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

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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) indentified 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

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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 al[7] revealed that between 1999 and 2002, a total of 151 303 animals were slaughtered in Akwa Ibom state. Nwanta et al[8] 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 al[9] 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 al[16] 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 al[26] 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 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 al[32] 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 km^2 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 Group[46] classifications of soil profile, the studied abattoir waste–impacted soils are in the Anthrosol (Hortic class). A study by Obasi et al[47] 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 Agriculture[48] 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 HNO_3 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	

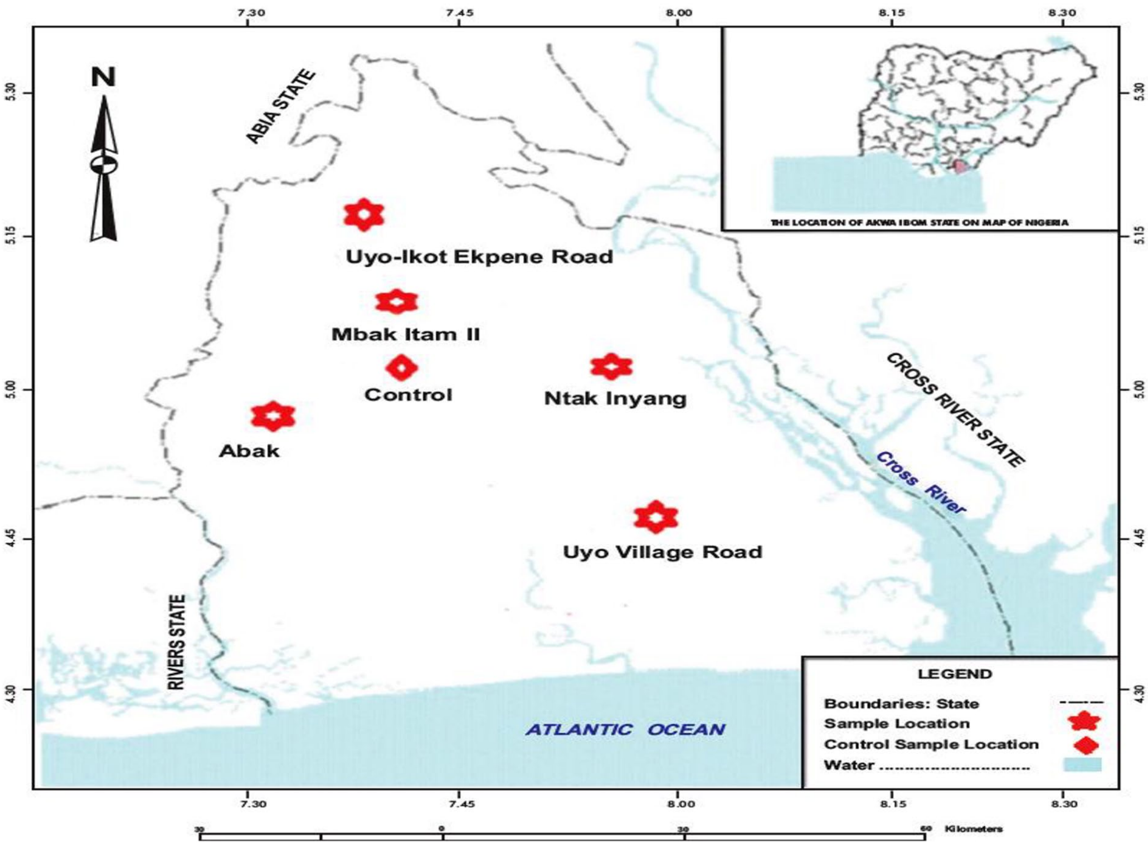

Figure 1. Map of Akwa Ibom state showing the studied abattoir soils and control plot.

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

ELEMENT	CERTIFIED VALUE ± SD (×2)	MEASURED MEAN VALUE ± SD (×2)	RECOVERY (%)
Fe (%)	2.16 ± 0.04	2.06 ± 0.03	95
Pb (%)	0.276 ± 0.0015	0.262 ± 0.002	95
Zn (mg/kg)	2090.00 ± 10.00	1973.00 ± 8.25	94
Cu (mg/kg)	1710.00 ± 25.00	1609.00 ± 36.43	94
Cr	CVNA	CVNA	CVNA
Ni (mg/kg)	4.00 ± 0.50	3.55 ± 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 Jimoh[59]

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

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 Hakanson[61] and Pekey et al[62]

$$CF = \frac{Cm}{Bm} \quad (2)$$

where CF is the contamination factor, Cm is the concentration of the metal in the studied sample, and Bm 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 Hakanson[61] and Mmolawa et al[64]

$$C_{deg} = \Sigma\left(\frac{Cm}{Bm}\right) \quad (3)$$

where Cm represents the level of the metal in the studied sample and Bm 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 Hakanson[61]

Table 4. Different categories of CF, C_{deg}, E_r^i, and RI as proposed by Hakanson[61] 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 ⩽ CF ⩽ 3 = fair contamination	8 < C_{deg} < 16 = moderate degree of contamination	40 < E_r ⩽ 80 = moderate ecological risk	150 < RI < 300 = modest ecological risk
C	3 ⩽ CF ⩽ 6 = considerable contamination	16 < C_{deg} < 32 = considerable degree of contamination	80 < E_r ⩽ 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 ⩽ 320 = high ecological risk	Significantly high risk
E			E_r > 320 = severe ecological risk	

