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Evaluating the Impact of Abattoir Wastes on Soil Properties in Benin City, Edo State, Nigeria

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Abstract

Abattoir wastes is a major environmental concern to both urban and peri-urban areas in Nigeria. Therefore, its impact on soil properties in Benin City, Edo State, Nigeria was evaluated. Variations in the morphological, physicochemical and microbial properties of the abattoir soils were assessed while the heavy metals toxicity of the soils were evaluated. A total of 24 soil samples were randomly collected from the abattoirs in Oluku and Ikpoba slope areas as well as the non-abattoir site (control) at depths of 0-15 cm (topsoil) and 15-30 cm (subsoil) respectively. Each of the soil samples was evaluated in-situ for key morphological characteristics. The physicochemical and microbial properties of the soils were determined in the laboratory following standard methods, while the heavy metal concentrations were estimated using the atomic absorption spectrophotometer method. Results revealed that the abattoir soils were predominantly black in colour. Consistent anthropogenic disturbances may have caused the abattoir soils to be more compact with higher mean bulk density (BD) values (1.25 - 1.35 Mg/m^3) than the control that had 1.15 Mg/m^3. The abattoir soils which were slightly alkaline and rich in organic matter could serve as a good source of manure for agricultural purposes. There were increased fungi and bacteria counts in the abattoir soils. All the examined heavy metals - lead (Pb), cobalt (Co), chromium (Cr) and cadmium (Cd) were more concentrated in soils of the abattoir sites than the control site, but were within the toxicity limits established by World Health Organization and the Department of Petroleum Resources (Nigeria). However, these heavy metals could pose potential risks to the soil environment and health of nearby residents. The study also revealed that contamination factor, geo-accumulation index, enrichment factor, contamination degree and pollution load index of the heavy metals were all within the acceptable ranges. In the correlation matrix, the major significant positive relationships that were observed were between silt and total porosity, potassium, chromium, total heterotrophic bacteria count; while the significant negative relationships were between sand and silt, total porosity, potassium, chromium, total heterotrophic fungi count. The study concluded that Pb was the major heavy metal contaminant among the investigated heavy metals in the abattoir soils which could have devastating effects on public health if left unchecked.

Keywords: Abattoir wastes, Morphological, Physicochemical properties, Microbial counts, Heavy metals, Contamination, Benin City

Introduction

Human activities create significant volume of wastes which pose serious threat to the soil ecosystem (Ezeoha & Ungwuishiwu, 2011). One type of waste that is of concern to both urban and peri-urban areas in Nigeria are wastes generated from abattoirs. An abattoir is defined as any environment approved and registered by regulatory bodies for hygienic inspection, slaughtering, processing and storage of livestock products for human consumption (Alonge, 1992). Due to the dependence on meat as a major source of protein for the rapidly increasing population, the number of abattoirs in Nigerian cities is increasing (Ibeaja & Njoku, 2024). Abattoir activities generate both solid and liquid wastes. These wastes vary spatially depending on the intensity of activities, types of livestock being slaughtered and the processing method. Akinyeye et al. (2012) stated that untreated abattoir wastes could pose a health risk and cause ecological imbalance when released into the environment.

Abattoir wastes include the residual materials obtained after the slaughter of animals which comprise of materials like blood, waste water/effluent, urine, undigested feed, chemicals added during processing operations etc., which when discharged into the soil could impact their morphological, physical, chemical and microbial properties (Emmanuel et al., 2018). Ogunlade et al. (2021) reported that different parts of animals such as liver, muscle, kidney, viscera, blood and fur have been found to contain heavy metals. The addition of organic wastes to soil can improve its quality by acting on the physicochemical as well as microbial properties. Some farmers use abattoir wastes as organic manure in arable farming. This implies that through the food chain, heavy metals in abattoir wastes may be transferred into humans which can cause serious health problems.

According to Eze (2016), almost all industries in Nigeria generate wastes which in most cases are disposed-off without due regard to proper environmental management practices. The unacceptable conditions by which abattoir wastes are disposed contribute to the degradation of soil quality in Benin City. Therefore, providing a broad understanding of the morphological, physicochemical and microbial properties of abattoir soils as well as their heavy metal concentrations can be viewed as a prerequisite for the design and successful implementation of response strategies in abattoir management.

