Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN
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J. Mater. Environ. Sci., 2026, Volume 17, Issue 10, Page 1517-1530

http://www.jmaterenvironsci.com

Pollution status, ecological risk, and potential human exposure risk of two abattoirs in Abak and Eket Local Government Areas, Akwa Ibom State, South-South Nigeria

Udofia I. M.[1,*], Asuquo P. O.[2], Moffat L. E.[1]

[1]*Department of Chemistry, University of Uyo, P.M.B. 1017, Uyo, Nigeria*
[2]*Department of chemistry, Akwa Ibom state University of Education, Afaha Nsit, Nigeria*
**Corresponding author, Email address: ifrekemfonudofia@gmail.com; Phone: +2348143363342*

Received *11 Aug 2026,*
Revised *23 Oct 2026,*
Accepted *26 Oct 2026*

Keywords:
- ✓ *Abattoir;*
- ✓ *Heavy metals;*
- ✓ *Soil;*
- ✓ *Contamination;*
- ✓ *Pollution*

Citation*: Udofia I. M., Asuquo P. O., Moffat L. E. (2026) Pollution status, ecological risk, and potential human exposure risk of two abattoirs in Abak and Eket Local Government Areas, Akwa Ibom State, South-South Nigeria, J. Mater. Environ. Sci., 17(10), 1517-1530.*

Abstract: This study employed pollution and ecological risk indices to evaluate the pollution status of two abattoirs in Abak and Eket Local Government Areas of Akwa Ibom State, South-South, Nigeria. Sample preparation and analysis were done using appropriate analytical methods. Concentrations of Pb, Hg, Co, V, As, Fe, Cu, Cd, Cr, Mn, Ni, and Zn were determined using AAS. Results indicated that concentrations of metals in the studied soils were below recommended limits of WHO, DUTCH, NESREA, and FEPA, except cadmium and chromium. Pollution indices showed that both abattoirs had low contamination factors for the metals except cadmium with moderate contamination and chromium with moderate to very high contamination. The Abak abattoir had a low degree of contamination, whereas the Eket abattoir had a moderate degree of contamination. The enrichment factor showed that the metals originated from an anthropogenic source, with Hg and Cr mostly from a geogenic source. The geoaccumulation index revealed that the metals were mostly geogenic. The pollution load index indicated that both abattoirs were not polluted by the metals. The potential ecological risk factor depicted low ecological risk except Cd with moderate ecological risk at the Abak abattoir, whereas the ecological risk index indicated a low ecological risk at both abattoirs. At the moment, both abattoirs have a moderate environmental impact and ecological health risk, but operations within these abattoirs are to be properly monitored by environmental agencies in order to avert further pollution, particularly by cadmium and chromium.

1. Introduction

The neglect of proper waste management and control, particularly in developing countries such as Nigeria, has led to a significant increase in environmental pollution by heavy metals. Heavy metals are a group of metallic elements characterized by their high density, atomic mass, and potential toxicity (Anweting *et al.*, 2024a,b; Nwokem *et al.*, 2023; Okon *et al.*, 2023a,b; Udofia *et al.*, 2024). Reports show that several industrial and artisanal activities such as oil exploration (Etim *et al.*, 2016; Onyedikachi *et al.*, 2021; Orhuebor *et al.*, 2025), transportation, mining, oil exploration (Barde *et al.*, 2024; Etuk *et al.*, 2023b; Sawadogo *et al.*, 2023), agriculture (Barau *et al.*, 2018; Bawa, 2023; Etuk *et al.*, 2023a), and automobile repairs (Daniel *et al.*, 2025; Imasuen & Omorogieva, 2013) elevate the concentrations of heavy metals in soil. Anweting *et al.* (2024b), Etuk *et al.* (2019), and Dan *et al.* (2018) have also reported the presence of these metals in abattoir soils.

Abattoirs, also known as slaughterhouses are dedicated areas approved by regulating authorities for slaughtering, inspection, processing, preservation, and storage of meat products for consumption (Vershima *et al.*, 2015). Mostly, meat processing in these abattoirs is done in places with poor hygienic conditions by untrained personnel; as a result, exposing the meats and some useful by-products to contaminants, either organic and/or inorganic. Unlike organic contaminants, inorganic contaminants such as heavy metals are not biodegradable, and their presence minimises the rate of degradation of organic contaminants. This characteristic leads to their accumulation in soils and biological systems, resulting in toxicity to these receiving media. Heavy metals can be found in livestock feeds and excreta from animals stored in the lairage. Also, muscle, blood, liver, and other organs of cattle have been reported to contain heavy metals (Olarewaju & Olufayo, 2014). Other sources of heavy metals in abattoirs include machinery and equipment, chemicals and cleaning agents, medication, waste generated from singeing of hides, skin removals, and clean-up operations. Although the nature and quantity of these wastes and effluents are dependent on the number and type of livestock being processed, and even the method used (Anweting *et al.*, 2024b), they eventually introduce heavy metals into the soil and surrounding boreholes, rivers, lakes, wells, and other water bodies (Azuonwu *et al.*, 2019), via leaching through the soil and surface runoffs. Consequently, reducing soil health, biodiversity, and human well-being (Bosede & Omokaro, 2022). These toxic metals are further introduced into the food chain through consumption of meats processed in these abattoirs or via vegetables grown within the abattoirs. This report was affirmed by Etuk *et al.* (2019) and Olusola *et al.* (2020) in their study on leafy vegetables grown in abattoir vicinity.

