-04	3.68E-09	1.56E-05				1.30E-03	1.23E-08	2.09E-04	1.51E-03	
Co	Children	1.81E-04	5.09E-10	5.08E-07	2.00E-02	5.70E-06	1.60E-02	9.07E-03	8.93E-05	3.18E-05	9.19E-03	0.20
	Adults	8.33E-06	7.84E-11	3.32E-07				4.17E-04	1.38E-05	2.08E-05	4.51E-04	
Cr	Children	2.51E-03	7.05E-09	7.04E-06	3.00E-03	3.00E-05	7.50E-05	8.38E-01	2.35E-04	9.38E-02	9.32E-01	18.66
	Adults	1.15E-04	1.08E-09	4.60E-06				3.84E-02	3.62E-05	6.14E-02	9.99E-02	

CDI, chronic daily intake; ing, ingestion; inh, inhalation; derm, dermal; RfD, oral reference dose; HQ, hazard quotient; HI, risk index; RR, relative risk; NA, not available.

factor was 29% out of the overall pollution sources accounted for in the area. Factor 3 showed a high pollution loading of Zn (79.7%), Cr (43.3%), and Cu (47.2%). These components are markers of emissions emanating through traffic dust from automobile exhaust, re-entrainment dust enriched with Zn and also from tire and brake abrasion (Adegunwa et al., 2019). Zn has also been reported as an indication of discharges from two-stroke automobiles as it is being used to formulate vehicles lubricating oils (Chueinta et al., 2000). The source factor was apportioned vehicular emission. This factor accounted for 33% of the total mass loads.

Risk assessment of essential and toxic metals in kerosene-contaminated soils

The health risk assessment of essential and toxic metals emanating from ingestion, inhalation and dermal exposure to the studied soils was calculated for adults and children, and their results are presented in Table 7. The hazard indexes (HIs) were below 1 for both children and adults except in the case of Mn (1.20E + 00) and Fe (2.62E + 00) for children. This indicated that the probable non-carcinogenic health risks associated with the essential and toxic metals in the studied soils are peculiar to Mn and Fe in children. On the average, the HIs for children and adults were 8.06E-01 and 7.17E-02 respectively which were both less than 1. This suggested that there are no non-carcinogenic health risks associated exposures to the studied soils. These results also indicated that relatively, children were the more vulnerable population of noncarcinogenic risks emanating from the cumulative exposure routes of ingestion, inhalation and dermal contact. This is in agreement with previous findings that reported the susceptibility of children to environmental contaminants (Zota et al., 2011; Qu et al., 2012; Li et al., 2014; Ma et al., 2018; Chonokhuu et al., 2019; Hanfi and Yarmoshenko, 2020). The ingestion pathway route was the main contributor for health risk in children while the dermal pathway route was the main contributor for health risk in adults. Relative risks indicated that the highest concern of toxic metal risks was attributed to Fe (57.63%).

The potential ecological risk assessment was determined using the potential ecological risk index (presented in Table 4). The potential ecological risk index indicated that the studied soils exhibited low ecological risk.

Conclusion

A detailed assessment of the contamination of essential and toxic metals in kerosene-contaminated soils, their source apportionment and associated health and ecological risks was presented in this study. The results of the study indicated that the studied soils showed varying degrees of contamination/pollution. Natural sources, vehicular emissions and industrial emissions were found to be the major contributors to the elevated levels of the investigated metals in the studied soils. The health risk assessment showed that there were no noncarcinogenic health risks associated with exposure to the metals and that children were the more vulnerable population to environmental contaminants. Ingestion and dermal exposure to the metals were found to be the major pathways to noncarcinogenic health risks. The ecological risk assessment indicated a low ecological risk by the metals.

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The authors declare that there is no conflict of interest

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References

Abrahim, G. M. S. 2005. *Holocene sediments of Tamaki Estuary: Characterization and impact of recent human activity on an urban estuary in Auckland, New Zealand.* PhD thesis, University of Auckland, Auckland, New Zealand, 361.

Adebiyi, F. M., and Ore, O. T. (2021). EDXRF analysis and risks assessment of potentially toxic elements in sand fraction (tailing) of Nigerian oil sands. *Energy, Ecology and Environment*, *6*(3), 258–270.