Recent studies on the impact of abattoir wastes on soil properties in Nigeria include effect of abattoir activities on the physicochemical properties of soil within a residential area in Omu-Aran town, Kwara State (Elemile, 2019); microbial and heavy metal assessment of abattoir soils in Iworoko, Ekiti State (Ogunlade et al., 2021); effect of abattoir wastes on the physical, chemical and bacteriological properties of soils from Choba abattoir in Rivers State (Sampson and Deele, 2022); effects of abattoir activities on the surrounding soils within Abuja (Useh et al., 2022); and abattoir wastes influence on soil quality at Ukwunwangwu, Uturu, Abia State (Ibeaja & Njoku, 2024). These studies revealed diverse impacts of abattoir activities on soil. Some of the studies reported variations in the soil physicochemical and microbial properties of the abattoir soils while others found varied concentrations of the heavy metals.

However, no study has carried out a comprehensive evaluation of the impact of abattoir wastes on the morphological, physical, chemical, microbial and heavy metal concentrations of soils in Benin City. The limited studies (Akinyeye et al., 2012; Akinnibosun & Ayejuyoni, 2015) that have been conducted in the study area did not account for the impact of abattoir wastes on the morphological characteristics and toxicity of heavy metals in the soil. Also, they did not take into account the significant variations in the physicochemical, microbial and heavy metal concentrations in soils of the different abattoir locations. Therefore, this research will deepen scientific knowledge and provide recent broad spectrum of data on the impact of abattoir wastes on soil in Benin City. The specific objectives of the study were to: (a) examine the morphological characteristics of the abattoir soils, (b) assess variations in their physicochemical and microbial properties, (c) determine the toxicity of heavy metals, and (d) evaluate the relationships between the soil properties.

Methods

Field work

This research was carried out in Benin City which is located within Latitudes 6° 16’ and 6° 33’ N and Longitudes 5° 31’ and 5° 45’ E (Figure 1). Benin City is situated in the tropical rainforest zone of southern Nigeria with mean annual temperature of between 22.88 and 31.50° C and average annual rainfall of approximately 1965.32 mm (Balogun et al., 2023a). The geology of Benin City is underlain by sedimentary formation of the south Sedimentary basin. The area is marked by top reddish earth, composed of deep, porous, non-mottled, nonconcretional soils which are described as Rhodic Kandiudulf (Ugwa et al., 2016).