Previous research evaluating the effect of wastes on these abattoir soils has only focused on a few metals, providing limited insights. To broadly assess the metal toxicity, a more extensive analysis is necessary. Hence, this study aimed to investigate the total concentrations of 12 heavy metals (lead, mercury, cobalt, vanadium, arsenic, iron, copper, cadmium, chromium, manganese, nickel, and zinc) and evaluate their environmental and ecological impacts, providing a more comprehensive understanding of the potential risks associated with these abattoirs. Results from this study will help abattoir workers, environmentalists, and governments to postulate policies for safer and more sustainable meat processing operations, aimed at securing the well-being of both consumers and the environment.

2. Materials and Methods

2.1 Study Area

Abak and Eket are both local government areas in Akwa Ibom State, in the Niger Delta region of Nigeria. Abak lies within latitude 4°50' and 5°10'N and longitude 7°40'E and 7°50'E, with a population of 139,090 (National Bureau of Statistics (NBS), n.d.). The area is characterized by green vegetation and two seasons: wet and dry seasons. The presence of the popular Ibagwa barrack, in addition to the rapid development and the establishments of some major oil palm depots, has resulted in a surge in population in the area, consequently raising the demand for meat products. The major economic activity in the area is farming, mainly cassava and palm produce (oil palm and kernel). Eket lies within latitudes 4°31' and 4°45' and longitudes 7°52' and 8°02', with a population of 172,856 (National Bureau of Statistics (NBS), n.d.). Eket experiences tropical weather conditions. The area has experienced a high influx of inhabitants due to increased developmental strides, and also the presence of an oil and gas exploration company. The economic activities in the area include farming, hunting, fishing, and trading.