Abbreviations: C_{deg}, degree of contamination; CF, contamination factor;, 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 al[65] and Yang et al[63]

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

where ΣE_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 al[66]

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

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 al[66]

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

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)

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

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)

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

The risk evaluation of parameters and values applied are ingestion rate (IR) (100 and 50 mg/d for children and adults, respectively[be]; 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, USEPA[69]; b, Grzetic and Ghariani[70]; c, Wang et al[71]; d, USEPA[67]; 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 al[24] 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 µS/cm with a mean value of 46.61 ± 15.01 (Table 3). This EC range is higher than 2.03 to 2.54 µS/cm obtained by Akan et al[74] but lower than 60.00 to 110.00 µS/cm reported by Chukwu and Anuchi[49] 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 ± 2.44%. The OM range obtained is higher than 0.7% to 7.4% by Yahaya et al[26] but lower than 5.6% to 24.1% obtained by Ubwa et al[24] 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 al[6] 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 al[82] 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 al[26] but higher than 59.36 to 81.70 mg/kg obtained by Simeon and Friday [33] 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 Anuchi[49] but higher than 0.18 to 0.83 mg/kg obtained by Ubwa et al[24] 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 al[24] 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 Okereke[25] 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 Anuchi[49] 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	46 000	20	95	45	90	68

Abbreviations: ACV, average crustal values by Turekian and Wedepohl (1961); Max, maximum; Min, minimum; RL, recommended limits by FEPA[27].

The mean values of all the metals determined were lower than their recommended limits by FEPA[27] 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 Olanipekun[91] 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 al[93] 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 al[66] 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 al[93] 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 >> 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 Łukowski[109] 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 >> 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	NC	1.000			
	EC	0.939*	0.741*	NC	NC	NC	NC	NC	1.000		
	OM	0.841*	0.870*	NC	NC	NC	NC	.NC	0.860*	1.000	
	CEC	0.949*	0.890*	0.696**	NC	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.

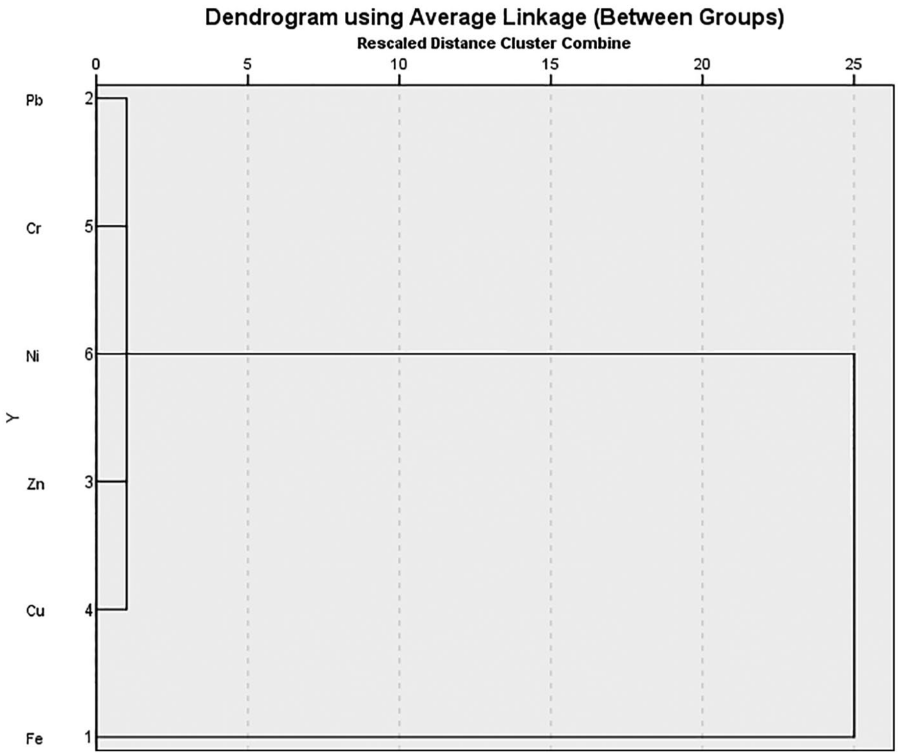

Figure 2. Hierarchical clusters with the trace metals determined in the studied abattoir soils.

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 al[103] 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 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]

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

	DI		HQ	
	CHILD	ADULTS	CHILD	ADULTS
Metal				
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.

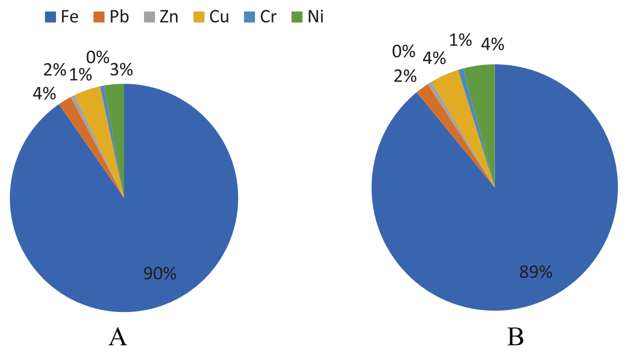

Figure 3. Average hazard quotient for children (A) and adults (B).

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 nonresidual fraction. Consequently, Fe and Cr exhibited low bioavailability 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.

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