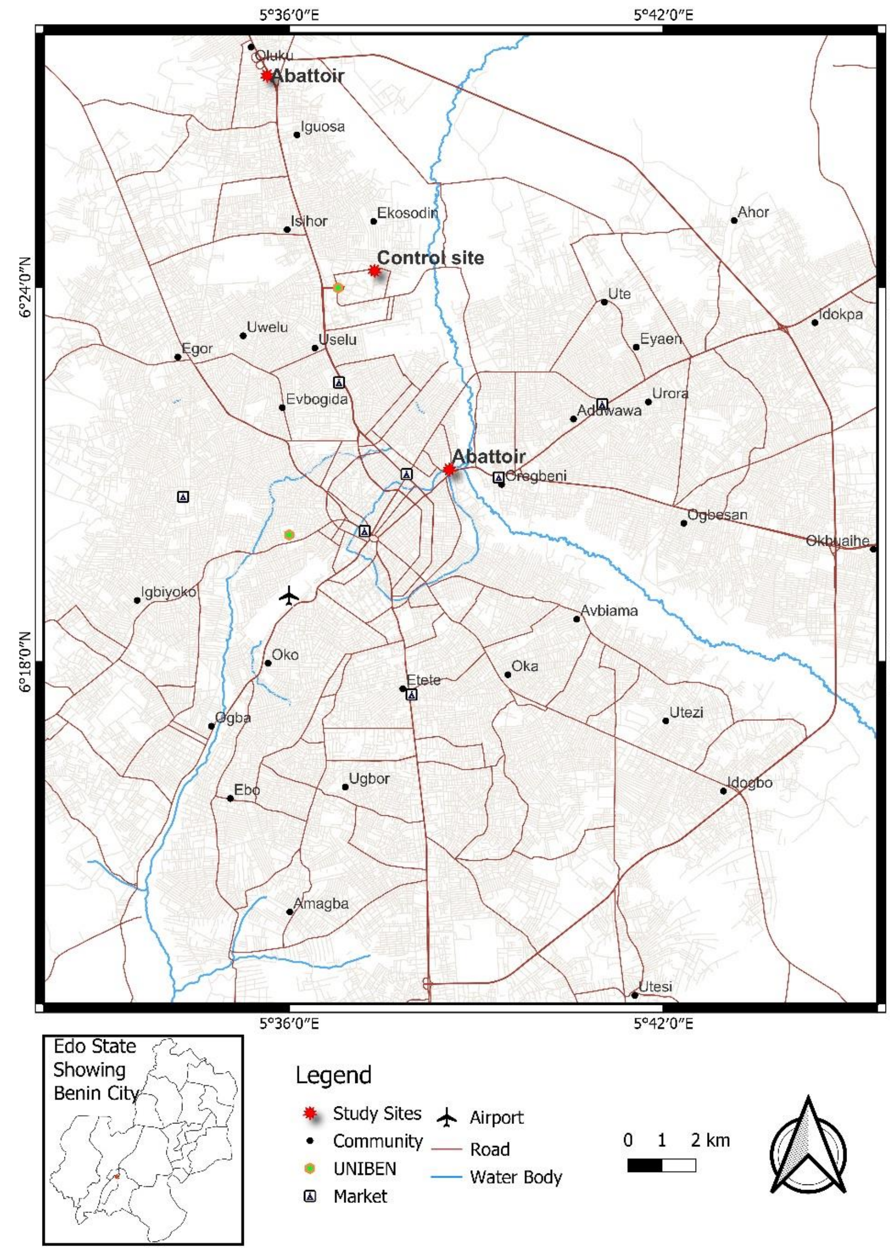

Figure 1: Benin City Showing the Study Sites.
Source: Compiled using Esri, USGS, Geobase, Ordnance Survey, OpenStreetMap, GIS user Community and Author's Field Data (2024).

The examined abattoirs which are in Ikpoba slope and Oluku communities are the two major abattoirs located in the urban core and peri-urban zones of Benin City. These abattoirs process large quantity of livestock and consequently were suitable for this study. The control soils were taken from a non-abattoir site within the University of Benin, Ugbowo campus (Figure 1). Eight soil samples each were randomly collected from four different sampling points at the topsoil (0-15 cm) and subsoil (15-30 cm) of the three sites using a soil auger, making a total of 24 soil samples for this study. The key morphological characteristics of the soil samples were evaluated in-situ using a Munsell soil colour chart and by hand-felt technique. The coordinates of each sampling points were taken using a Garmin® GPSMAP 64st receiver. The 24 soil samples were taken to the laboratory for analysis.

Soil laboratory analysis

The soil samples were air dried and passed through 2 mm sieve to remove coarse materials and impurities. The soil samples were air dried and allowed to harmonize for some days prior laboratory analyses. Soil texture (sand, silt and clay) was determined using hydrometer method (Gee and Or, 2002). Bulk density was determined after the soil samples were oven dried at 105°C for 24 hours (Grossman & Riensah, 2002). Total porosity was derived from the relationship of particle density (Dp) to the bulk density (BD) using the Brady and Weil (2007) formular: $TP\ (\%) = \left(1 - \frac{BD}{Dp}\right) \times 100$, where TP = total porosity, BD = bulk density and Dp = particle density. The average Dp of mineral soil which is 2.65 Mg/m^3 was used in the computation.

Soil pH was determined by McLean (1982) method. Organic carbon was determined by the dichromate wet oxidation method of Nelson and Sommers (1982). Total nitrogen was determined using micro-kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined calorimetrically by molybdenum blue method (Bray and Kurtz, 1945). For the exchangeable cations, calcium and magnesium were determined by ammonium acetate method while sodium and potassium were by flame photometer. The extractable micronutrients (copper, iron, zinc and manganese) were obtained by leaching the soil with 0.1 NN HCL and their concentrations were measured with Perkin-Elmer Analyst 300 atomic absorption spectrophotometer (AAS) (Lindsay and Norvell, 1978). Heavy metal (cobalt, chromium, lead and cadmium) concentrations in the soil samples were extracted by leaching into 0.1 M ethylenediaminetetraacetic acid (EDTA) and subsequently analyzed using atomic absorption spectrophotometer (AAS) (Ogbonna and Okeke, 2010). Enumeration of the bacteria and fungi populations was by the method used by Useh and Dauda (2018).

