

Impact of Abattoir Wastes on Trace Metal Accumulation, Speciation, and Human Health–Related Problems in Soils Within Southern Nigeria

Authors: Ebong, Godwin Asukwo, Ettesam, Ekomobong Samuel, and Dan, Emmanuel Udo

Source: Air, Soil and Water Research, 13(1)

Published By: SAGE Publishing

URL: <https://doi.org/10.1177/1178622119898430>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Impact of Abattoir Wastes on Trace Metal Accumulation, Speciation, and Human Health–Related Problems in Soils Within Southern Nigeria

Air, Soil and Water Research
Volume 13: 1–14
© The Author(s) 2020
DOI: 10.1177/1178622119898430



Godwin Asukwo Ebong^{1b}, Ekombong Samuel Ettesam and Emmanuel Udo Dan

Chemistry Department, University of Uyo, Uyo, Nigeria.

ABSTRACT: The slaughtering of animals and processing of meats for human consumption generates enormous wastes which are not properly managed in most developing nations including Nigeria. Majority of people in Akwa Ibom state in southern Nigeria depend on meat as their major source of protein, and abattoir wastes are applied in farms as organic manure by some farmers. This study examined the role of abattoir-related waste products in the physicochemical properties, total metal, and metal speciation of the soil. The data obtained were also subjected to some treatments using some environmental models to establish the degree of contamination by the parameters determined, studied locations, and the associated human health problems. Samples were collected from 5 designated abattoirs in Akwa Ibom state. Thirty composite samples were used for the research. Results obtained showed higher levels of pH, electrical conductivity, organic matter, and cation exchange capacity in the abattoir waste-impacted soils than in the control plot. Levels of pseudo total heavy metals were also higher in the studied soils than in the control plot. The mean values of the metals are below 400, 85, 140, 36, 100, and 35 mg/kg of recommended limits for Fe, Pb, Zn, Cu, Cr, and Ni, respectively by the Federal Environmental Protection Agency (FEPA) in Nigerian soil. The results also revealed that Fe and Cr existed mainly in residual fraction. However, Zn, Cu, and Ni existed principally in the form bound to organic matter/sulfide. In addition, we detected that Pb existed mainly in the reducible fraction. Disparities were also observed in the speciation results of the metals between the studied soils and the control plot. Principal component analysis (PCA) identified that both the geogenic and anthropogenic factors contributed to the accumulation of metals determined in the studied soils. Variable relationships were also observed for the heavy metals determined in the studied soils. Fe showed a high-risk potential, and children were more vulnerable due to its toxicity. We conclude this study was able to expose the consequences of indiscriminate dumping of abattoir wastes on the quality of soil and the associated human health problems.

KEYWORDS: Abattoir soil, metal speciation, multivariate analysis, modified Community Bureau of Reference sequential extraction, pollution index, noncancer risk, Nigeria

RECEIVED: November 17, 2019. **ACCEPTED:** December 2, 2019.

TYPE: Original Research

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Godwin Asukwo Ebong, Chemistry Department, University of Uyo, Uyo, Nigeria. Email: g_ebong@yahoo.com

Introduction

An abattoir is a place where the slaughtering of animals and processing of meat products for human consumption is performed.^{1,2} Activities in abattoir generally result in the generation of a high volume of wastes which are mostly managed improperly.³ In Africa, reports have shown that these wastes have a high potential of affecting the quality of receiving environment negatively.^{4–6} A research conducted by Opara et al⁷ revealed that between 1999 and 2002, a total of 151 303 animals were slaughtered in Akwa Ibom state. Nwanta et al⁸ reported the existence of about 30 abattoirs, 132 slaughter houses, and 1077 slaughter slabs in Nigeria with a total annual slaughter capacity of 14 127 868 animals.

A recent study by Dan et al⁹ identified 8 major abattoirs in Akwa Ibom state. Consequently, a large volume of waste products is expected to be generated in the study area. Several authors confirmed that abattoir wastes are able to reduce soil fertility; deplete biodiversity; affect human health; and pollute the air, water, and soil with toxic metals.^{10–12} In addition, other researchers have pointed out that animal feeds and other additives contain high levels of Cu, Fe, Zn, As, and Cr.^{13–15} Elemile et al¹⁶ reported that animal feeds, water, and

the environment affect the Ni and Pb loads in abattoir wastes. It has also been confirmed that organic wastes from abattoirs have the capacity to elevating the level of Fe, Pb, and Zn in the environment.^{17,18}

The blood, hair, and most organs of cattle have been found to contain toxic metals.¹⁹ Some authors confirmed that abattoir wastes have the possibility of modifying the physicochemical properties of soil considerably.^{20–23} Specifically, the most affected parameters commonly highlighted are the heavy metals.^{9,24,25} For instance, Yahaya et al²⁶ reported that the levels of trace metals in abattoir waste-impacted soils in Yauri, Nigeria, were higher than their acceptable limits stated by the Federal Environmental Protection Agency (FEPA).²⁷

However, wastes from abattoirs are disposed off indiscriminately, and some farmers use animal wastes as organic manure in their farms for the cultivation of edible plants. Hence, a high level of poisonous metal accumulation in the studied soils is expected, and the negative impact of abattoir wastes could be experienced in the area. The sequential extraction of metals (speciation) in soil is a necessary tool for identifying the bioavailability and toxicity of the metals. Speciation gives comprehensive data concerning the availability of trace metals in the



Creative Commons CC BY: This article is distributed under the terms of the Creative Commons Attribution 4.0 License (<https://creativecommons.org/licenses/by/4.0/>) which permits any use, reproduction and distribution of the work without further permission

provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).
Downloaded From: <https://bioone.org/journals/Air,-Soil-and-Water-Research> on 09 Oct 2024
Terms of Use: <https://bioone.org/terms-of-use>

environment under investigation.²⁸⁻³¹ Also, the applications of contamination indices for the evaluation of pollution status of abattoir waste-impacted soils has been reported by Marcus et al³² and Simeon and Friday.³³ Multivariate analysis has also been used for the assessment of trace metals in soils and their relationship with their source.³⁴⁻³⁷ The availability of trace metals in soil and human health-related problems are usually examined using health risk assessment models.³⁸⁻⁴⁰ However, previous studies on abattoirs in Akwa Ibom state did not assess the impact of abattoir wastes on the physicochemical properties of soil, metal speciation, the actual sources of trace metals, and human health-related problems.^{7,9,41}

Consequently, this research aims to fill the gap created by the previous studies by undertaking the following steps: (1) assessing the impact of abattoir wastes on the physicochemical properties of the studied soils, (2) confirming the impact on total metal loads and speciation, (3) applying multivariate analysis techniques on data obtained, and (4) analyzing the human health risks associated with the exposure to waste products from abattoirs. To achieve these goals, the total metal loads and physicochemical properties of the abattoir waste-impacted soils were evaluated and compared with their corresponding levels in the control plot. The modified Community Bureau of Reference (BCR) speciation method was employed for extraction of trace metals in both the studied soils and the control plot. The degrees of contamination, ecological and potential ecological risk indices (RIs) of trace metals in the studied abattoir soils were calculated. Moreover, multivariate analysis, daily intake (DI) rate, noncarcinogenic risk, and total chronic hazard index (THI) were computed for trace metals in the studied abattoir soils.

This investigation was conducted in the area because of the elevated population density, high number of abattoirs, and high volume of wastes generated. The area was also used for the study due to the lack of documented information on the influence of waste products from abattoir on the soil quality in the area. Thus, it is hoped that the outcome of this study will address the existing shortcomings on the environmental and human health problems related with abattoir wastes. The study will enhance the awareness on the consequences of improper management of abattoir wastes on soil quality and the attendants' human health problems.

Materials and Method

Study area

Akwa Ibom state covers a total land mass of 8412 km² of Nigeria with inhabitants more than 5 million in 2016.⁴² It is located in the coastal south-south part of the country, lying between latitudes (4°32'N and 5°33'N) and longitudes (7°25'E and 8°25'E). The state has both wet and dry seasons; the wet season lasts between 8 and 9 months.⁴³ The dry season starts in the last week of November or early December and ends in early

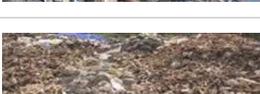
March. The state is located within the humid tropics; this attribute and its closeness to sea makes the state generally humid. On the basis of its geographical location, the climate of the state is a tropical rainy type which experiences abundant rainfall with very high temperature. The mean annual temperature of the state lies between 25°C and 29°C, while mean annual rainfall ranges from 2000 to 3000 mm. The highest humidity is observed in July; meanwhile, the minimum happens in January.⁴⁴ Annual evaporation ranges between 1500 and 1800 mm.⁴⁵ As an oil-producing state in Nigeria, the area is experiencing intensive oil-related activities. The climatic conditions in the state permits farming both at the subsistence and commercial levels. Based on the International Union of Soil Sciences World Reference Base (IUSS-WRB) Working Group⁴⁶ classifications of soil profile, the studied abattoir waste-impacted soils are in the Anthrosol (Hortic class). A study by Obasi et al⁴⁷ indicated that the animals supplying meat to the inhabitants of Akwa Ibom state for some years now are as follows: cattle, pig, goat, dog, chicken, and sheep. According to the United States Department of Agriculture⁴⁸ classifications of soil texture, the dominant soil texture in Akwa Ibom state is sandy loam. This study was undertaken in Akwa Ibom state because majority of the inhabitants depend on meat as a major source of protein; thus, a lot of animals have been slaughtered in abattoirs within the state. Consequently, a large volume of waste products has been generated and deposited indiscriminately in the area. Other author previously indicated that these wastes have the potential of elevating the metal load of the receiving environment.^{25,49}

The studied locations, their coordinates, and some images are shown in Table 1. Figure 1 shows the location of the studied abattoirs in Akwa Ibom state.