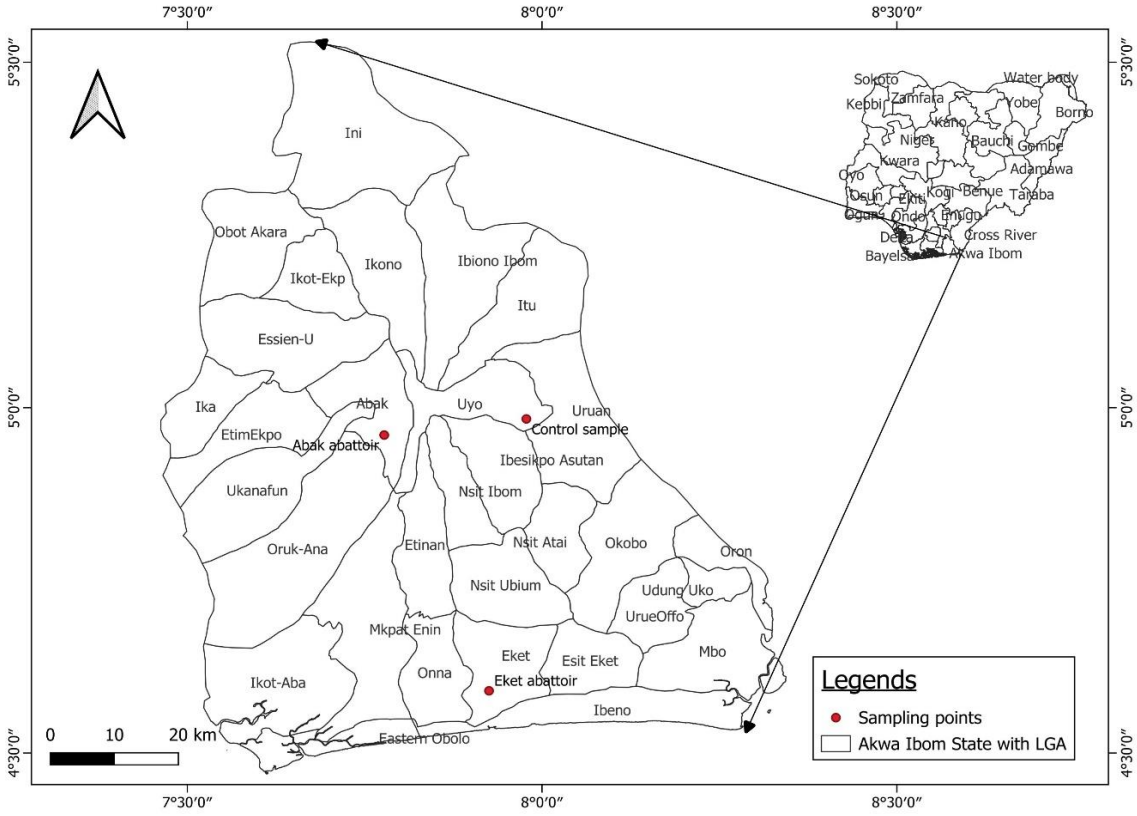


Figure 1. Location of sampling stations on the map of Akwa Ibom, Nigeria

2.2 Sampling

Samples were collected randomly from three points and mixed together to form a composite soil sample for each of the locations. A control soil sample was also collected from university of Uyo, Uyo, Akwa Ibom State. A total of three composite soil samples were collected across the sampling locations, packed in labeled sample bottles and conveyed to the laboratory for preparation and analysis.

2.3 Sample Preparation and Analysis

The samples were prepared and digested following the procedures outlined by Anweting *et al.* (2024b). The filtrate obtained from the digestion was analyzed for the concentration of lead, mercury, cobalt, vanadium, arsenic, iron, copper, cadmium, chromium, manganese, nickel, and zinc using an atomic absorption spectrophotometer (GBC XplorAA Dual, ACN005472686) at the AKS MST-RD Laboratory, Ministry of Science and Technology, Uyo, Akwa Ibom State.

2.4 Quality Control

All apparatus used was washed with nitric acid and rinsed with distilled water. Analytical grade chemicals and distilled water were used for preparing solutions. Calibration of AAS was done following the manufacturer's specifications.

2.5 Appraisal of Pollution Status and Soil Quality

2.5.1 Contamination factor (CF)

This index assessed the contribution of natural and anthropogenic sources to the heavy metal loads on these abattoirs. The equation below highlighted by Hakanson (1980) and Olusola *et al.* (2020) was used in the evaluation:

$$CF = \frac{\text{Concentration of metal in this study}}{\text{Standard concentration in unpolluted soil}} \qquad \text{Eqn. 1}$$

The following classification was used to quantify the extent of contamination: (i) CF < 1 - Low contamination (ii) 1 < CF < 3 - Moderate contamination (iii) 3 < CF < 6 - High contamination, and (iv) 6 > CF - Very high contamination (Hakanson, 1980).

2.5.2 Degree of contamination (Cdeg)

This is an integrated index used to evaluate the level of pollution by heavy metals at a particular location. It is simply the summation of the contamination factors of all studied metals in a sample/location.

$$C_{deg} = \sum CF \qquad \text{Eqn. 2}$$

Udofia *et al.* (2024) classified Cdeg into four categories: (i) Cdeg < 8 = low degree of contamination, (ii) 8 < Cdeg < 16 = moderate degree of contamination, (iii) 16 < Cdeg < 32 = considerable degree of contamination, and (iv) 32 < Cdeg = very high degree of contamination.

2.5.3 Enrichment factor (EF)

This is a parameter used to assess the extent of enrichment or depletion of a pollutant in a sample with respect to the background or reference level. This factor aids in determining whether a pollutant's concentration is influenced by anthropogenic activities or natural processes. Moez *et al.* (2018) defined enrichment factor by the equation below:

$$EF = \frac{\frac{Cx}{CFe}\,Sample}{\frac{Cx}{CFe}\,Control} \qquad \text{Eqn. 3}$$

Where EF is the enrichment factor, Cx is the metal (x) concentration of the studied sample and control as identified in the equation, and CFe is the background concentration of Fe. Fe was chosen because of its natural abundance in the earth's crust. The calculated EF values could be interpreted as follows: (i) EF ≤ 1: no enrichment, (ii) 1 < EF < 3: minor enrichment, (iii) 3 < EF < 5: moderate enrichment, (iv) 5 < EF < 10: moderate-to-severe enrichment, (v) 10 < EF < 25: severe enrichment, (vi) 25 < EF < 50: very severe enrichment, and (vii) EF > 50: extremely severe enrichment.