Statistical analysis

Descriptive statistics were computed for the examined soil properties. Analysis of variance (ANOVA) was used to test for significant variations of the soil properties among the studied sites. Pearson correlation coefficient analysis was carried out to identify relationships between the soil properties. The correlation coefficients were calculated using the entire soil data. This means that data from each of the two examined abattoirs and soil depths were summed and treated as one whole. This was aimed at eliminating repetitiveness of results from each abattoir site and soil depth. All the statistical analyses were carried out using Microsoft Excel (2010) and IBM SPSS statistics 16.00 software packages.

Toxicity assessment of heavy metals in soil

To quantify the extent of heavy metals contamination of the abattoir soils relative to the average crustal composition, the contamination factor (CF_i) of each heavy metal was calculated using the Hakanson (1980) formula (Equation 1). The toxicity values for each examined heavy metals were: cadmium (Cd) = 0.80, cobalt (Co) = 50.00, lead (Pb) = 85.00 and chromium (Cr) = 100.00 (WHO, 2006; DPR, 2002). The contamination factor(CF_i) for each heavy metal was rated accordingly: $CF_i < 1$ = low contamination; $1 < CF_i < 3$ = moderate contamination; $3 < CF_i < 6$ = high contamination; and $CF_i > 6$ = very high contamination.

$$Contamination\ factor\ (CF_i) = \frac{mean\ heavy\ metal\ concentration\ in\ soil}{toxicity\ value\ of\ heavy\ metal} \text{……Equation 1}$$

All the contamination factors (CF_i) for all the heavy metals were summed to derive the degree of contamination (C_{deg}) for each abattoir site (Kowalska et al., 2018), and was interpreted as: $C_{deg} < 8$ = low degree of contamination, $8 \leq C_{deg} < 16$ = moderate degree of contamination, $16 \leq C_{deg} < 32$ = considerable degree of contamination, and $C_{deg} > 32$ = high degree of contamination.

Enrichment factor (EF) was used to evaluate the impact of abattoir activities on heavy metal abundance in the soil. According to Moez et al. (2018), EF is derived using Equation 2. The calculated EF values were interpreted as: EF ≤ 1 = no enrichment, 1 < EF < 3 = minor enrichment, 3 < EF < 5 = moderate enrichment, 5 < EF < 10 = moderate to severe enrichment, 10 < EF < 25 = severe enrichment, 25 < EF < 50 = very severe enrichment, and EF > 50 = extremely severe enrichment.

$$\text{Enrichment factor} = \frac{\left(\frac{mean\ heavy\ metal\ concentration\ in\ soil}{F_e\ concentration\ for\ normalization}\right)}{\left(\frac{toxicity\ value\ of\ heavy\ metal}{Fe\ concentration\ for\ normalization}\right)} \text{ ……………………… Equation 2}$$

Geo-accumulation index (Igeo) was used to compare the current heavy metal concentrations with pre-industrial levels (Equation 3). Values of the geo-accumulation index were interpreted as: Igeo < 0 = uncontaminated, 1 ≤ Igeo < 2 = uncontaminated to moderately contaminated, 2 ≤ Igeo < 3 = moderately to heavily contaminated, 3 ≤ Igeo < 4 = heavily contaminated, 4 ≤ Igeo < 5 = heavily to extremely contaminated, and Igeo ≥ 5 = extremely contaminated.

$$Geo - accumulation\ index = \text{Log}_2 \left(\frac{mean\ heavy\ metal\ concentration\ in\ soil}{1.5 \times toxicity\ value\ of\ heavy\ metal}\right) \text{……. Equation 3}$$

Pollution load index (PLI) provides an easy way to prove the deterioration of soil quality as a result of the accumulation of heavy metals. The PLI was calculated using Equation 4 according to the procedure of Simeon and Friday (2018). The values of the PLI were rated as: PLI ≤ 1 = unpolluted, 1 < PLI ≤ 2 = unpolluted to moderately polluted, 2 < PLI ≤ 3 = moderately polluted, 3 < PLI ≤ 4 = moderately to highly polluted, 4 < PLI ≤ 5 = highly polluted, and PLI ≥ 5 = very highly polluted (Jorfi et al., 2017).

$$\text{Pollution load index (PLI)} = \left(CF_{i1} \times CF_{i2} \times CF_{i3} \ldots \ldots \ldots \ldots CF_{in}\right) \frac{1}{n} \text{……………Equation 4}$$