Sampling, pretreatment, and analysis

The top layer (0-15 cm) of the studied soils was selected, and samples were collected from 3 separate points and merged together to form a composite sample for the location.⁵⁰ At each location, 15 subsamples and 5 composite samples were obtained for this study. Samples were collected between December 2015 (dry season) and May 2016 (wet season) to cover the climate of the study area. Surface soil samples were collected within the same period from a garden in Uyo local government as well and used as control. A total of 90 subsamples and 30 composite samples were obtained for this study. Soil samples were air dried for 3 days, ground, and sieved using a 2-mm mesh. One gram of the sieved soil sample was mixed with aqua regia (HCl and HNO₃ in the ratio of 3:1) and digested on a hot plate. The levels of Fe, Pb, Zn, Cu, Cr, and Ni in filtrates obtained from the digestion process were analyzed using an Agilent 710 inductively coupled plasma optical emission spectrometer (ICP-OES). The instrument was standardized following the requirements by ISO 11466 and ISO/IEC 17025.⁵¹⁻⁵³

Table 1. Names, coordinates, and pictures of studied abattoir soils and control.

S. NO.	LOCATION	COORDINATE	
1	Ntak Inyang abattoir	Latitude 50°04'N-50°05'N and longitude 70°55'E-70°56'E	
2	Mbak Itam II abattoir	Latitude 50°02'N-50°03'N and longitude 70°53'E-70°54'E	
3	Abak abattoir	Latitude 40°58'N-40°59'N and longitude 70°46'E-70°47'E	
4	Uyo-Ikot Ekpene Road abattoir	Latitude 50°06'N-50°08'N and longitude 70°48'E-70°49'E	
5	Uyo-Village Road abattoir	Latitude 50°03'N-50°04'N and longitude 70°56'E-70°58'E	
6	Control	Latitude 50°05'N-50°06'N and longitude 70°54'E-70°55'E	

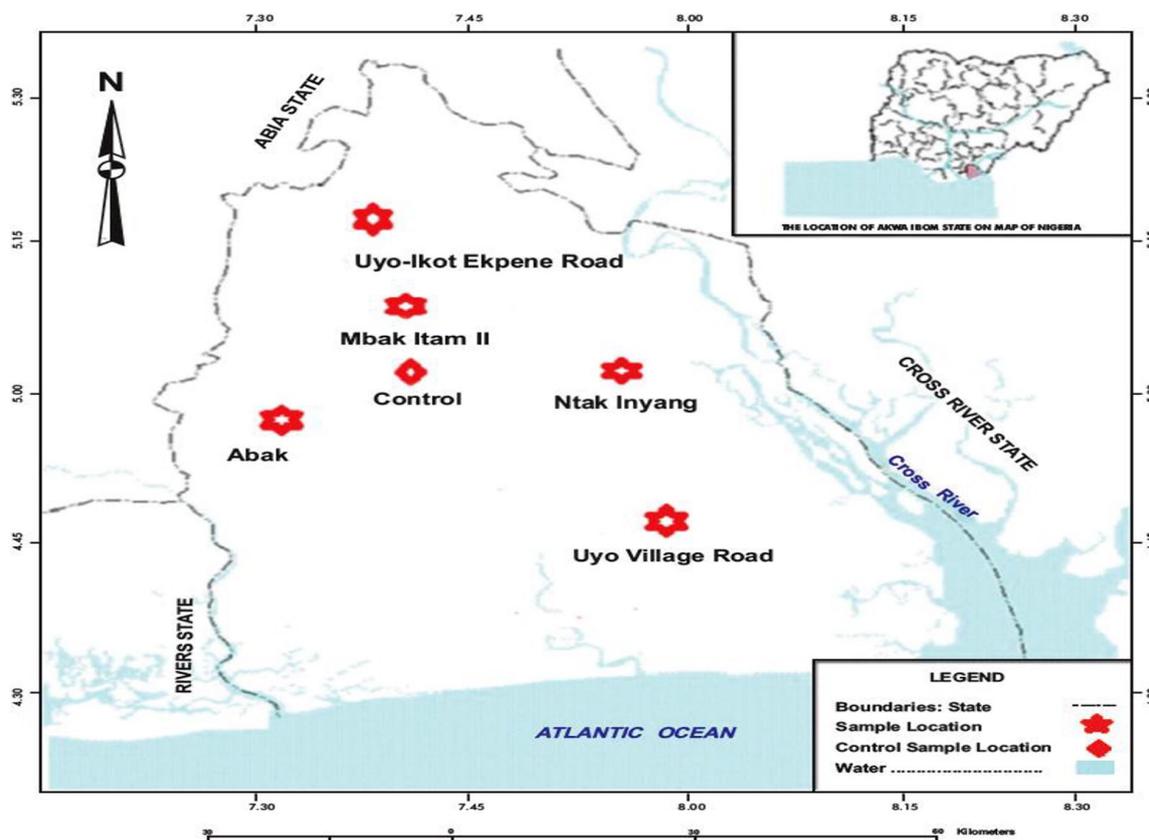


Figure 1. Map of Akwa Ibom state showing the studied abattoir soils and control plot.

Table 2. Summary of measured and certified reference trace metal concentrations in Montana soil 1 (SRM 2710a).

ELEMENT	CERTIFIED VALUE \pm SD ($\times 2$)	MEASURED MEAN VALUE \pm SD ($\times 2$)	RECOVERY (%)
Fe (%)	2.16 \pm 0.04	2.06 \pm 0.03	95
Pb (%)	0.276 \pm 0.0015	0.262 \pm 0.002	95
Zn (mg/kg)	2090.00 \pm 10.00	1973.00 \pm 8.25	94
Cu (mg/kg)	1710.00 \pm 25.00	1609.00 \pm 36.43	94
Cr	CVNA	CVNA	CVNA
Ni (mg/kg)	4.00 \pm 0.50	3.55 \pm 0.31	89

Source: Gaithersburg et al.⁶⁰

Abbreviations: CVNA, certified value not available.

Determination of physicochemical properties of soils

pH of studied abattoir soils and control was determined in a 1:2.5 (v/v) soil/water suspension as described by Van-Reeuwijk.⁵⁴ Organic matter (OM) content was determined by wet oxidation methods of Walkley and Black.⁵⁵ Electrical conductivity of the soil samples was determined by the photometric methods described by Rhoades et al.⁵⁶ The cation exchange capacity (CEC) of the studied soils was analyzed using photometric methods by ISO 11260.⁵⁷

Procedures for optimized BCR speciation method of trace metals. The optimized BCR sequential extraction procedures of metals as described by Rauret et al.⁵⁸ were used for the separation of trace metals into the following fractions: (1) acid extractable (2) reducible (3) oxidizable, and (4) residual. Metal fractions in the filtrates obtained were determined using the Agilent 710 ICP-OES.

Percentage recovery. Percentage recovery for trace metal was computed with equation (1) according to Uduma and Jimoh⁵⁹

$$\% \text{ Recovery} = \frac{\sum n \text{ Sequential Extraction Procedure}}{\text{Single Digestion with Strong Acids}} \times 100 \quad (1)$$

In the equation, n denotes the concentration of a particular metal and the single digestion with strong acids represents the total concentration of a particular metal obtained.

Validation of techniques and results

Montana 1 (SRM 2710a) as a standard reference soil was used for the authentication of analytical techniques and results obtained. The standard reference material was digested using similar procedures applied for the studied abattoir soils. The levels of Fe, Pb, Zn, Cu, Cr, and Ni were obtained in the filtrate using Agilent 710 inductively coupled optical emission spectrometer. The results are presented in Table 2 and are consistent with those in the certified results.

Table 3. Mean physicochemical properties of the studied abattoir soils and control.

LOCATION	pH	EC (MSM)	OM (%)	CEC (CMOL/KG)
Abak	6.41	37.32	6.29	27.42
Mbak II	6.28	30.90	7.50	26.25
Ntak Inyang	6.11	48.42	6.80	27.59
Uyo Village	6.69	70.38	12.41	34.46
Uyo-IK	5.74	46.04	8.43	30.13
Min	5.74	30.90	6.29	26.25
Max	6.69	70.38	12.41	34.46
Mean	6.25	46.61	8.29	29.17
SD	0.35	15.01	2.44	3.28
Control	4.77	23.43	4.94	23.67

Abbreviations: CEC, cation exchange capacity; EC, electrical conductivity; OM, organic matter.

Category of pollution of trace metals

These parameters were used to ascertain the actual source, their extent of contamination/pollution, and the pollution status of the studied locations. These pollution indices were also exploited to evaluate the contributions of both natural and anthropogenic factors on the accumulation of trace metals in the studied soils.

Contamination factor of trace metals. Contamination factor (CF) of the trace metals in studied abattoir soils was determined using equation (2) in line with Hakanson⁶¹ and Pekey et al.⁶²

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

where CF is the contamination factor, C_m is the concentration of the metal in the studied sample, and B_m is the background value which is the average crust value of the metals shown in Table 3. The different classes of CF are shown in Table 4 below.

Degree of contamination. Degree of contamination (C_{deg}) denotes the summation of all the CFs of trace metals for a particular abattoir soil and was determined using equation (3) as reported by Hakanson⁶¹ and Mmolawa et al.⁶⁴

$$C_{deg} = \sum \left(\frac{C_m}{B_m} \right) \quad (3)$$

where C_m represents the level of the metal in the studied sample and B_m is the background concentration of the metal obtained in the study (control); the different classes of C_{deg} are shown in Table 4.

Ecological risk factor (E_r^i) of trace metals. The ecological risk factor of trace metals determined was determined using equation (4) according to Hakanson⁶¹

Table 4. Different categories of CF, C_{deg} , E_r^i , and RI as proposed by Hakanson⁶¹ and Yang et al.⁶³.

	CF	C_{deg}	E_r^i	RI
A	$CF < 1$ = low contamination	$C_{deg} < 8$ = low degree of contamination	$E_r < 40$ = low ecological risk	$RI < 150$ = low ecological risk
B	$1 \leq CF \leq 3$ = fair contamination	$8 < C_{deg} < 16$ = moderate degree of contamination	$40 < E_r \leq 80$ = moderate ecological risk	$150 < RI < 300$ = modest ecological risk
C	$3 \leq CF \leq 6$ = considerable contamination	$16 < C_{deg} < 32$ = considerable degree of contamination	$80 < E_r \leq 160$ = appreciable ecological risk	$300 < RI < 600$ = high ecological risk
D	$CF > 6$ = very high contamination	$32 < C_{deg}$ = very high degree of contamination	$160 < E_r \leq 320$ = high ecological risk	Significantly high risk
E			$E_r > 320$ = severe ecological risk	

Abbreviations: C_{deg} , degree of contamination; CF, contamination factor; E_r^i , ecological risk factor; RI, potential ecological risk index.

$$E_r^i = Tr \times CF \quad (4)$$

T_r is the toxic-response factor for metal and CF is the contamination factor. Toxic-response factors of metals determined are Pb (5.00), Cd (30.00), Ni (5.00), Fe (0.00), Zn (1.00), and Cu (5.00). The different classes of ecological risk factor are shown in Table 4.