Adebiyi, F. M., Ore, O. T., Akhigbe, G. E., and Adegunwa, A. O. 2020. Metal fractionation in the soils around a refined petroleum products depot. *Environmental Forensics* 21(2):121–131.

Adegunwa, A. O., Adebiyi, F. M., and Asubiojo, O. I. 2019. Heavy metal analysis in rainwaters as indicator of aerial pollution. *Research and Reviews: Journal of Environmental Sciences* 1(3):1–13.

Aigberua, A. O., Ekubo, A. T., Inengite, A. K., and Izah, S. C. 2017. Assessment of some selected heavy metals and their pollution indices in an oil spill contaminated soil in the Niger Delta: A case of Rumuolukwu community. *Biotechnological Research* 3(1):11–19.

Aigberua, A. O., and Inengite, A. K. 2019. Chemical speciation and mobility of heavy metal (Pb, Cd, Zn, Mn) pollutants in crude oil contaminated soils of Niger Delta, Nigeria. *Elixir Applied Chemistry* 126:52543–52548.

Akakuru, O. C., Akudinobi, B. E. B., and Usman, A. O. 2017. Organic and heavy metal assessment of groundwater sources around Nigeria National Petroleum Cooperation Oil Depot Aba, South-Eastern Nigeria. *Journal of Natural Sciences Research* 7(24):48–54.

Akhigbe, G. E., Adebiyi, F. M., and Torimiro, N. 2019. Analysis and hazard assessment of potentially toxic metals in petroleum hydrocarbon-contaminated soils around transformer installation areas. *Journal of Health and Pollution* 9(24):191213.

Al-Anbari, R., Al Obaidy, A. H. M. J., and Ali, F. H. A. 2015. Pollution loads and ecological risk assessment of heavy metals in the urban soil affected by various anthropogenic activities. *International Journal of Advanced Research* 2:104–110.

Barbieri, M. 2016. The Importance of Enrichment Factor (EF) and Geoaccumulation Index (Igeo) to evaluate the soil contamination. *Journal of Geology and Geophysics* 5(237):1–4.

Birke, M., and Rauch, U. 2000. Urban geochemistry: Investigations in the Berlin metropolitan area. *Environmental Geochemistry and Health* 22(3):233–248.

Buccolieri, A., Buccolieri, G., and Cardellicchio, N. 2006. Heavy metals in marine sediments of taranto gulf (Ionian Sea, Southern Italy). *Marine Chemistry* 99:227–235.

Bukar, L. I., Hati, S. S., Dimari, G., and Tijjani, M. 2012. Study of vertical migration of heavy metals in dumpsites soil. *Journal of Science and Technology* 2(2):50–55.

Chonokhuu, S., Batbold, C., Chuluunpurev, B., Battsengel, E., Dorjsuren, B., and Byambaa, B. 2019. Contamination and health risk assessment of heavy metals in the soil of major cities in Mongolia. *International Journal of Environmental Research and Public Health* 16(14):2552.

Collins, C. D. 2007. Implementing phytoremediation of petroleum hydrocarbons. In N. Willey (Ed.), *Methods in Biotechnology. Vol.* 23. 99–108. Humana Press, Totowa, New Jersey.

Chueinta, W., Hopke, P. K., and Paatero, P. 2000. Investigations of sources of atmospheric aerosols at urbanm and sub-urban residential area in Thailand by positive matrix factorization. *Atmospheric Environment* 34:3319–3329.

Collins, R. N., and Kinsela, A. S. 2010. The aqueous phase speciation and chemistry of cobalt in terrestrial environments. *Chemosphere* 79(8):763–771.

Department of Petroleum Resources (DPR). 2002. *Environmental Guidelines and Standards for the Petroleum Industry in Nigeria*, Revised Edition. Abuja, Nigeria: Department of Petroleum Resources, Ministry of Petroleum and Mineral Resources.

Douay, F., Pelfrêne, A., Planque, J., et al. 2013. Assessment of potential health risk for inhabitants living near a former lead smelter, Part 1: Metal concentrations in soils, agricultural crops, and home- grown vegetables. *Environmental Monitoring and Assessment* 185:3665–3680.