Results and Discussion

Impact of abattoir wastes on the soil morphological characteristics

The morphological characteristics of the abattoir soils are presented in Table 1. Although the soil samples had varying hue and chroma values, they were predominantly of black colour in Oluku and Ikpoba slope abattoir sites, and dark reddish brown in the control site. The dominant black colour of the abattoir soil is indicative of high organic matter content which may be due to the decomposition of animal parts and the discharge of abattoir wastes into the soil. This outcome could also be the result of ash, arisen from fire which the soils are constantly subjected to during livestock processing. These processes imply that abattoir activities impact the soil with black colour. Radha et al. (2011) reported similar colour notations in their study.

The dominant texture from in-situ evaluation of the soil samples revealed no clear variation between the three sites as they were majorly silty loam. However, a few samples were sandy loam in the control site (Table 1). This result suggests that the soils had a balanced mix of sand, silt and clay, and were well drained and aerated. This is true because the sand, silt and clay mean contents for all the soil samples were 514 g/kg or less, implying equilibrium in their distribution. Furthermore, silty loam soils are known to be slightly acidic to slightly alkaline. This observation is consistent with the friable and loose consistency of majority of soils which infers the fragile nature of the soil. The structure of the soils varied from strong, weak, moderate, fine, coarse, medium to sub angular.

Table 1: Results of abattoir wastes impact on the morphological characteristics of the soil

Sampling point	Soil depth	Major colour (moist)	Texture (field)	Structure	Consistency (moist)
		Oluku abattoir			
A_1	Topsoil	gley 2.5/1; bluish black	sandy loam	moderate, coarse, sub angular	loose
A_2	Subsoil	5YR 2.5/1; black	sandy loam	moderate, medium, sub angular	friable
B_1	Topsoil	gley 2.5/1; bluish black	sandy loam	strong, coarse, sub angular	friable
B_2	Subsoil	2.5YR 3/4; dark reddish brown	sandy loam	weak, coarse, sub angular	friable
C_1	Topsoil	10R 4/3; weak red	silty loam	weak, coarse, sub angular	friable
C_2	Subsoil	5YR 2.5/1; black	silty loam	weak, fine, granular	loose
D_1	Topsoil	5Y 2.5/1; black	silty loam	weak, fine, granular	friable
D_2	Subsoil	5YR 2.5/1; black	silty loam	weak, fine, granular	loose
		Ikpoba slope abattoir			
E_1	Topsoil	2.5YR 2.5/1; reddish black	silty loam	weak, fine, granular	loose
E_2	Subsoil	5YR 2.5/1; black	loam	weak, fine, granular	friable
F_1	Topsoil	10YR 2/2; very dark brown	silty loam	weak, medium, granular	loose
F_2	Subsoil	7.5YR 2.5/3; very dark brown	silty loam	weak, fine, granular	loose
G_1	Topsoil	5YR 2.5/1; black	silty loam	strong, coarse, sub angular	firm
G_2	Subsoil	5Y 2.5/1; black	silty loam	moderate, medium, sub angular	firm
H_1	Topsoil	5Y 2.5/1; black	silty loam	moderate, medium, sub angular	firm
H_2	Subsoil	5YR 2.5/1; black	silty loam	moderate, medium, sub angular	friable
		Control site			
I_1	Topsoil	2.5YR 3/2; very dusky red	silty loam	weak, medium, sub angular	loose
I_2	Subsoil	2.5YR 4/4; reddish brown	silty loam	weak, coarse, granular	loose
J_1	Topsoil	2.5YR 2.5/2; very dusky red	silty loam	moderate, medium, granular	friable
J_2	Subsoil	2.5YR 3/4; dark reddish brown	loam	moderate, coarse, sub angular	firm
K_1	Topsoil	2.5YR 2.5/2; very dusky red	silty loam	weak, medium, granular	loose
K_2	Subsoil	2.5YR 3/2; dusky red	silty loam	weak, fine, crumb	loose
L_1	Topsoil	2.5YR3/4; dark reddish brown	loam	weak, fine, granular	loose
L_2	Subsoil	2.5YR 3/4; dark reddish brown	loam	moderate, medium, sub angular	friable

Impact of abattoir wastes on the physical properties of the soil

The physical properties of soils from the studied sites (Table 2) revealed non-significant difference ($p > 0.05$) in sand, silt and clay fractions. However, sand contents were higher in the topsoil (514.00 and 417.30 g/kg) than in the subsoil (393.50 and 374.30 g/kg) of both abattoirs with the reverse order observed for silt and clay contents. This result indicates that as sand contents were decreasing with depth, silt and clay were increasing. This is not surprising as recent studies (Ugwa et al., 2023; Ekpenkhio & Ugwa, 2023) in the tropical rainforest zone revealed similar results. Since this climate zone is distinctive of heavy rainfall, silt and clay may have translocated below the topsoil thereby leaving sand dominant in the topsoil.