Potential ecological risk index. The RI of the different abattoir soils studied was determined using equation (5) as reported by Cao et al⁶⁵ and Yang et al⁶³

$$RI = \sum E_r^i \quad (5)$$

where $\sum E_r^i$ indicates the summation of trace metals determined in dumpsite soils studied. Classifications of ecological risk and RIs are indicated in Table 4.

Anthropogenic fraction

The anthropogenic fraction which indicates the proportion of each metal contributed to the studied soils by human activities was determined using equation (6) by following the methods of Ghaderi et al⁶⁶

$$AF = \frac{F1 + F2 + F3}{TM} \times 100 \quad (6)$$

where AF is the anthropogenic portion, F1 represents the acid extractable, F2 means the reducible fraction, F3 is the oxidizable proportion, and TM means the total metal.

Lithogenic fraction. The lithogenic fraction of trace metal signifies the level of each metal contributed by the natural soil-forming process in studied soils was evaluated using equation (7) according to Ghaderi et al⁶⁶

$$LF = 100 - AF \quad (7)$$

where LF is the lithogenic fraction and AF is the anthropogenic fraction

Health risk assessment

The following health risk assessment parameters were determined: DI rate, noncarcinogenic risk, and a THI.^{67,68}

Daily intake of trace metals. The risk associated with human exposure to these metals in studied abattoir soils was examined to evaluate the noncancer toxicity on human beings within the study area. Daily intake was computed using the United States Environmental Protection Agency (USEPA)⁶⁹ and the National Environmental Protection Agency of China (NEPAC; 2013). The DI of soil ingested was validated using equation (8)

$$DI = C \times \text{IngR} \times \text{EF} \times \text{ED} \times \text{BW} \times \text{AT} \quad (8)$$

where C is the mean metal concentration, IngR means the ingestion rate (IR), EF denotes the exposure frequency per day per year, ED is the exposure period in a year, BW represents the body weight in kilograms, and AT signifies the average time for noncarcinogens.^{69,70} Numerical values for parameters used for the computation of DI are indicated below.

Non carcinogenic risk (hazard quotient). A noncarcinogenic risk for individual metal expressed as hazard quotient (HQ) was evaluated using equation (10)

$$HQ = \frac{DI}{Rfd} \quad (9)$$

where HQ represents the noncancer hazard quotient and Rfd denotes the chronic reference dose of trace metal. The Rfd mg/kg day for metals determined are Fe (0.07), Pb (0.0035), Zn (0.04), Cu (0.04), Cr (0.001), and Ni (0.02).⁶¹

Total chronic hazard index of trace metals. Total chronic hazard index which is the sum of all the individual HQs was determined using equation (10)

$$THI = \sum HQ = HQFe + HQPb + HQZn + HQCu + HQCr + HQNi \quad (10)$$

The risk evaluation of parameters and values applied are ingestion rate (IR) (100 and 50 mg/d for children and adults, respectively^{bc}; exposure rate (d/y) (350 d/y^c); exposure duration (y) (6 years—child^b, 30 years—adult^b); average duration for noncarcinogens (d/y) (365 d/y^d); and body weight (kg) (15 kg—child^{ad}, 70 kg—adult^d). a, USEPA⁶⁹; b, Grzetic and Ghariani⁷⁰; c, Wang et al⁷¹; d, USEPA⁶⁷; and e, USEPA.⁶⁹

Statistical analysis

Statistical analysis of data obtained in this research was performed using IBM SPSS Statistics 20 (IBM USA). The multivariate analyses, namely, Pearson correlation analysis, factor analysis, and cluster analysis, were performed with Duncan's multiple range tests at 1% level of probability. Correlation analysis was performed for 10 factors, and the statistical significance was tested at 95% confidence limit. The factor analysis was performed on 10 parameters using the varimax rotation method, and values from 0.560 and above were considered significant. Cluster analysis was done using dendrograms to identify homogeneous groups of variables with common properties.

Results and Discussion

Analysis of physicochemical properties

The results for physicochemical properties of studied abattoir soils and control are presented in Table 3. pH of the studied abattoir soils varied between 5.74 and 6.69 with a mean of 6.25 ± 0.25 . This pH range is lower than 6.22 to 7.44 reported by Chukwu and Anuchi,⁴⁹ consistent with 4.99 to 6.73 obtained by Ubwa et al²⁴ in abattoir soils. The mean pH value obtained in studied soils is above 4.77 reported in the control. Thus, the waste products generated within these abattoirs may have affected the pH of the studied abattoir soils, thereby making the pH of the soils more alkaline than the control. This could be the impact of higher OM and CEC of soils.^{72,73}

The electrical conductivity (EC) of the soils varied from 30.90 to 70.38 $\mu\text{S}/\text{cm}$ with a mean value of 46.61 ± 15.01 (Table 3). This EC range is higher than 2.03 to 2.54 $\mu\text{S}/\text{cm}$ obtained by Akan et al⁷⁴ but lower than 60.00 to 110.00 $\mu\text{S}/\text{cm}$ reported by Chukwu and Anuchi⁴⁹ in abattoir soils. The results obtained also revealed that EC values obtained in the studied abattoir soils were higher than values in the control site. This is consistent with the results reported for EC in abattoir waste-impacted soils by Onweremadu.⁷⁵ This could be attributed to the low CEC of the control soil and variations in the rate at which OM complexes are formed.^{76,77} Hence, the waste products generated in the abattoirs may have influenced the EC of the studied abattoir soils significantly.

Organic matter is an important soil property that may influence metal availability, cation exchange, and complex formation.^{78,79} The OM content of the studied abattoir soils varied between 6.3% and 12.4% with a mean value of $8.3 \pm 2.44\%$. The OM range obtained is higher than 0.7% to 7.4% by Yahaya

et al²⁶ but lower than 5.6% to 24.1% obtained by Ubwa et al²⁴ in abattoir soils. Generally, OM values of studied abattoir soils were higher than values at the control. This is consistent with the result of OM content between the studied abattoir soils and control obtained by Ojo et al.⁸⁰ This could be due to the low volume of biodegradable wastes at the control site. Hence, the high amounts of biodegradable wastes in the abattoir soils may have affected the organic content of the studied soils considerably.

Cation exchange capacity of the soil has a considerable impact on the accumulation of total metal in soil.⁸¹ The CEC of studied soils ranged from 26.25 to 34.46 cmol/kg with a mean of 29.17 ± 3.28 cmol/kg (Table 3). The CEC range reported is higher than 12.54 to 16.84 cmol/kg obtained by Neboh et al⁶ in abattoir soils. The mean value of CEC obtained in the studied abattoir soils is more than 23.67 cmol/kg reported in control site. This is similar to the findings by Iwegbue et al⁸² in abattoir waste-impacted soils. This may be attributed to the high organic content of the studied abattoir soils. Thus, this study has shown that abattoir wastes have the potential of influencing the CEC of soil considerably.

Distribution of trace metals

The concentrations of trace metals determined in the studied abattoir soils and control are shown in Table 5.

Total Fe ranged from 623.88 to 887.80 mg/kg with a mean value of 728.01 ± 92.65 mg/kg. This range is below 2569.00 to 4130.00 mg/kg obtained by Yahaya et al²⁶ but higher than 59.36 to 81.70 mg/kg obtained by Simeon and Friday³³ in the studied soils. Pb varied between 0.55 and 0.99 mg/kg with a mean value of 0.74 ± 0.20 mg/kg. This is lower than 7.17 to 12.50 mg/kg reported by Chukwu and Anuchi⁴⁹ but higher than 0.18 to 0.83 mg/kg obtained by Ubwa et al²⁴ in abattoir waste-impacted soils. The range and mean value for total Zn is 14.92 to 24.86 mg/kg and 20.61 ± 4.56 mg/kg, respectively. The range of Zn obtained is higher than 1.302 to 5.236 mg/kg reported by Ubwa et al²⁴ but lower than 50.91 to 92.50 mg/kg obtained by Yahaya et al.²⁶ The level of total Cu in studied soils ranged between 15.66 and 19.34 mg/kg with a mean of 17.49 ± 1.40 mg/kg. The range is higher than 0.05 to 1.70 mg/kg reported by Osu and Okereke²⁵ but lower than 36.46 to 40.60 mg/kg obtained by Ojo et al.⁸⁰ The range and mean concentration of total Cr are 15.66 to 19.34 mg/kg and 17.49 ± 1.40 mg/kg, respectively. This range is lower than 4.25 to 5.86 mg/kg reported by Chukwu and Anuchi⁴⁹ but higher than 0.072 to 0.136 mg/kg obtained by Ubwa et al.²⁴ Concentrations of total Ni ranged from 8.80 to 10.39 mg/kg with a mean of 9.59 ± 0.58 mg/kg. Generally, the mean values of all the metals were higher in the studied soils than in the control plot. This could be attributed to the elevated OM and the metals being components of animal feeds.⁸³⁻⁸⁶ Higher levels of these metals have also been confirmed in animal wastes.^{87,88} Hence, this study has revealed that abattoir wastes have the potential of elevating the concentrations of metals in the environment.

Table 5. Mean (mg/kg) of total metals in the studied soils and control plot.