2.5.4 Geoaccumulation index (I_{geo})

Geoaccumulation index serves as a tool to quantify metal pollution in soil, sediment, and water. This index was evaluated using the equation below:

$$I_{geo} = \log_2 \frac{Cn}{1.5Bn} \qquad \text{Eqn. 4}$$

Where Cn represents the concentration of the metal (n) in the sampled and analyzed soil, Bn represents the background concentration of the same metal (n) and factor 1.5 is the background matrix correction factor due to lithogenic effects. According to Muller (1969), calculated Igeo values could be grouped into 7 classes as follows: (i) Class 0 = Igeo ≤ 0: Uncontaminated, (ii) Class 1 = 0 < Igeo < 1: From uncontaminated to moderately contaminated, (iii) Class 2 = 1 < Igeo < 2: Moderately contaminated, (iv) Class 3 = 2 < Igeo < 3: From moderately contaminated to strongly contaminated, (v) Class 4 = 3

< Igeo < 4: Strongly contaminated, (vi) Class 5 = 4 < Igeo < 5: From strongly to extremely contaminated, and (vii) Class 6 = Igeo > 5: Extremely contaminated.

2.5.5 Pollution load index (PLI)

This index provides information on the level of deterioration caused by the metals. **Eqn. 5** was utilized in the evaluation:

$$PLI = \sqrt[n]{CF_1 \text{ x } CF_2 \text{ x } CF_3 \text{ ... x } CF_n} \qquad \text{Eqn. 5}$$

where CF represents the contamination factor for the metals, and n is the number of analyzed heavy metals. The different categories of PLI are as follows: (i) PLI < 2: No pollution, (ii) 2 < PLI < 3: Heavy pollution, and (iii) 3 < PLI: Extremely heavy pollution (Anweting *et al.*, 2024b).

2.5.6 Potential ecological risk factor (E_r)

Potential ecological risk factor was introduced by Hakanson in 1980. **Eqn. 6** below was used in the calculation:

$$Er = Tr \text{ x } CF \qquad \text{Eqn. 6}$$

Where Tr is the toxic-response factor for metal and CF is the contamination factor. The toxic response factors (Tr) implemented in this study were Pb=Ni=Co=Cu = 5, Cd = 30, As = 10, Cr = 2, Mn=Zn=Fe = 1, Hg = 40, V = 2 (Hakanson, 1980; Ebong *et al.* 2020; Eze *et al.*, 2022; Thongyuan *et al.*, 2021; Umeh *et al.*, 2023). The classification of potential ecological risk factor was (i) Er < 40 = low ecological risk, (ii) 40 < Er ⩽ 80 = moderate ecological risk, (iii) 80 < Er ⩽ 160 = appreciable ecological risk, (iv) 160 < Er ⩽ 320 = high ecological risk, and (v) Er > 320 = severe ecological risk (Udofia *et al.*, 2024).

2.5.7 Ecological risk index (RI)

This is an integrated index used to determine the level of ecological effect caused by the studied metals. This involves the summation of the potential ecological risk factor for all metals for a particular sample/location as defined in the equation below:

$$RI = \sum E_r \qquad \text{Eqn. 7}$$

where ΣEr indicates the summation of metals determined in abattoir soils studied. The classification of Mamat *et al.* (2023) was adopted, viz., (i) RI < 150 = low ecological risk, (ii) 150 < RI < 300 = modest ecological risk, (iii) 300 < RI < 600 = high ecological risk, and (iv) RI > 600 = extremely high ecological risk.

3. Results and Discussion

3.1 Distribution of Metals in Soil

Table 1 shows the concentration of 42.176mg kg^{-1}, 26.318mg kg^{-1} and 17.114mg kg^{-1} of Fe in Abak, Eket, and control, respectively. Values obtained for the studied soils were below 728.01mg kg^{-1} obtained by Ebong *et al.* (2020) in abattoir soils in Akwa Ibom State, Nigeria, but above the values of 1.267mg kg^{-1} and 2.229mg kg^{-1} obtained by Okwakpam *et al.* (2022) in Bayelsa State, Nigeria. The

studied soil had values below the recommended limit of (NESREA, 1999) and (Federal Environmental Protection Agency (FEPA), 1999) (400mg kg^{-1}). The values in the abattoir soils were higher than the control; this portrays that activities and waste generated at the abattoir elevated its concentrations in the surrounding soil. Iron, an essential metal helps in the production of heamoglobin and development of the central nervous system. Its deficiency can result in anemia, fatigue, and other health problems. High level of Fe can result in abdominal pain, joint pain, and organ damage in humans and can also lead to increased acidity and infertility in soil. Pb had concentrations of 1.746mg kg^{-1} and 1.628mg kg^{-1} in Abak and Eket, respectively (**Table 1**). These values were above the values obtained in the control (0.862mg kg^{-1}) but below the permissible limit of 25mg kg^{-1} (Federal Environmental Protection Agency (FEPA), 1999). Results from the studied soils were lower than 18.43±5.59mg kg^{-1} obtained by Numbere (2021) in Rivers State, Nigeria, but above 0.66-1.01mg kg^{-1} obtained in Akwa Ibom State, Nigeria, by Dan *et al.* (2018). Lead, even at very low concentrations, is very hazardous. Accumulation of lead ions in the brain could lead to death, kidney, and gastrointestinal tract as well as central nervous system disorders. Growth retardation in children can be attributed to lead ions (Useh *et al.*, 2017).