Duodu, G. O., Goonetilleke, A., and Ayoko, G. A. 2016. Comparison of pollution indices for the assessment of heavy metal in Brisbane River sediment. *Environmental Pollution (Barking, Essex: 1987)* 219:1077–1091.

Ebong, G. A., and Moses, E. A. 2016. Metal speciation and pollution status of trace metals in roadside dusts in high traffic density areas of Akwa Ibom State, Nigeria. *Iranian (Iranica) Journal of Energy & Environment* 7(4):340–348.

Ebong, G. A., Offiong, O. E., and Ekpo, B. O. 2015. Pollution Indices of trace metals in urban dumpsite soils within Akwa Ibom State. *International Research Journal of Pure and Applied Chemistry.* 6(2):84–94.

Ezeh, G. C., Abiye, O. E., and Obioh, I. B. (2017). Elemental analyses and source apportionment of PM2. 5 and PM2. 5–10 aerosols from Nigerian urban cities. *Cogent Environmental Science*, *3*(1), 1323376.

Facchinelli, A., Sacchi, E., and Mallen, L. 2001. Multivariate statistical and GIS-based approach to identify heavy metal sources in soils. *Environmental Pollution (Barking, Essex: 1987)* 114(3):313–324.

Grzebisz, W., Ciesla, L., Komisarek, J., and Potarzycki, J. 2002. Geochemical assessment of the heavy metals pollution of urban soils. *Polish Journal of Environmental Studies* 11(5):493–500.

Hakanson, L. 1980. An ecological risk index for aquatic pollution control: A sedimentological approach. *Water Research* 14:975–1001.

Hanfi, M. Y., and Yarmoshenko, I. V. 2020. Health risk assessment quantification from heavy metals contamination in the urban soil and urban surface deposited sediment. *Journal of Taibah University for Science* 14(1): 285–293.

Harrison, U. E., Osu, S. R., and Ekanem, J. O. 2018. Heavy metals accumulation in leaves and tubers of cassava (Manihot esculenta Crantz) grown in crude oil contaminated soil at Ikot Ada Udo, Nigeria. *Journal of Applied Sciences and Environmental Management* 22(6):845–851.

Hu, B., Jia, X., Hu, J., Xu, D., Xia, F., and Li, Y. 2017. Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze River Delta. *International Journal of Environmental Research and Public Health* 14(9):1042.

Ikhajiagbe, B., and Ogwu, M. C. 2020. Hazard quotient, microbial diversity, and plant composition of spent crude oil-polluted soil. *Beni-Suef University Journal of Basic and Applied Sciences* 9(1):1–9.

Kabata-Pendias, A., and Pendias, H. 2001. *Trace Elements in Soils and Plants*. Boca Raton, FL: CRC Press LLC.

Kummer, U., Pacyna, J., Pacyna, E., and Friedrich, R. 2009. Assessment of heavy metal releases from the use phase of road transport in Europe. *Atmospheric Environment* 43(3):640–647.

Li, C., Lu, F. Y., Zhang, Y., Liu, T. W., and Hou, W. 2008. Spatial distribution characteristics of heavy metals in street dust in Shenyang city. *Ecology and Environment* 17(2):560–564.

Li, Z., Ma, Z., van der Kuijp, T. J., Yuan, Z., and Huang, L. 2014. A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. *Science of the Total Environment* 468:843–853.

Ma, W., Tai, L., Qiao, Z., et al. 2018. Contamination source apportionment and health risk assessment of heavy metals in soil around municipal solid waste incinerator: A case study in North China. *The Science of the Total Environment* 631–632:348–357.

Ma, Z., Chen, K., Li, Z., Bi, J., and Huang, L. 2016. Heavy metals in soils and road dusts in the mining areas of Western Suzhou, China: A preliminary identification of contaminated sites. *Journal of Soils and Sediments* 16(1): 204–214.

Nabulo, G., Oryem-Origa, H., and Diamond, M. 2006. Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. *Environmental Research* 101(1):42–52.

Nicholson, F. A., Smith, S. R., Alloway, B. J., Carlton-Smith, C., and Chambers, B. J. 2003. An inventory of heavy metals inputs to agricultural soils in England and Wales. *Science of the Total Environment* 311(1–3):205–219.