LOCATION	Fe	Pb	Zn	Cu	Cr	Ni
Abak	719.55	0.55	22.70	19.34	0.27	10.39
Mbak II	623.88	0.63	14.92	16.77	0.16	9.37
Ntak Inyang	697.38	0.60	16.53	15.66	0.17	8.80
Uyo Vil	877.80	0.99	24.04	18.20	0.24	9.68
Uyo-IK	721.44	0.93	24.86	17.47	0.20	9.71
Min	623.88	0.55	14.92	15.66	0.16	8.80
Max	887.80	0.99	24.86	19.34	0.27	10.39
Mean	728.01	0.74	20.61	17.49	0.21	9.59
SD	92.65	0.20	4.56	1.40	0.05	0.58
Control	376.73	0.21	7.53	9.15	0.11	5.64
RL	400.00	85.00	140.00	36.00	100.00	35.00
ACV	46000	20	95	45	90	68

Abbreviations: ACV, average crustal values by Turekian and Wedepohl (1961); Max, maximum; Min, minimum; RL, recommended limits by FEPA²⁷.

The mean values of all the metals determined were lower than their recommended limits by FEPA²⁷ for Nigerian soil except Fe. Consequently, Fe could be considered as a pollutant in the studied soils; however, as an important element for both plants and animals including humans, the effect may not be alarming.⁸⁹ Total metals in the studied soils fluctuated from one location to the other, and this could be attributed to the discrepancy in the activities, size, and age of these abattoirs. Total metals in the studied abattoir soils is in the order Fe > Zn > Cu > Ni > Pb > Cr. This is an indication that the studied soils accumulated more of the essential elements than the toxic ones. This may be attributed to the wastes generated from these abattoirs as their feeds have high level of these essential elements.⁹⁰

Sequential extraction of metals, anthropogenic, and lithogenic fractions of metals

The results of sequential extraction of trace metals in the studied abattoir soils and control are shown in Table 6. The results revealed that Fe existed mostly in the residual (inert) fraction both in the studied soils and control. This is in agreement with the findings by Fagbote and Olanipekun⁹¹ and Osakwe.⁹² The residual fraction contributed 34.8% and 58.9% of the several fractions in abattoir soils and control, respectively. The proportions of other fractions of Fe are indicated in Table 6. The high proportion of Fe in the residual fraction is an indication of its low bioavailability. As indicated in Table 6, the human factor (anthropogenic) contributed 61.5% of Fe in the studied soils, while the natural influence supplied 38.8%. However, 61.2% of Fe was contributed by the natural source in the control soil, while anthropogenic factor contributed 38.6%.

Accordingly, wastes from abattoirs might have added significant amounts of Fe to the underlying soil as reported by Osu and Okereke.²⁵ The proportion of the different fractions of Fe in both the studied soils and control followed the order RES > RED > OX > AEX.

Pb existed primarily in reducible fraction in studied soils and control. This is consistent with the findings by Ajiboso et al⁹³ and Umoren et al.⁹⁴ The reducible fraction contributed 39.7% and 35.3% of the total fractions in the studied soils and control, respectively. The proportions of acid extractable, reducible, and oxidizable fractions are shown in Table 6. Reports have shown that the existence of metal in residual fraction symbolizes anthropogenic addition of the element to the studied environment.^{95,96} This is confirmed by the high 79.3% and 61.9% anthropogenic factors of Pb in the studied soils and control site, respectively. The high anthropogenic factor reported is consistent with findings by Ghaderi et al⁶⁶ in a contaminated environment. The reported high anthropogenic factor of Pb in the control site could be attributed to atmospheric deposition.^{97,98} The proportion of the fractions of Pb in the studied soils and control followed the order RED > AEX > OX > RES and RED > AEX = RES > OX, respectively.

Zn existed mainly in the oxidizable fraction in the studied soils; this is similar to the reports by Ajiboso et al⁹³ and Olubunmi and Olorunsola.⁹⁹ Thus, Zn might not be available for plants as it is strongly adsorbed to the OM.^{100,101} However, at the control site, the residual fraction contributed 57.2% of the total fractions. This reveals the negative impact of high organic abattoir wastes on the bioavailability of Zn in soil. The anthropogenic factor contributed 76.7% of Zn in the studied soils and 36.7% in the control. However, the natural factor contributed a low 23.3% of Zn in the studied soils, whereas a high

Table 6. Mean speciation (mg/kg), percentage composition, % recovery, anthropogenic fraction, and lithogenic fraction of trace metals in the studied abattoir soils.

	AEX (%)	RED (%)	OX (%)	RES (%)	TF	TM	%REC	AF	LF
Abattoirs									
Fe	123.34 (18.0)	180.29 (26.3)	144.28 (21.0)	238.99 (34.8)	686.90	728.01	94	61.5	38.5
Pb	0.18 (26.5)	0.27 (39.7)	0.14 (20.6)	0.09 (13.2)	0.68	0.74	92	79.7	20.3
Zn	3.61 (19.0)	4.75 (25.0)	7.45 (39.1)	3.23 (17.0)	19.04	20.61	92	76.7	23.3
Cu	2.81 (17.2)	4.01 (24.5)	6.47 (39.6)	3.06 (18.7)	16.35	17.49	94	76.0	24.0
Cr	0.03 (15.8)	0.04 (21.1)	0.05 (26.3)	0.07 (36.8)	0.19	0.21	91	57.1	42.9
Ni	1.84 (20.4)	2.45 (27.2)	3.20 (35.5)	1.52 (16.9)	9.01	9.59	91	78.1	21.9
Control									
Fe	38.25 (10.8)	62.41 (17.6)	45.41 (12.8)	209.42 (58.9)	355.49	376.73	94	38.8	61.2
Pb	0.04 (23.5)	0.06 (35.3)	0.03 (17.7)	0.04 (23.5)	0.17	0.21	81	61.9	38.1
Zn	0.90 (14.0)	1.36 (21.1)	0.50 (7.8)	3.69 (57.2)	6.45	7.53	86	36.7	63.3
Cu	1.27 (15.0)	1.20 (14.2)	1.37 (16.2)	4.64 (54.7)	8.48	9.15	93	42.0	58.0
Cr	0.01 (10.0)	0.01 (10.0)	0.02 (20.0)	0.06 (60.0)	0.10	0.11	91	36.4	63.6
Ni	0.59 (11.8)	1.07 (21.4)	0.46 (9.2)	2.87 (57.5)	4.99	5.64	89	37.6	62.4

Abbreviations: %REC, percent recovery; AEX, acid extractable; AF, anthropogenic fraction; LF, lithogenic fraction; OX, oxidizable; RED, reducible; RES, residual; TF, total fractions; TM, total metal.

63.3% of Zn at the control site was contributed by the natural factor. The trends for the several fractions of Zn in the studied soils and control site are $OX > RED > AEX > RES$ and $RES \gg RED > AEX > OX$, respectively.

Cu also existed principally in the oxidizable fraction which is in agreement with the results by Svendsen et al.¹⁰² and Ebong et al.¹⁰³ This could be the consequence of the high tendency of OM in forming stable complexes with organic substances in soil.^{104,105} Nevertheless, Cu existed mostly in the residual fraction in the control site. The oxidizable fraction contributed 39.6% of Cu in the studied soils, while the other fractions contributed a total of 60.4%. However, the residual fraction contributed 54.7% of the total fractions in the control site, while the acid extractable, reducible, and oxidizable fractions contributed 45.3%. The anthropogenic factor contributed 76% of Cu in the studied soils, while the natural factor supplied 24%. However, the anthropogenic influence added 42% of Cu in the control site, while lithogenic factor contributed 58%. The proportion of Cu in the different fractions in the studied soils and control varied as follows: $OX > RED > RES > AEX$ and $RES > OX > AEX > RED$, respectively.

Cr occurred largely in the inert (residual) fraction in the studied abattoir soils and control (Table 6). This is in agreement with the reports by the literature.^{71,106,107} Consequently, a greater portion of the metal is bound to clay minerals and is unavailable for plant uptake in the study area.¹⁰⁸ The residual fraction contributed 36.8% and 60.0% of the total fraction of

Cr in the studied abattoir soils and control, respectively. The other fractions contributed 63.2% and 40% of the fraction of Cr in the studied soils and control, respectively. The anthropogenic factor contributed 57.1% and 36.4% of Cr in the studied soils and control, while the natural factor added 42.9% and 63.6% to the studied soils and control, respectively. The trend of Cr in the different fractions in the studied soils is $RES > OX > RED > AEX$ but $RES < OX < RED = AEX$ in the control site.

The results of speciation studies revealed that Ni occurred mainly in the oxidizable fraction in the studied soils. This is in agreement with the report by Łukowski¹⁰⁹ and Osakwe.¹¹⁰ However, most of Ni in the control site was in the residual fraction; hence, the proportion of acid extractable fraction was relatively lower than in the studied soils (Table 6). The results indicated that 78.1% and 37.6% of Ni was contributed by the anthropogenic factor in the studied soils and control. Nevertheless, 21.9% and 62.4% of Ni in the studied soils and control originated from the natural forming processes, respectively. The variations of Ni in the different fractions in the studied soils followed the order $OX > RED > AEX > RES$. But a different trend was observed for the different fractions in the control site as follows: $RES \gg RED > AEX > OX$.

Generally, the results in Table 6 indicate very high values for the percentage recovery of metals determined. This is an indication of a high level of accuracy in analytical techniques and reliability of results obtained. The result has also shown that

Table 7. Results for metal contamination and ecological risk indices in soils.

INDICES						
	Fe	Pb	Zn	Cu	Cr	Ni
CF	1.66-2.33	2.62-4.71	1.98-3.30	1.71-2.11	1.46-2.46	1.56-1.84
E_r^i	–	13.19-23.55	1.98-3.30	8.55-10.55	2.92-4.92	7.80-9.20
C_{deg}	11.59-16.12					
RI	35.95-49.65					

Abbreviations: C_{deg} , degree of contamination; CF, contamination factor; E_r^i , ecological risk factor; RI, potential ecological risk index.

waste products from abattoirs could affect the availability and toxicity of metals in soil. Hence, the indiscriminate dumping of abattoir wastes in the environment should be discouraged to avoid the attendants' consequences along the food chain.

Pollution status of trace metals and the studied abattoir soils

The average crustal values of these elements in Table 3 were used as the background levels for the metals. The results of the CF of metals in the studied soils are shown in Table 7. The CF values of Fe ranged from 1.66 to 2.33; thus, it belongs to the moderate contamination class. The CF of Pb varied between the moderate and considerable contamination classes with a CF range of 2.62 to 4.71. The CF for Zn also varied between the moderate and considerable contamination classes. However; the CF for Cu, Cr, and Ni varied as follows: 1.71 to 2.11, 1.46 to 2.46, and 1.56 to 1.84, respectively. Consequently, Cu, Cr, and Ni belong to the moderate contamination class.