Table 1. Results of the heavy metal concentrations of the studied soils in mg kg^{-1}.

Metals	Abak	Eket	Mean	SD	CV (%)	Control	RL
Pb	1.746	1.628	1.687	0.083	4.946	0.862	25.000
Hg	0.001	0.001	0.001	0.000	0.000	0.001	0.300
Co	0.528	0.064	0.296	0.328	110.844	0.009	9.000
As	0.018	0.014	0.016	0.003	17.678	0.002	29.000
Fe	42.176	26.318	34.247	11.213	32.742	17.114	400.000
Cu	5.348	4.824	5.086	0.371	7.285	3.927	36.000
Cd	4.724	3.621	4.173	0.780	18.692	1.684	3.000
Cr	0.121	0.314	0.218	0.136	62.746	0.831	0.050
Mn	0.584	0.573	0.579	0.008	1.345	0.345	200.000
Ni	1.342	2.104	1.723	0.539	31.272	1.114	6.700
Zn	18.312	16.218	17.265	1.481	8.576	14.102	140.000
V	0.048	0.126	0.087	0.055	63.396	0.007	42.000

Key: SD= Standard deviation, CV= Coefficient of variation, RL= Recommended limits

Nausea, insomnia, loss of memory, and anorexia are also health risks associated with lead. Hg had the least concentration. <0.001mg kg^{-1} was obtained at Abak, Eket, and control. This value was below the recommended value of 0.3mg kg^{-1} (DUTCH, n.d.). Values obtained are similar to 0.001mg kg^{-1} obtained by Bosede & Omokaro (2022) in abattoirs at Rivers State, Nigeria. Results show that Co had concentrations of 0.528mg kg^{-1} and 0.064mg kg^{-1} for the Abak and Eket abattoirs, respectively. These values were similar to 0.452 and 0.084mg kg^{-1} reported by Anweting *et al.* (2024b) in abattoir soils at Akwa Ibom State, Nigeria, but lower than 10.13-30.02mg kg^{-1} obtained by Yahaya *et al.* (2010) in Yauri, Kebbi State, Nigeria. These values were higher than 0.009mg kg^{-1} of control but below the 9mg kg^{-1} permissible limit of (DUTCH, n.d.). Cobalt is an essential metal that aids in the production of red blood cells and normal brain function. Its deficiency is rare, but can cause anemia and neurological problems in humans. High concentration of cobalt can result in increased acidity of the soil. 0.018mg kg^{-1} and 0.014mg kg^{-1} were obtained for As in Abak and Eket, respectively (**Table 1**). This study