Bulk density (BD) and TP provide insight into soil strength and the resistance it gives to root penetration. The values of BD in both top- and sub-soils of the abattoir sites were higher than those of the control site. Anthropogenic disturbances such as livestock trampling on topsoil and burning of animal residues in the abattoir sites may have accounted for this outcome. The higher organic carbon content in the abattoir soils may have accounted for the significant difference ($p \leq 0.05$) of BD at the topsoil. The range of BD values obtained from the abattoir sites were lower than the 1.75 Mg/m^3 maximum limit (Arshad & Martin, 2002). This result agrees with the work of Olayinka et al. (2017) who examined abattoir soils in western Nigeria. The mean values for TP in all the soils were classified as very high (FAO, 2006). However, the control site was more porous than the abattoir sites which implied freer water and air movements in the control soils.

Impact of abattoir wastes on the chemical and microbial properties of the soil

Using the Foth and Ellis (1997) classification tool, Table 2 revealed that the pH values of the control soils were slightly acidic (6.03 - 6.59) while that of the two abattoir soils were slightly alkaline (7.72 - 8.05). The pH values were in the order: Oluku abattoir > Ikpoba slope abattoir > Control. The slightly alkaline soil condition of the abattoir site in this study is in agreement with earlier works by Sampson and Deele (2022) and Ogunlade et al. (2021). The significantly high ($p \leq 0.05$) pH values in both soil depths of the abattoir sites than the control site could be attributed to the decomposing abattoir wastes, thereby lowering anaerobic activities and modifying soil reaction. However, the pH values were within the World Health Organization recommended threshold limits of between 6.5 and 8.5 for abattoir soils (Useh et al., 2022).

The values of organic carbon (OC) were significantly higher ($p \leq 0.05$) in soils of the two abattoir sites compared to that of the control site (Table 2). The observation that OC in topsoil of abattoir sites were five times higher than the control site may be attributed to the volume of organic wastes present in the surface soil of the abattoir sites. This indicates that the abattoir waste significantly and positively impacted OC availability in the soil. Since OC gives an indication of organic matter (OM) in soil (Brady, 2002), it can be inferred that OM in the soil had similar pattern as OC which showed that the soils were rich in organic matter content. This outcome is in line with Useh et al. (2022).

The concentrations of total nitrogen (TN) and available phosphorous (Avl. P) were significantly higher ($p \leq 0.05$) in the abattoir sites than in the control site which implies that abattoir wastes are N and P enriching. This may be due to the decomposition of proteinaceous and nitrogenous compounds (Emmanuel et al., 2018; Useh et al., 2022). The order of TN concentrations was Ikpoba slope abattoir > Oluku abattoir > Control. The increase in TN with depth in the abattoir sites maybe the result of high sand contents in the topsoil which weakens surface accretion resulting in the absorptive capability for soils to hold nutrients. High concentration of P in soil may reduce the concentrations of micronutrients - Zn, Cu, Mn and Fe (Ediene et al., 2016). Table 2 shows that all the micronutrients were significantly lower ($p \leq 0.05$) in the abattoir sites than in the control site.