The degree of contamination of studied abattoir soils ranged from 11.59 in Mbak II to 16.12 at Uyo Village Road. The degree of contamination of all the abattoir soils studied except Uyo Village Road belongs to the moderate degree of contamination class. However, the C_{deg} for Uyo Village Road with a value of 16.12 belongs to the considerable degree of contamination class.⁶¹

The ecological risk factor (E_r^i) for metals determined in soils are indicated in Table 7. Fe as an essential element for all biological systems has not been assigned a toxic-response factor; hence, no ecological risk factor has been assigned to the element. The ecological risk factor for Pb varied from 13.19 to 23.55, thus belongs to the low ecological risk class as indicated in Table 4.⁶³ The ecological risk factor for Zn, Cu, Cr, and Ni ranged as follows: 1.98 to 3.30, 8.55 to 10.55, 2.92 to 4.92, and 7.80 to 9.20, respectively. Consequently, they belong to the low-risk class.⁶³ Nevertheless, the accumulation of these metals in the studied abattoir soils should be monitored due to the toxic and relentless nature of metals.

The results of the RI used to assess the possible risk associated with metals determined in the studied abattoir soils are shown in Table 7.¹¹¹ Table 7 indicates that RI varies from 35.95

in Ntak Inyang to 49.65 in Uyo Village. Consequently, the RIs of the studied abattoir soils were in the low ecological risk class according to Yang et al.⁶³ Generally, the results obtained for the ecological risk index have shown that the level of metals determined has not reached their nuisance level. However, with the incessant dumping of abattoir wastes, serious health problems may be experienced in the studied locations. Hence, proper waste management methods should be adopted by the authority concern.

Multivariate analysis of trace metals

Pearson correlation analysis, principal component analysis (PCA), and hierarchical cluster analysis were employed for the identification of relationships among parameters determined and the factors responsible for their presence in studied abattoir soils.

The interrelationship among trace metals and other properties in the studied abattoir soils was evaluated with correlation analysis. Table 8 indicates that Fe correlated positively and significantly with Pb, EC, OM, and CEC at 99% confidence limit, but with Zn at $P < .02$. Fe also exhibited a positive relationship with Cr but at $P < .05$. Fe correlated positively but insignificantly with Cu, Ni, and pH at $P < .05$. Pb correlated positively and significantly with EC, OM, and CEC at $P < .01$, but with Zn at 95% confidence limit. Pb showed a very weak positive relationship with Cu, Cr, and Ni but a weak negative one with pH at $P < .05$. Zn correlated positively and significantly with Cr at 99% confidence limit but with Cu, Ni, and CEC at 98% confidence limit. Zn also correlated positively and significantly with Ni but at $P < .05$. Zn showed a positive but insignificant associated with pH, EC, and OM at 95% confidence limit. Cu correlated positively and significantly with Cr and Ni at $P < .01$ but a weak positive relationship with pH, EC, OM, and CEC at $P < .05$. Cr correlated positively and significantly with Ni at $P < .01$ but insignificantly with pH, EC, OM, and CEC at 95% confidence limit. Ni showed a positive but insignificant relationship with pH, OM, and CEC but a weak negative correlation with EC at $P < .05$. This shows the common properties and source among the parameters with significant positive relationships.^{112,113}

Table 8. Correlation matrix between metals and physicochemical properties of the studied abattoir soils.

	Fe	Pb	Zn	Cu	Cr	Ni	pH	EC	OM	CEC
Correlation	Fe	1.000								
	Pb	0.708*	1.000							
	Zn	0.701**	0.662**	1.000						
	Cu	0.429	NC	0.698**	1.000					
	Cr	0.607***	NC	0.745*	0.929*	1.000				
	Ni	NC	NC	0.661**	0.975*	0.856*	1.000			
	pH	NC	NC	NC	NC	NC	1.000			
	EC	0.939*	0.741*	NC	NC	NC	NC	1.000		
	OM	0.841*	0.870*	NC	NC	NC	NC	0.860*	1.000	
	CEC	0.949*	0.890*	0.696**	NC	NC	NC	0.937*	0.940*	1.000

Abbreviations: CEC, cation exchange capacity; EC, electrical conductivity; OM, organic matter; NC, not correlated.

*Significant at the 0.01 level.

**Correlation is significant at the 0.02 level.

***Correlation is significant at the 0.05 level (2 tailed).

Table 9. Total variance explained for parameters determined in the studied soils.

COMPONENT	INITIAL EIGEN VALUES			EXTRACTION SUMS OF SQUARED LOADINGS			ROTATION SUMS OF SQUARED LOADINGS		
	TOTAL	% OF VARIANCE	CUMULATIVE %	TOTAL	% OF VARIANCE	CUMULATIVE %	TOTAL	% OF VARIANCE	CUMULATIVE %
1	5.75	57.5	57.5	5.75	57.5	57.5	4.79	47.9	47.9
2	2.71	27.1	84.5	2.71	27.1	84.5	3.49	34.9	82.8
3	1.19	11.9	96.4	1.19	11.9	96.4	1.37	13.7	96.4

Principal component analysis was used to identify the actual sources of parameters determined in the studied abattoir soils according to Wu and Kuo.¹¹⁴ Table 9 shows 3 key factors with eigen values greater than 1 with a 96.4% of the total variance. Factor one (F1) contributed 57.5% of the total variance with strong positive loadings on Fe, CEC, OM, Zn, EC, Pb, Cr, and Cu (Table 10). This signifies the negative impact of the natural and anthropogenic factors on the soil quality.¹¹⁵ The second factor (F2) contributed 27.1% of the total variance with significant positive loadings on Cr, Ni, and Cu (Table 10). This signifies explicitly the anthropogenic impact of abattoir wastes on the studied soils.¹¹⁶ The third factor (F3) contributed 11.9% of the overall variance with a strong positive loading on soil pH only (Table 10). This signifies the negative impact of organic substances from abattoirs on the soil environment.¹¹⁷

The pair-wise relationships among parameters determined in the studied abattoir soils are illustrated in Figure 2. Figure 2 indicates 2 main clusters as follows: the one linking Pb, Cr, Ni, Zn, and Cu together and the second one that links Fe alone. Consequently, the presence of abattoir wastes might have

Table 10. Total variance explained.

	COMPONENT		
	1	2	3
Fe	0.957	-0.177	0.132
CEC	0.934	-0.355	-0.043
OM	0.832	-0.467	0.112
Zn	0.825	0.268	-0.483
EC	0.823	-0.494	0.124
Pb	0.758	-0.459	-0.392
Cr	0.704	0.671	0.086
Ni	0.470	0.855	-0.135
Cu	0.616	0.778	0.007
pH	0.485	0.145	0.854

Abbreviations: CEC, cation exchange capacity; Cr, chromium; Cu, copper; EC, electrical conductivity; Fe, iron; Ni, nickel; OM, organic matter; Pb, lead; Zn, zinc. The extraction method is the principal component analysis.

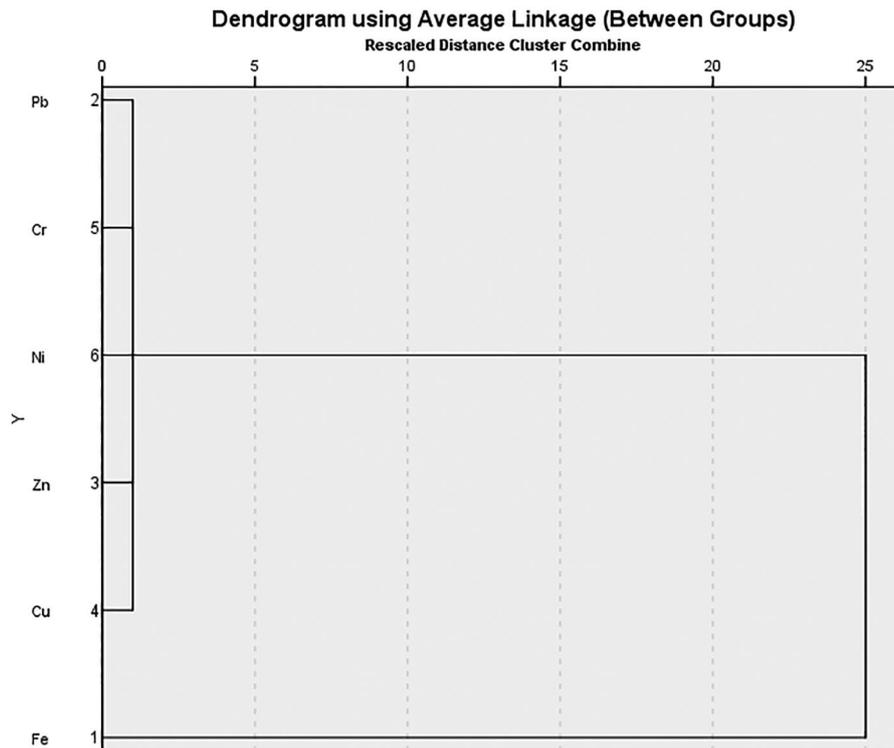


Figure 2. Hierarchical clusters with the trace metals determined in the studied abattoir soils.

impacted significantly on Pb, Cr, Ni, Zn, and Cu concentrations in the studied soils. However, substantial amounts of Fe in the studied soils might have been contributed from a source different from the other metals.

Human health risk appraisal

The effect of metal toxicity on human could be explained by assessing the DI rate of metals in waste-impacted soil. Daily intake rate, HQ, and THI of each metal are presented in Table 11. The results obtained revealed that the DI rate for all the metals in the studied soils was below their recommended oral RfDs by the USEPA.¹¹⁸ The general trend for the DI rate of these metals is Fe > Zn > Cu > Ni > Pb > Cr. Fe recorded the highest DI rate for both the children and adults, whereas the lowest rate was recorded by Cr. This is consistent with the report by Ebong et al¹⁰³ for Fe in Lemna dumpsite soil. The high DI recorded by Fe may not be harmful because the metal is vital for life, but its availability should be monitored to avoid toxicity along food chain.^{119,120} Although Cr, Pb, and Ni show low DI rates, it should not be neglected because they are highly hazardous even at a very low concentration and are capable of being transferred into edible plants or leached into groundwater.