reported values higher than the control (0.002mg kg^{-1}) and 0.003-0.012mg kg^{-1} of Anweting *et al.* (2024) for abattoir soils in Akwa Ibom State, Nigeria. The results were below the recommended limit of 29mg kg^{-1} (DUTCH, n.d.). Arsenic is a non-essential metal and exposure to high levels can cause cancer and skin lesions. The concentration of Cu was 5.348mg kg^{-1} and 4.824mg kg^{-1} for Abak and Eket, respectively. These values were above 0.05-1.70mg kg^{-1} obtained by Osu & Okereke (2015) in soils of an abattoir at Umuahia, Abia State, Nigeria, but lower than 36.46-40.60mg kg^{-1} of Owagboriaye *et al.* (2016) in Abeokuta, Ogun State, Nigeria. The values were higher than control (3.927mg kg^{-1}), but lower than the 36mg kg^{-1} recommended limit of DUTCH. Although copper at the permissible level helps in the syntheses of blood (Garba *et al.*, 2010), copper at high concentrations can result in blood deformation, liver disease, kidney diseases, and gastric problems (Auwalu *et al.*, 2015; Inengite *et al.*, 2016), and its deficiency can lead to slow growth and a weakened immune system. This study revealed that Cd had concentrations of 4.724mg kg^{-1} and 3.621mg kg^{-1} for Abak and Eket abattoirs, respectively. These values were higher than the control (1.684mg kg^{-1}) and the World Health Organization (2011) permissible limit (3mg kg^{-1}). The values were within 2.1-9.1mg kg^{-1} of Olusola *et al.* (2020) at Ekiti State, Nigeria, but higher than 0.43-0.71mg kg^{-1} of Chukwu & Anuchi (2016) in Obiaakpor, River State, Nigeria. Inhalation of cadmium fumes can result in metal fume fever, and may progress to chemical pneumonitis, pulmonary edema, and death (Hayes, 2008). The observed concentration of Zn was 18.312mg kg^{-1} and 16.218mg kg^{-1} for Abak and Eket, respectively. These values were higher than the 1.302–5.236mg kg^{-1} reported by Ubwa *et al.* (2013) in abattoir soils at Benue State, Nigeria, but below the 23.29mg kg^{-1} of Etuk *et al.* (2019) in Akwa Ibom State, Nigeria. The values were higher than 14.102mg kg^{-1} in the control soil, but lower than the 140mg kg^{-1} permissible limit of Federal Environmental Protection Agency (FEPA). It has been reported that Zn is beneficial to man, as its deficiency can cause congenital abnormalities in children, but an excess of zinc intake can cause health disorders (Morgan *et al.*, 2008). Cr had concentrations of 0.121mg kg^{-1} and 0.314mg kg^{-1} in Abak and Eket, respectively. These values were lower than 0.831mg kg^{-1} of control. However, values obtained at Abak, Eket, and control were all higher than the 0.05 mg kg^{-1} recommended limit of NESREA, 1999. The high value of the control soil could be attributed to natural and/or anthropogenic activities within the area. Concentrations in the studied soils were similar to 0.210±0.050mg kg^{-1} obtained in Akwa Ibom State, Nigeria by Ebong *et al.* (2020). Auwalu *et al.* (2015) reported that chromium can cause allergic dermatitis in human beings. Results indicated 1.342mg kg^{-1} and 2.104mg kg^{-1} of Ni in Abak and Eket, respectively. These values were below 4.107-12.42mg kg^{-1} of Ofomatah *et al.* (2023) in Ogbor Hill, Abia State, Nigeria, and 75.45 mg kg^{-1} of Ande *et al.* (2015) in soils of Wurukum abattoir, Makurdi, Benue State, Nigeria. Values obtained in the studied soils were higher than the control (1.114mg kg^{-1}), but lower than the 6.7 mg kg^{-1} permissible limit of World Health Organization (WHO). Ediene & Iren (2017) had reported that nickel is one of the major causes of cancer in human beings. Manganese had concentrations of 0.584mg kg^{-1} and 0.573mg kg^{-1} in Abak and Eket, respectively. These values were above 0.345mg kg^{-1} of the control, but below the 200mg kg^{-1} permissible limit of NESREA. Results from this study were lower than 249.72–561.03mg kg^{-1} reported by Yahaya *et al.* (2010) in Yauri, Kebbi State, Nigeria, but similar to 0.547 and 0.685mg kg^{-1} obtained by Anweting *et al.* (2024b) in Akwa Ibom State, Nigeria. Manganese is an essential element in the human diet; it helps in macronutrient metabolism, the free radical defense system, and bone formation (Erikson & Aschner, 2019), and it is mostly found in bones, liver, kidneys, and brain (Emsley, 2001). **Table 1** indicated concentrations of 0.048mg kg^{-1} and 0.126mg kg^{-1} of vanadium in Abak and Eket, respectively. These values were higher than 0.007mg kg^{-1} obtained from the control plot, but lower than 42mg kg^{-1} standard

of DUTCH. This study had values similar to 0.034 and 0.123mg kg^{-1} of Anweting *et al.* (2024b) in abattoir soils in Itu and Ikot Ekpene, Akwa Ibom State, Nigeria.

Table 2. Comparing the heavy metal concentrations in mg kg^{-1} of this study with previous studies on these study areas

Ref.	Pb	Hg	Co	As	Fe	Cu	Cd	Cr	Mn	Ni	Zn	V
TSA	1.746	0.001	0.528	0.018	42.176	5.348	4.724	0.121	0.584	1.342	18.312	0.048
EGA	0.55	-	-	-	719.55	19.34	-	0.27	-	10.39	22.7	-
EKA	0.72	-	-	-	642.4	20.55	1.25	-	-	-	36.13	-
TSE	1.628	0.001	0.064	0.014	26.318	4.824	3.621	0.314	0.573	2.104	16.218	0.126
DNE	0.95	-	-	-	638.07	18.61	0.49	0.2	-	9.525	21.345	-

Key: TSA= This study (Abak), EGA= Ebong *et al.* (2020) (Abak), EKA= Etuk *et al.* (2019) (Abak), TSE= This study (Eket), DNE= Dan *et al.* (2018) (Eket)

The data in **Table 2** indicated that this study had concentrations of Pb and Cd higher than previous studies by Etuk *et al.* (2019) and Ebong *et al.* (2020) at the Abak abattoir, whereas, Fe, Cu, Cr, Ni and Zn were lower. At the Eket abattoir, the concentrations of Fe, Cu, Ni and Zn obtained were lower than the values obtained in previous study by Dan *et al.* (2018), and vice versa for Pb, Cd and Cr. Although there are no baseline values for comparison of Hg, Co, As, Mn and V at both abattoirs, values from this study will serve as a baseline for future studies. The disparities observed in this study from previous studies on these abattoirs can be attributed to the rate of activities, reduced/increased dumping of waste and number of animals slaughtered.