Table 2: Results of abattoir wastes impact on the physical, chemical and microbial properties of the soil

Soil property	Soil depth	Oluku abattoir			Ikpoba slope abattoir			Control site			*p*-value
		Range	Mean	CV (%)	Range	Mean	CV (%)	Range	Mean	CV (%)	
Sand (g/kg)	Topsoil	250.00 - 625.00	514.00	34.82	222.00 - 625.00	417.30	50.50	461.50 - 571.40	530.90	9.02	0.58
	Subsoil	143.00 - 625.00	393.50	59.30	222.00 - 625.00	374.30	49.31	428.60 - 555.00	494.00	12.53	0.60
Silt (g/kg)	Topsoil	250.00 - 625.00	364.50	48.84	250.00 -189.10	429.00	44.09	285.70 - 384.60	349.40	12.48	0.74
	Subsoil	250.00 - 714.00	480.50	46.58	250.00 - 625.00	457.70	36.58	274.00 - 363.60	325.50	13.10	0.38
Clay (g/kg)	Topsoil	111.00 - 125.00	121.50	5.76	125.00 - 222.00	153.80	30.10	90.90 - 153.90	119.70	27.97	0.31
	Subsoil	111.00 - 143.00	126.00	10.41	125.00 - 222.00	168.00	30.03	155.00 - 214.20	180.50	13.86	0.10
BD (Mg/m^3)	Topsoil	1.25 - 1.25	1.25	0.00	1.25 - 1.25	1.25	0.00	1.08 - 1.25	1.15	6.18	0.01*
	Subsoil	1.25 - 1.25	1.25	0.00	1.25 - 1.66	1.35	15.16	1.11 - 1.19	1.15	3.18	0.11
TP (%)	Topsoil	33.30 - 50.00	43.18	16.70	33.30 - 50.00	42.93	19.64	65.20 - 75.00	69.80	5.98	0.00*
	Subsoil	33.50 - 50.00	43.18	16.70	33.30 - 50.00	39.85	20.36	68.10 - 73.80	70.73	3.85	0.00*
pH	Topsoil	7.74 - 8.05	7.89	1.65	7.73 - 7.88	7.79	0.85	6.18 - 6.48	6.33	2.16	0.00*
	Subsoil	7.72 - 8.05	7.88	2.03	7.65 - 7.88	7.77	1.24	6.03 - 6.59	6.25	3.99	0.00*
OC (g/kg)	Topsoil	2.8 - 3.81	3.09	15.46	2.84 - 3.86	3.19	14.93	0.45 - 0.58	0.52	11.64	0.00*
	Subsoil	1.26 - 2.60	1.69	36.18	2.41 - 2.72	2.51	5.78	0.15 - 0.28	0.19	29.06	0.00*
TN (g/kg)	Topsoil	0.23 - 0.32	0.27	14.50	0.27 - 0.33	0.29	9.26	0.13 - 0.15	0.14	5.83	0.00*
	Subsoil	0.23 - 0.33	0.28	17.44	0.26 - 0.34	0.30	12.17	0.11 - 0.13	0.12	6.80	0.00*
Avl. P (mg/kg)	Topsoil	4.80 - 6.14	5.59	10.20	4.66 - 6.14	5.37	13.22	1.47 - 1.71	1.59	7.85	0.00*
	Subsoil	2.98 - 4.52	3.63	17.91	3.42 - 4.65	3.87	13.84	0.98 - 1.38	1.19	14.16	0.00*
Mg (cmol/kg)	Topsoil	1.68 - 2.21	2.02	11.56	2.01 - 2.90	2.36	16.65	0.53 - 0.84	0.70	21.35	0.00*
	Subsoil	1.52 - 2.01	1.83	12.53	1.98 - 2.20	2.09	4.30	0.50 - 0.79	0.66	21.92	0.00*
Ca (cmol/kg)	Topsoil	4.75 - 6.81	5.92	14.62	5.8 - 7.1	6.56	8.97	1.26 - 2.14	1.62	25.83	0.00*
	Subsoil	4.32 - 5.81	5.35	13.17	5.10 - 6.80	6.05	11.65	1.22 - 2.10	1.56	25.59	0.00*
Na (cmol/kg)	Topsoil	0.43 - 0.59	0.49	14.64	0.42 - 0.60	0.53	16.04	0.60 - 0.71	0.65	7.85	0.02*
	Subsoil	0.40 - 0.59	0.49	19.96	0.46 - 0.61	0.55	11.59	0.56 - 0.69	0.63	9.33	0.09