The results for HQ for the metals determined in the studied abattoir soils are shown in Table 10. The HQ for each of the metal is less than 1; thus, these metals may not be hazardous to both the children and adults. The HQ values for trace metals in children is in the order Fe > Cu > Ni > Pb > Zn > Cr, while

Table 11. Results ($\times 1/10^2$) for noncarcinogenic risk for each trace metal and exposure pathway.

Metal	DI		HQ	
	CHILD	ADULTS	CHILD	ADULTS
Fe	5.587	2.992	79.806	42.743
Pb	0.006	0.003	1.717	0.854
Zn	0.157	0.085	0.521	0.283
Cu	0.133	0.072	3.326	1.802
Cr	0.002	0.001	0.501	0.332
Ni	0.074	0.040	2.476	1.977
THI			88.347	47.991

Abbreviations: DI, daily intake; HQ, hazard quotient; THI, total chronic hazard index.

for the adults is in the order Fe > Ni > Cu > Pb > Cr > Zn. Accordingly, Fe recorded the highest HQ value for both the children and adults. The lowest HQ values for the children and adults were recorded by Cr and Zn, respectively. Consequently, the potential risk of Fe toxicity is high in both the children and adults, but children were more vulnerable than the adults. Although the THI value is less than 1, there is a tendency of these people being exposed to noncarcinogenic health problems which are directly proportional to the THI value.¹²¹

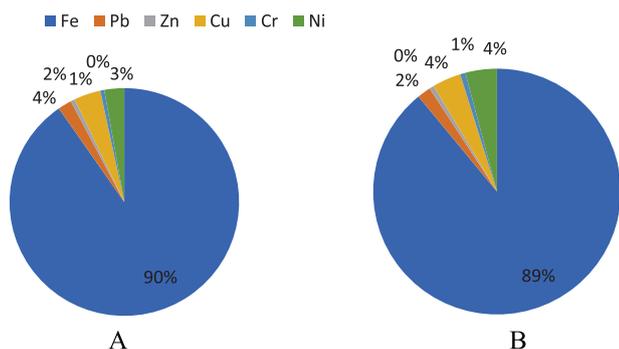


Figure 3. Average hazard quotient for children (A) and adults (B).

The THI of oral exposure to abattoir waste-impacted soils by Fe, Pb, Zn, Cu, Cr, and Ni in human is shown in Table 10. The mean THI values of trace metals for the children and adults are $88.347E-2$ and $47.991E-2$, respectively. The mean THI value for the children was much higher than that for the adults. Consequently, children within the studied locations are more vulnerable to health hazard than the adults. Figures 3A and B indicate that HQ of Fe in children and adults contributed 90% and 89%, respectively, to the total hazard index. The THI values for both the children and adults are less than 1, thus may not result in a serious health risk. Cu, Cr, Ni, Pb, and Zn contributed a total of 10% and 11% to the entire total hazard index for the children and adults, respectively.

Conclusions

This research has indicated that the use of information from total metals, speciation, pollution indices, multivariate analyses, and human-related risks can reveal comprehensively the environmental issues in relation to the area under study. The results obtained indicate that waste products from abattoirs have the possibility of elevating Fe, Pb, Zn, Cu, Cr, and Ni contents in soil. Nevertheless, the mean levels of these metals in the studied abattoir waste-impacted soils were within their recommended limits except for Fe. The sequential extraction of the metals revealed that Fe and Cr existed mainly in the residual (inert) fraction, whereas Pb, Cu, Zn, and Ni were in the non-residual fraction. Consequently, Fe and Cr exhibited low bio-availability in the studied soils, while anthropogenic factor affected the accumulation of Pb, Zn, Cu, and Ni significantly. This has also shown that wastes from abattoirs can affect metal speciation in soil. The pollution status of the studied soils has not reached a nuisance level based on the results of ecological risk assessment. Multivariate analyses identified that both the natural soil-forming processes and anthropogenic factor are responsible for metal accumulation in the studied soils. Human health risk assessment revealed that children are vulnerable to Fe toxicity than the adults in the studied soils. This study has indicated that indiscriminate dumping of waste products from abattoir can affect the environment negatively and significantly. Hence, the Waste Management and Control Agency in Akwa

Ibom state should stop the indiscriminate dumping of untreated wastes from abattoir. The use of untreated wastes from abattoirs by farmers as organic manures should be discouraged to forestall the associated problems along the food chain.

Author Contributions

This study was done in partnership with all the authors. GAE designed the study, wrote the protocol and interpreted the data. ESE handled the sample collection and treatment, gathered the initial data and performed preliminary data analysis. EUD worked on the literature review and produced the initial draft. All authors read and approved the final manuscript.

ORCID iD

Godwin Asukwo Ebong  <https://orcid.org/0000-0003-4555-3090>

REFERENCES

- Hornby AS. *Oxford Advanced Learner's Dictionary of Current English*. 7th ed. Oxford: Oxford University Press; 2006.
- Atuanya EI, Nwogu NA, Akpor EA. Effluent qualities of government and private abattoirs and their effects on Ikpoba River, Benin City, Edo State, Nigeria. *Adv Biol Res*. 2012;6:196-201.
- Osibanjo O, Adie GU. Impact of effluent from Bodija abattoir on the physico-chemical parameters of Oshunkaye stream in Ibadan city, Nigeria. *African Journal of Biotechnology*. 2007;6:1806-1811.
- Nwachukwu MI, Akinde SB, Udjih OS, Nwachukwu IO. Effect of abattoir wastes on the population of proteolytic and lipolytic bacteria in a recipient water body (Otamiri River). *Glob Res J Sci*. 2011;1:40-42.
- Mohammed S, Musa JJ. Impact of abattoir effluent on river Landau, Bida, Nigeria. *J Chem Biol Phys Sci*. 2012;2:132-136.
- Neboh HA, Iusanya OA, Ezekoye CC, Orji FA. Assessment of Ijebu-Igbo abattoir effluent and its impact on the ecology of the receiving soil and river. *IOSR J Environ Sci Food Technol*. 2013;7:61-67.
- Opara MN, Ukpong UM, Okoli IC. Quantitative analysis of abattoir slaughtering of animals in Akwa Ibom State, Nigeria. *J Agricult Soc Res*. 2005;5:118-126.
- Nwanta JA, Onunkwo JI, Ezenoduka VE, Phil-Eze POSC, Egege SC. Abattoir operations and waste management in Nigeria: a review of challenges and prospects. *Sok J Veter Sci*. 2008;7:61-67.
- Dan EU, Raymond K, Okon MU. Comparative proximate, nutrient density, minerals and trace metals composition of vegetables from abattoir wastes impacted soils. *J Scient Eng Res*. 2018;5:90-101.
- Adesemoye AO, Opere BO, Makinde SCO. Microbial Content of abattoir wastewater and its contaminated soil in Lagos, Nigeria. *Afr J Biotech*. 2006;5: 1963-1968.
- Rabah AB, Oyeleke SB, Manga SB, Hassan LG, Ijah UJJ. Microbiological and physicochemical assessment of soil contaminated with abattoir effluents in Sokoto metropolis, Nigeria. *Sci World J*. 2010;5:31-34.
- Magaji JY, Chup CD. The effects of abattoir waste on water quality in Gwagwalada-Abuja, Nigeria. *Ethiop J Environ Stud Manage*. 2012;54:542-549.
- Poulsen HD. Zinc and copper as feed additives, growth factors or unwanted environmental factors. *J Ani Feed Sci*. 1998;7:135-142.
- Cang L, Wang YJ, Zhou DM, Dong YH. Heavy metals pollution in poultry and livestock feeds and manures under intensive farming in Jiangsu Province, China. *J Environ Sci*. 2004;16:371-374.
- Zhang F, Li Y, Yang M, Li W. Content of heavy metals in animal feeds and manures from farms of different scales in northeast China. *Int J Environ Res Public Health*. 2012;9:2658-2668.
- Elemile OO, Raphael DO, Omole DO, Oloruntoya EO, Ajayi EO, Ohwavorua NA. Assessment of the impact of abattoir effluent the quality of groundwater in a residential area of Omu-Aran, Nigeria. *Environ Sci Europ*. 2019;31:1-10.
- Omole DO, Longe EO. An assessment of the impact of abattoir effluents on river Illo, Ota, Nigeria. *J Environ Sci Technol*. 2008;1:56-64.
- Ezeoha SL, Ugwuishiwu BO. Status of abattoir wastes research in Nigeria. *Nigeria J Technol*. 2011;30:143-148.
- Jukna C, Jukna V, Suigzdaite J. Determination of heavy metals in viscera and muscles of cattle. *Bulgar J Veter Med*. 2006;9:35-41.
- Osemwota IO. Effect of abattoir effluent on the physical and chemical properties of soils. *Environ Monit Assess*. 2010;167:399-404.