Ogunbanjo, O., Onawumi, O., Gbadamosi, M., Ogunlana, A., and Anselm, O. 2016. Chemical speciation of some heavy metals and human health risk assessment in soil around two municipal dumpsites in Sagamu, Ogun state, Nigeria. *Chemical Speciation & Bioavailability* 28(1–4):142–151.

Olutona, G. O., Oyekunle, J. A. O., Dawodu, M. O., Ogunwale, T. O., and Kehinde, P. 2017. Physicochemical characteristics of soil and health risk assessment of potentially toxic metals in soil and vegetables from roadside farmlands in Iwo, South-Western Nigeria. *Journal of Environmental Science and Pollution Research* 3(3): 213–218.

Oluyemi, E. A., Asubiojo, O. I., Oluwole, A. F., and Touissant, N. 1994. Elemental characterization and source apportionment of air particulate matter at a Nigeria Site. *Journal of Radioanalytical and Nuclear Chemistry* A179: 187–194.

Onojake, M. C., and Frank, O. 2013. Assessment of heavy metals in a soil contaminated by oil spill: A case study in Nigeria. *Chemistry and Ecology* 29(3):246–254.

Onyejekwe, I. M., Osuji, L. C., and Nwaichi, E. O. 2019. Accumulation of heavy metals in the seeds of *Zea mays* L. from crude oil impacted soils in Kom-Kom, Rivers State, Nigeria. *Journal of Scientific Research and Reports* 25(3):1–8.

Papa, S., Bartoli, G., Pellegrino, A., and Fioretto, A. 2010. Microbial activities and trace element contents in an urban soil. *Environmental Monitoring and Assessment* 165(1):193–203.

Pierzynski, G. M., Sims, J. T., and Vance, G. F. 2000. *Soils and Environmental Quality*. 2nd ed. London, UK: CRC Press.

Qu, C., Sun, K., Wang, S., Huang, L., and Bi, J. 2012. Monte carlo simulation-based health risk assessment of heavy metal soil pollution: A case study in the Qixia mining area, China. *Human and Ecological Risk Assessment: An International Journal* 18(4):733–750.

Ravindra, K., Sokhi, R., and Van Grieken, R. 2008. Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmospheric Environment* 42(13):2895–2921.

Singh, A., Sharma, R. K., Agrawal, M., and Marshall, F. M. 2010. Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 48: 611–619.

Tenebe, I. T., Emenike, C. P., and Chukwuka, C. D. 2019. Human and ecological risk assessment: An international prevalence of heavy metals and computation of its associated risk in surface water consumed in Ado. *Human and Ecological Risk Assessment* 25(4):882-904.

Tomlinson, D. L., Wilson, J. G., Harris, C. R., and Jeffrey, D. W. 1980. Problem in the assessment of heavy metals levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen* 33:566–575. Vol

USEPA. 1989. *Risk Assessment Guidance for Superfund. Human Health Evaluation Manual Part A, Interim Final*. Vol. I. EPA/540/1-89/002. Washington, DC.

USEPA. 1997. *Exposure Factors Handbook*. Washington DC: Office of Research and Development, National Center for Environmental Assessment.

USEPA. 2001. *Baseline Human Health Risk Assessment. Vasquez Boulevard and I-70 Superfund Site Denver*. Denver, CO.

Uzoekwe, S. A., and Oghosanine, F. A. 2011. The effect of refinery and petrochemical effluent on water quality of Ubeji creek Warri, Southern Nigeria. *Ethiopian Journal of Environmental Studies and Management* 4(2):106–118.

Wilcke, W., Müller, S., Kanchanakool, N., and Zech, W. 1998. Urban soil contamination in Bangkok: Heavy metal and aluminium partitioning in topsoils. *Geoderma* 86(3–4):211–228.

Zota, A. R., Schaider, L. A., Ettinger, A. S., Wright, R. O., Shine, J. P., and Spengler, J. D. 2011. Metal sources and exposures in the homes of young children living near a mining-impacted Superfund site. *Journal of Exposure Science & Environmental Epidemiology* 21(5):495–505.