3.2 Appraisal of Pollution Status and Soil Quality

3.2.1 Contamination factor (CF) and degree of contamination (Cdeg)

The contamination factor is presented in **Table 3**, the results were determined using **Eqn. 1**. Results ranged from 6.21E-04 - 2.42E+00 (Abak) and 4.83E-04 - 6.28E+00 (Eket). The contamination of the metals increased in the order As > V > Mn > Hg > Co > Pb > Fe > Zn > Cu > Ni > Cd > Cr, and As > Mn > V > Hg > Co > Pb > Fe > Zn > Cu > Ni > Cd > Cr for Abak and Eket abattoirs respectively. Based on the classification defined by Hakanson (1980), cadmium at both abattoirs and chromium in Abak abattoirs showed a moderate contamination, chromium in Eket abattoir showed a high contamination, while the other metals had low contamination. The degree of contamination was calculated using **Eqn. 2**, and the results are presented in **Table 3**. According to the classification adopted by Udofia *et al.* (2024), Abak abattoir with a value of 4.716 had low degree of contamination, and Eket with a value of 8.198 had a moderate degree of contamination.

3.2.2 Enrichment factor (EF)

This factor determines if the concentration of the metals is from geogenic or anthropogenic source. The results ranged from 0.146 - 58.667 in Abak abattoir and 0.378 - 18.000 in Eket abattoir. Results show that except for Hg and Cr originating mostly from geogenic source, the metals were from anthropogenic origin. The sequence observed for Abak and Eket abattoirs were Cr < Hg < Ni < Zn < Cu < Mn < Pb < Fe < Cd < V < As < Co and Cr < Hg < Zn < Cu < Fe < Mn < Pb < Ni < Cd < As < Co < V respectively. Based on the established classification, the findings revealed that Hg and Cr showed no enrichment,

Pb, Fe, Cu, Cd, Mn, Ni, and Zn showed minor enrichment, Co at Eket, V at Abak, and As showed a moderate-to-severe enrichment, V at Eket showed a severe enrichment, and Co at Abak showed an extremely severe enrichment.

Table 3. Pollution and ecological indices of the studied soils

	CF		EF		Er	
Metals	**Abak**	**Eket**	**Abak**	**Eket**	**Abak**	**Eket**
Pb	6.98E-02	6.51E-02	2.026	1.889	0.349	0.326
Hg	3.33E-03	3.33E-03	1.000	1.000	0.133	0.133
Co	5.87E-02	7.11E-03	58.667	7.111	0.293	0.036
As	6.21E-04	4.83E-04	9.000	7.000	0.006	0.005
Fe	1.05E-01	6.58E-02	2.464	1.538	0.105	0.066
Cu	1.49E-01	1.34E-01	1.362	1.228	0.743	0.670
Cd	1.57E+00	1.21E+00	2.805	2.150	47.240	36.210
Cr	2.42E+00	6.28E+00	0.146	0.378	4.840	12.560
Mn	2.92E-03	2.87E-03	1.693	1.661	0.003	0.003
Ni	2.00E-01	3.14E-01	1.205	1.889	1.001	1.570
Zn	1.31E-01	1.16E-01	1.299	1.150	0.131	0.116
V	1.14E-03	3.00E-03	6.857	18.000	0.002	0.006
Cdeg	**4.72E+00**	**8.20E+00**				
PLI	**4.34E-02**	**3.98E-02**				
RI					**54.848**	**51.700**

Key: CF = Contamination factor, EF = Enrichment factor, Er = Potential ecological risk factor, Cdeg = Degree of contamination, PLI = Pollution load index, RI = Ecological risk index