21. Abubakar GA, Tukur A. Impact of abattoir effluent on soil chemical properties in Yola, Adamawa State, Nigeria. *Int J Sustain Agricult Res.* 2014;1:100-107.
22. Akinnibosun FI, Ayejuyoni TP. Assessment of microbial population and physico-chemical properties of abattoir effluent-contaminated soils in Benin City, Nigeria. *J Trop Agricult Food Environ Exten.* 2015;14:1-6.
23. Edeine VF, Iren OB, Idiong MM. Effects of abattoir effluent on the physico-chemical properties of surrounding soils in Calabar Metropolis. *Int J Adv Res.* 2016;4:37-41.
24. Ubwa ST, Atoo GH, Offem JO, Abah J, Asemave K. Effect of activities at the Gboko abattoir on some physical properties and heavy metals levels of surrounding soil. *Int J Chemist.* 2013;5:49-57.
25. Osu CI, Okereke VC. Heavy metal accumulation from abattoir wastes on soils and some edible vegetables in selected areas in Umuahia metropolis. *Int J Curr Microbiol Appl Sci.* 2015;4:1127-1132.
26. Yahaya MI, Mohammad S, Abdullahi BK. Seasonal variations of heavy metals concentration in abattoir dumping site soil in Nigeria. *J Appl Sci Environ Manag.* 2009;13:9-13.
27. FEPA. *Federal Environmental Protection Agency, National Guidelines and Standards for Soil Quality in Nigeria.* Port Harcourt, Nigeria: FEPA, Rivers State Ministry of Environment and Natural Resources; 1999.
28. Tack FMG, Verloo MG. Chemical speciation and fractionation in soil and sediment heavy metal analysis: a review. *Int J Environ Anal Chemist.* 1995;59:225-238.
29. Kirpichtchikova AT, Mancau A, Spadini L, Panfili F, Marcus MA, Jacquet T. Speciation and solubility of heavy metals in contaminated soil using X-ray micro fluorescence, EXAFS spectroscopy, chemical extraction and thermodynamic modeling. *Geochim et Cosmo Acta.* 2006;70:2163-2190.
30. Ratuszny T, Gong Z, Wilke BM. Total concentrations and speciation of heavy metals in soils of the Shenyang Zhangshi Irrigation Area, China. *Environ Monit Assess.* 2009;156:171-180.
31. Benson NU, Anake WU, Olanrewaju IO. Analytical relevance of trace metal speciation in environmental and biophysicochemical systems. *Am J Anal Chemist.* 2013;4:633-641.
32. Marcus AC, Nwineewii JD, Edor OS. Heavy metals assessment of leachate contaminated soils from selected dumpsites in Port Harcourt, Rivers state, South-South, Nigeria. *Int J Chem Stud.* 2017;5:1507-1511.
33. Simeon EO, Friday K. Index models assessment of heavy metal pollution in soils within selected abattoirs in Port Harcourt, Rivers State, Nigeria. *Singapore J Sci Res.* 2017;7:9-15.
34. Pujiwati AK, Nakamura K, Watanabe N, Komai T. Application of multivariate analysis to investigate the trace element contamination in top soil of coal mining district in Jorong, South Kalimantan, Indonesia. *IOP Conf Ser Earth Environ Sci.* 2018. <https://iopscience.iop.org/article/10.1088/1755-1315/118/1/012062>
35. Gupta S, Jena V, Matic N, Kapralova V, Solanki JS. Assessment of geo-accumulation index of heavy metal and source of contamination by multivariate factor analysis. *Int J Hazard Mater.* 2014;2:18-22.
36. Tahri M, Benyaich F, Bounakla M, et al. Multivariate analysis of heavy metal contents in soils, sediments and water in the region of Meknes (Central Morocco). *Environ Monit Assess.* 2005;102:405-417.
37. Praveena SM, Pradhan B, Ismail SNS. Spatial assessment of heavy metals in surface soil from Klang District (Malaysia): an example from a tropical environment. *Hum Ecol Risk Assess.* 2015;21:1980-2003.
38. Li Y, Wang YB, Gou X, Su YB, Wang G. Risk assessment of heavy metals in soils and vegetables around non-ferrous metals mining and smelting sites, Baiyin, China. *J Environ Sci.* 2006;18:1124-1134.
39. Xiao MS, Li F, Zhang JD, Lin SY, Zhuang ZY, Wu ZX. Investigation and health risk assessment of heavy metals in soils from partial areas of Daye city, china. *IOP Conf Ser Earth Environ Sci.* 2017;64:1-8.
40. Chonokhuu S, Batbold C, Chuluunpurev B, Battengel E, Dorjsuren B, Byamba B. Contamination and health risk assessment of heavy metals in the soil of major cities in Mongolia. *Int J Environ Res Public Health.* 2019;16:E2552.
41. Offiong EEA, Obioku EO, Etim UM, Habib M, Nkeme KK. The incidence of tuberculosis in goats in Abak local Government Area—A case study of Abak Abattoir. *Int J Develop Sustain.* 2014;3:692-695.
42. National Population Commission (NPC). *Estimated Population Figures.* Abuja, Nigeria: National Population Commission of Nigeria; 2006.
43. Udo-Inyang UC, Edem ID. Analysis of rainfall trends in Akwa Ibom State, Nigeria. *J Environ Earth Sci.* 2012;2:60-70.
44. Ekpenyong RE. *A remote sensing and GIS mapping of land cover change and erosion risk in Akwa Ibom State, Southern Nigeria* [PhD Thesis]. University of Uyo, Uyo; 2012.
45. Afangideh AI, Okpiliya F, Ekanem E. The changing annual rainfall and temperature averages in the humid tropical City of Uyo, Southern Nigeria. *Afr J Environ Pollut Health.* 2005;4:54-61.
46. IUSS-WRB Working Group. World reference base for soil resources 2014. <http://www.fao.org/3/i3794en/I3794en.pdf>. Updated 2015.
47. Obasi OL, Ekanem E O, Ifut OJ, Ogbobor ME. Food animal supply and consumption pattern in Akwa Ibom State, Nigeria. *Glob J Agricult Sci.* 2002;1:1-6.
48. United States Department of Agriculture (USDA). *Natural Resources Conservation Service.* Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook; 2006. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/soils/?cid=nrcs142p2_053624
49. Chukwu UJ, Anuchi SO. Impact of abattoir wastes on the physicochemical properties of soils within Port Harcourt metropolis. *Int J Eng Sci.* 2016;5:17-21.
50. Aydinalp C. Concentration and speciation of Cu, Ni, Pb and Zn in cultivated and uncultivated soils. *Bulg J Agricult Sci.* 2009;15:129-134.
51. ISO 11466. *Soil Quality—Extraction of Trace Elements Soluble in Aqua Regia.* Geneva, Switzerland: International Organization for Standardization; 1995.
52. Rauret G, Lopez-Sanchez JF, Sahuquillo A, et al. Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials. *J Environ Monit.* 1999;1:57-61.
53. ISO/IEC 17025. *General Requirements for the Competence of Testing and Calibration Laboratories*, 3rd ed. Geneva, Switzerland: ISO; 2017.
54. Van-Reeuwijk LP. *Procedures for soil analysis* (Technical Paper 9). Wageningen, The Netherlands: ISRIC; 1993.
55. Walkley A, Black IA. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37:29-37.
56. Rhoades JD, Corwin DL, Lesch SM. Geospatial measurements of soil electrical conductivity to assess soil salinity and diffuse salt loading from irrigation. In: Corwin DL, ed. *Assessment of Non-point Source Pollution in the Vadose Zone* (Geophysical Monograph 108). Washington, DC: American Geophysical Union; 1999:197-215.
57. ISO 11260. *Soil quality—Determination of Effective Cation Exchange Capacity and Base Saturation Level Using Barium Chloride Solution.* Geneva, Switzerland: International Organization for Standardization; 1994.
58. Rauret G, Lopez-Sanchez JF, Sahuquillo A, Rubio R, Quevauiller P. Application of a modified BCR sequential extraction (three step) procedure for the determination of extractable trace metal content in a sewage sludge-amended soil reference material (CRM 483), complemented by a three-year study of acetic acid and EDTA extractable metal content. *J Environ Monit.* 2000;2:228-233.
59. Uduma AU, Jimoh WLO. Sequential extraction procedure for partitioning of lead, copper, cadmium, chromium, and zinc in contaminated arable soils of Nigeria. *Am J Environ Ener Power Res.* 2013;1:9186-9208.
60. Gaithersburg MD, May E, Willie Rumble J. *Standard Material Reference (SRM) 2710A (Montana Soil 1), Highly Elevated Trace Element Concentrations.* London, England: National Institute of Standards and Technology Certificate of Analysis; 2003.
61. Hakanson L. An ecological risk index for aquatic pollution control: a sedimentological approach. *Water Res.* 1980;4:975-1001.
62. Pekey H, Karakas D, Ayberk S, Tolun L, Bakoglu M. Ecological risk assessment using trace elements from surface sediments of Izmit Bay (Northeastern Marmara Sea) Turkey. *Mar Pollut Bull.* 2004;48:946-953.
63. Yang Z, Wang Y, Shen Z, Niu J, Tang Z. Distribution and speciation of heavy metals in sediments from the mainstream, tributaries, and lakes of the Yangtze River catchment of Wuhan, China. *J Hazard Mater.* 2009;166:1186-1194.
64. Mmolawa KB, Likuku AS, Gaboutloeloe GK. Assessment of heavy metal pollution in soils along major roadside areas in Botswana. *Afr J Environ Sci Technol.* 2011;5:186-196.
65. Cao HC, Luan ZQ, Wang JD, Zhang XL. Potential ecological risk of cadmium lead and arsenic in agricultural black soil in Jilin province China. *Stochast Environ Res Risk Assess.* 2007;3:57-64.
66. Ghaderi AA, Abduli MA, Karbassi AR, Nasrabadi T, Khajeh M. Evaluating the effects of fertilizers on bioavailable metallic pollution of soils, case study of sistan farms, Iran. *Int J Environ Res.* 2012;6:2565-2570.
67. United States Environmental Protection Agency (USEPA). *Risk-Based Concentration Table.* Philadelphia, PA; Washington, DC: Environmental Protection Agency; 2000.
68. Hough RL, Breward N, Young SD, et al. Assessing potential risk of heavy metal exposure from consumption of home-produced vegetables by urban populations. *Environ Health Perspect.* 2004;112:215-221.
69. United States Environmental Protection Agency (USEPA). *Exposure Factors Handbook.* Washington, DC: USEPA; 2011.
70. Grzetic I, Ghariani RHA. Potential health risk assessment for soil heavy metal contamination in the central zone of Belgrade (Serbia). *J Serb Chem Soc.* 2008;73:923-934.
71. Wang X, Wang F, Chen B, et al. Comparing the health risk of toxic metals through vegetable consumption between industrial polluted and non-polluted fields in Shaoguan, South China. *J Food Agri Environ.* 2012;10:943-948.
72. Odu CTI, Esurusu OF, Nwaboshi IC, Ogunwale JA. *Environmental study (Soil and Vegetation) of Nigeria Agip Oil Company Operation Area.* Lagos, Nigeria: Nigeria Agip Oil Company Limited; 1985:102-107.