3.2.3 Geoaccumulation index (I_{geo})

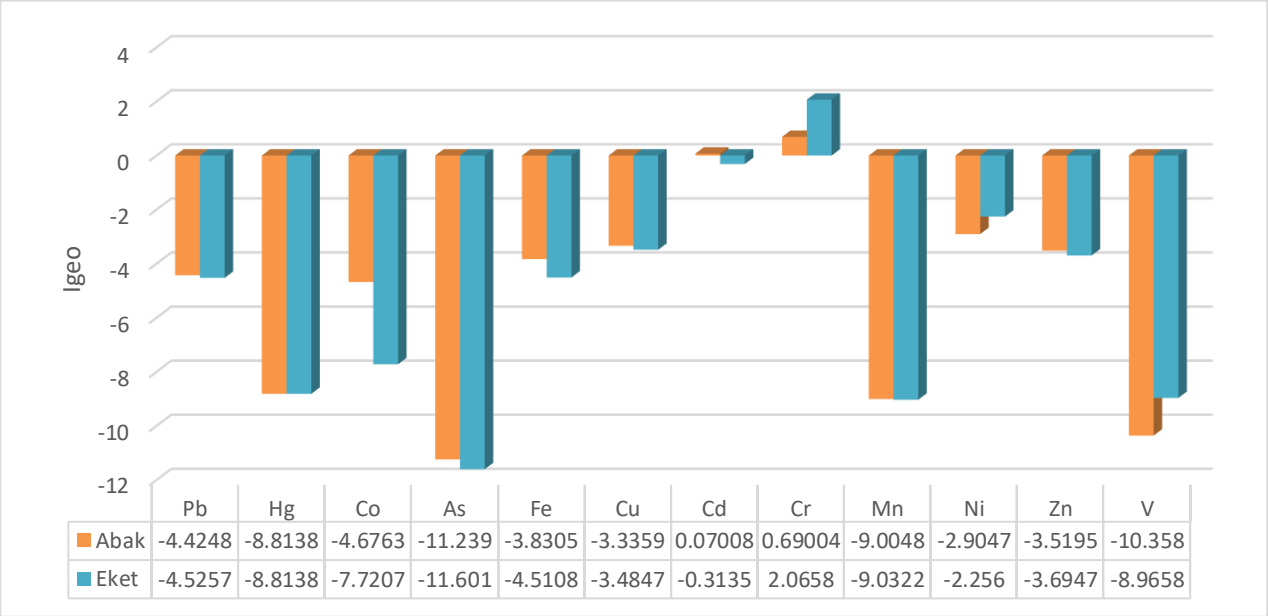
The geological accumulation of heavy metals in the abattoir soils was calculated using **Eqn. 4**. Following the classification of Muller (1969), at the Abak abattoir, the results showed that Cd and Cr posed an uncontaminated to moderately contaminated risk, whereas, the remaining metals showed no contamination. At the Eket abattoir, Cr showed moderate contamination, while the other metals showed no contamination (**Figure 2**).

Pollution load index (PLI): The pollution load index evaluates the level of deterioration caused by heavy metals for a particular sample/location. This index can also be used to compare the level of deterioration between two or more samples/locations. The PLI values for Abak and Eket abattoirs were 4.34E-02 and 3.98E-02 respectively. Both values were in the class 1 category of PLI < 2, this indicates that both abattoirs were not polluted by the studied metals.

3.2.4 Potential ecological risk factor (E_r) and ecological risk index (RI)

The potential ecological risk factor and ecological risk index are summarized in **Table 3**. This study revealed that the ecological risk factor ranged from V (0.002) - Cd (47.240) for Abak abattoir and Mn (0.002) - Cd (36.210) for Eket abattoir. The classification of Udofia *et al.* (2024) adopted for this study showed that all metals had a low ecological risk except Cd (47.240) with moderate ecological risk at Abak abattoir. The values for ecological risk index for Abak and Eket abattoirs were 54.848 and 51.700

respectively. Following the classification of Mamat *et al.* (2023), both values were in class 1 category of RI < 150, indicating a low ecological risk.



	Pb	Hg	Co	As	Fe	Cu	Cd	Cr	Mn	Ni	Zn	V
Abak	-4.4248	-8.8138	-4.6763	-11.239	-3.8305	-3.3359	0.07008	0.69004	-9.0048	-2.9047	-3.5195	-10.358
Eket	-4.5257	-8.8138	-7.7207	-11.601	-4.5108	-3.4847	-0.3135	2.0658	-9.0322	-2.256	-3.6947	-8.9658

Figure 2. Geoaccumulation index of the studied abattoirs

4. Conclusion

This research indicated that the activities resulting in inappropriate disposal of waste elevate the concentration of heavy metals in the soils of the studied abattoirs. This is evident in the observation of higher values in the studied soils than control soil. The concentrations of the metals were below the standards of WHO, DUTCH, NESREA and FEPA, except cadmium and chromium. Comparatively, the concentrations in this study with previous studies (between 3-5 years before this study) on these abattoir soils indicated that the concentrations of most of the metals had reduced and vice versa. Generally, pollution indices showed a minimal status of pollution, although Cd and Cr showed potential threat of pollution. Ecological health indices depicted low ecological risk. Cadmium and chromium are highly carcinogenic, their concentrations which are above recommended limits needs urgent remedial action.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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