73. Agbaire PO, Emoyan OO. Bioaccumulation of heavy metals by earthworm (*Lumbricus terrestris*) and associated soils in domestic dumpsites in Abraka, Delta State, Nigeria. *Int J Plant Animal Environ Sci.* 2012;2:210-217.
74. Akan JC, Abdulrahman FI, Sodipo OA, Lange AG. Physicochemical parameters in soil and vegetable samples from Gongulon agricultural site, Maiduguri, Borno State, Nigeria. *J Am Sci.* 2010;6:75-87.
75. Onweremadu EU. Physico-chemical characterization of a farmland affected by wastewater in relation to heavy metals. *J Zhejiang Univ Sci A.* 2008;9:366-372.
76. Nafarnda WD, Yaji A, Kubkomawa HI. Impact of abattoir waste on aquatic life: a case study of Yola abattoir. *Glob J Pure Appl Sci.* 2006;12:31-33.
77. Chaudhari PR, Ahire DV, Ahire VD. Correlation between physicochemical properties and available nutrients in sandy loam soils of Haridwar. *J Chem Biol Phys Sci.* 2012;2:1493-1500.
78. Alloway BJ, Ayres DC. *Chemical Principles of Environmental Pollution*, 2nd ed. London, England: Blackie Academic and Professional, Chapman and Hall; 1997.
79. David NO, Benjamin LK, Patrick OY. Some physicochemical and heavy metal levels in soils of dumpsites in Port Harcourt municipality and environs. *J Appl Sci Environ Manag.* 2009;13:65-70.
80. Ojo OF, Adewumi DG, Oluwatoyin AK. Glutathione-S-transferase production in earthworm (Annelida: Eudrilidae) as a tool for heavy metal pollution assessment in abattoir soil. *Rev Biol Trop.* 2016;64:779-789.
81. Mansur UD, Garba KA. Effects of some heavy metal pollutants on fertility characteristics of an irrigated Savannah Alfisol. *Bay J Pure Appl Sci.* 2010;3: 255-259.
82. Iwegbue CMA, Egobueze F, Opuene K. Preliminary assessment of heavy metals levels of soils of an oil field in the Niger Delta, Nigeria. *Int J Environ Sci Technol.* 2006;3:167-172.
83. Chaney RL, Oliver DP. Sources, potential adverse effects and remediation of agricultural soil contaminants. In: Naidu R, ed. *Contaminants and the soil environments in the Australia-Pacific Region.* Dordrecht, The Netherlands: Kluwer Academic Publishers; 1996:323-359.
84. Sumner ME. Beneficial use of effluents, wastes, and biosolids. *Commun Soil Sci Plant Anal.* 2000;31:1701-1715.
85. Basta NT, Ryan JA, Chaney RL. Trace element chemistry in residual-treated soil: key concepts and metal Bioavailability. *J Environ Qual.* 2005;34:49-63.
86. Wuana RA, Okieimen FE. Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. *Int Scholar Res Netw.* 2011;2011:1-20.
87. Keller C, McGrath SP, Dunham SJ. Trace metal leaching through a soil-grassland system after sewage sludge application. *J Environ Qual.* 2002;31: 1550-1560.
88. McLaren RG, Clucas LM, Taylor MD, Hendry T. Leaching of macronutrients and metals from undisturbed soils treated with metal-spiked sewage sludge. *Austral J Soil Res.* 2004;42:459-471.
89. Prashanth L, Kattapagari KK, Chitturi RT, Baddam VR, Prasad LK. A review on role of essential trace elements in health and disease. *JNTR Univ Health Sci.* 2015;4:75-85.
90. Ampofo EA, Awortwe D. Heavy metal (Cu, Fe and Zn) pollution in soils: pig waste contribution in the Central Region of Ghana. *Adv Appl Sci Res.* 2017;8:1-10.
91. Fagbote EO, Olanipekun EO. Speciation of heavy metal in sediment of Agbabu Bitumen deposit area, Nigeria. *J Appl Sci Environ Manag.* 2010;14:47-51.
92. Osakwe SA. Chemical partitioning of iron, cadmium, nickel, and chromium in contaminated soils of south-eastern Nigeria. *Res J Chem Sci.* 2012;2:1-9.
93. Ajiboso T, Olayinka KO, Alo BI. Speciation of heavy metal contaminants at metal dumpsites by improved sequential fractionation technique. *J Niger Environ Soc.* 2003;1:178-186.
94. Umoren IU, Udoh AP, Udousoro II. Concentration and chemical speciation for the determination of Cu, Zn, Ni, Pb and Cd from refuse dump soils using the optimized BCR sequential extraction procedure. *Environmentalist.* 2007;27:241-252.
95. Samannidou V, Fytianos K. Partitioning of heavy metals into selective chemical fractions from rivers in northern Greece. *Sci Tot Environ.* 1987;67:279-285.
96. Farkas A, Erratico C, Viganò L. Assessment of the environmental significance of heavy metal pollution in surficial sediments of the River Po. *Chemosphere.* 2007; 68:761-768.
97. Johnson CE, Siccama TG, Driscoll CT, Likens GE, Moeller RE. Changes in forest lead cycling in response to decreasing atmospheric inputs. *Ecol Appl.* 1995; 5:813-822.
98. Polkowska Z, Gryniewicz M, Gorecki T, Namiesnik J. Levels of lead in atmospheric deposition in a large urban agglomeration in Poland. *J Environ Monit.* 2001;3:146-149.
99. Olubunmi FE, Olorunsola OE. Evaluation of the status of heavy metal pollution of sediment of Agbabu bitumen deposits area, Nigeria. *Eur J Scient Res.* 2010;41: 373-382.
100. Kaasalainen M, Yli-Halla M. Use of sequential extraction to assess metal partitioning in soils. *Environ Pollut.* 2003;126:225-233.
101. Forghani G, Moore F, Lee S, Qishlaqi A. Geochemistry and speciation of metals in sediments of the Maharlu Saline Lake, Shiraz, SW Iran. *Environ Earth Sci.* 2009;59:173-184.
102. Svendsen ML, Steinnes E, Blom HA. Partitioning of Zn, Cd, Pb, and Cu in organic-rich soil profiles in the vicinity of a zinc smelter. *Chem Speciat Bioavailab.* 2011;23:189-200.
103. Ebong GA, Dan EU, Inam E, Offiong NO. Total concentration, speciation, source identification and associated health implications of Trace metals in Lemna dumpsite soil, Calabar Nigeria. *J King Saud Univ Sci.* 2018;31:886-897.
104. Haug JR, Haug R, Jiao JJ, Chen K. Speciation and mobility of heavy metals in mud, in coastal reclamation areas in Shenzhen, China. *Environ Geol.* 2007;53: 221-228.
105. Ashraf MA, Maah MI, Yusoff I. Chemical speciation and potential mobility of heavy metals in the soil of former tin mining catchment. *Sci World J.* 2012;2012: 1-11.
106. Umoren IU, Udousoro II. Fractionation of Cd, Cr, Pb and Ni in roadside soils of Uyo, Niger Delta Region: Nigeria using the optimized BCR sequential extraction technique. *Environmentalist.* 2009;29:280-286.
107. Ebong GA, Offiong OE, Ekpo BO. Seasonal variations in trace metal levels, speciation and physicochemical determinants of metal availability in dumpsite soils within Akwa Ibom State, Nigeria. *Chemis Ecol.* 2014;30:403-417.
108. Borgese L, Federici S, Zacco A, et al. Metal fractionation in soils and assessment of environmental contamination in the Vallecamonica, Italy. *Environ Sci Pollut Res Int.* 2013;20:5067-5075.
109. Łukowski A. Fractionation of selected heavy metals (Zn, Ni, and Cu) in municipal sewage sludges from Podlasie Province. *J Ecol Eng.* 2017;18:133-139.
110. Osakwe SA. Chemical speciation and mobility of some heavy metals in soils around automobile waste dumpsites in northern part of Niger Delta, South Central Nigeria. *J Appl Sci Environ Manag.* 2010;14:123-130.
111. Mugosa B, Durovic D, Nedovic-Vukovic M, Barjaktarovic-Labovic S, Vrvic M. Assessment of ecological risk of heavy metal contamination in coastal municipalities of Montenegro. *Int J Environ Res Public Health.* 2016;13:393-405.
112. Al-Khashman OA, Shawabkeh RA. Metals distribution in soils around the cement factory in southern Jordan. *Environ Pollut.* 2006;140:387-394.
113. Yang Z, Lu W, Long Y, Bao X, Yang Q. Assessment of heavy metals contamination in urban topsoil from Changchun City, China. *J Geochem Explorat.* 2011;108: 27-38.
114. Wu EM, Kuo SL. Applying a multivariate statistical analysis model to evaluate the water quality of a watershed. *Water Environ Res.* 2012;84:2075-2085.
115. Yin L, Wei Y, Feng Z, GanLin Z. The spatial distribution and sources of metals in urban soils of Guangzhou, China. In: Proceedings of the 19th World Congress of Soil Science: Soil Solutions for a Changing World; August 1-6, 2010; Brisbane, QLD, Australia:77-80. <https://www.iuss.org/19th%20WCSS/Symposium/pdf/0417.pdf>
116. Olabanji IO, Oluyemi EA, Obianjuwa EI. Nondestructive analysis of dumpsite soil and vegetable for elemental composition. *J Environ Chemist Ecotoxicol.* 2015;7:1-10.
117. Azeze JO, Hassan OA, Egunjobi PO. Soil contamination at dumpsites: implication of soil heavy metals distribution in municipal solid waste disposal system: a case study of Abeokuta, Southwestern Nigeria. *Soil Sed Contaminat Int J.* 2011;20:370-386.
118. USEPA. *Integrated risk information system (IRIS).* United States Environmental Protection. <https://www.epa.gov/iris>. Updated 2010. Accessed October 4, 2011.
119. Goyer RA. Nutrition and metal toxicity. *Am J Clin Nutr.* 1995;61:646S-650S.
120. World Health Organization (WHO). *Permissible limits of heavy metals in soil and plants.* Geneva, Switzerland: World Health Organization; 1996.
121. Man YB, Sun XL, Zhao YG, et al. Health risk assessment of abandoned agricultural soils based on heavy metal contents in Hong Kong, the world's most populated city. *Environ Int.* 2010;36:570-576.