K (cmol/kg)	Topsoil	0.51 - 0.71	0.57	16.52	0.53 - 0.62	0.58	6.45	0.78 - 0.81	0.79	1.62	0.00*
	Subsoil	0.48 - 0.41	0.58	19.35	0.51 - 0.60	0.57	7.44	0.74 - 0.78	0.76	2.25	0.00*
Fe (mg/kg)	Topsoil	14.60 - 16.70	15.50	5.70	10.21 - 27.80	17.86	44.63	158.41 - 174.22	166.76	4.21	0.00*
	Subsoil	12.09 - 48.91	23.00	75.43	10.21 - 27.24	17.14	44.23	170.10 - 192.65	181.85	5.16	0.00*
Cu (mg/kg)	Topsoil	0.90 - 1.63	1.30	23.31	0.76 - 0.88	0.81	6.76	11.92 - 14.20	13.26	8.27	0.00*
	Subsoil	0.90 - 1.60	1.20	24.53	0.75-0.96	0.81	11.96	11.25 - 13.90	12.84	9.89	0.00*
Mn (mg/kg)	Topsoil	1.91 - 2.58	2.14	14.06	2.40 - 3.10	2.72	10.98	11.92 - 14.20	13.26	8.26	0.00*
	Subsoil	1.90 - 2.72	2.35	17.75	2.20 - 2.80	2.45	10.27	11.25 - 13.90	12.85	9.89	0.00*
Zn (mg/kg)	Topsoil	9.20 - 10.61	9.69	6.81	6.10 - 9.89	8.14	19.12	20.82 - 24.82	22.24	8.40	0.00*
	Subsoil	8.50 - 10.60	9.25	10.24	6.10 - 9.80	8.01	18.96	18.90 - 23.47	20.94	9.68	0.00*
THBC (mg/kg)	Topsoil	1.04 - 9.20	5.13	90.29	1.09 - 8.00	5.45	55.25	1.90 - 4.00	3.28	29.00	0.61
	Subsoil	1.12 - 8.00	5.33	53.31	4.80 - 7.80	6.05	20.84	2.00 - 3.20	2.70	20.73	0.07
THFC (mg/kg)	Topsoil	1.00 - 9.00	3.62	100.34	3.20 - 7.00	4.17	45.12	1.80 - 2.40	2.23	12.90	0.51
	Subsoil	1.30 - 6.00	2.55	90.36	2.40 - 3.10	2.80	10.51	1.60 - 2.20	2.05	14.63	0.73

BD = bulk density, TP = total porosity, OC = organic carbon, TN = total nitrogen, Avl. P = available phosphorous, Mg = magnesium, Ca = calcium, Na = sodium, K = phosphorous, Fe = iron, Cu = copper, Mn = manganese, Zn = zinc, THBC = total heterotrophic bacteria count, THFC = total heterotrophic fungi count, CV = coefficient of variation, * = significant at 0.05 level, Topsoil = 0-15 cm, Subsoil = 15-30 cm.

The order of calcium (Ca) and magnesium (Mg) concentrations was Ikpoba slope abattoir > Oluku abattoir > Control while that of sodium (Na) and potassium (K) was Control > Ikpoba slope abattoir > Oluku abattoir respectively (Table 2). The concentrations of Ca and Mg were significantly higher ($p \leq 0.05$) in the two soil depths of the abattoir sites compared to the control site. The most dominant cation in the exchangeable complex was Ca with values varying between 4.32 and 6.81 cmol/kg. The enrichment of exchangeable bases (Ca and Mg) in abattoir sites may be attributed to decomposed and mineralized abattoir wastes. The abattoir sites are therefore rich in nutrients and suitable for agricultural purpose. The low mean Na values recorded in the abattoir soils implies that they were less sodic than the control soils and thus do not constitute any negative effect on the soil. Available micronutrients (Fe, Cu, Mn and Zn) were significantly higher ($p \leq 0.05$) in the control site compared to the treatment sites across all the soil depths. Brady (2002) argued that micronutrients are more available in acidic soils than alkaline soils. This may have accounted for the higher concentrations of micronutrients in the control site (Table 2).

Bacteria and fungi counts were insignificantly higher ($p > 0.05$) in both top- and sub- soils of the abattoir sites compared to the control. The order of bacteria and fungi population density was Ikpoba slope abattoir > Oluku abattoir > Control. The higher microbial population density in the abattoir soils may be ascribed to the accumulation of organic waste in the soil from the abattoir activities. This means that abattoir wastes influence bacteria and fungi growth in soil, which could destabilize soil ecological balance. The high number of microbes in the abattoir soils, if eroded into nearby surface water can pose serious health concerns for both animals and humans who use the water. Radha et al. (2011) had earlier established that soils contaminated with abattoir effluent contain higher counts of bacteria and fungi.

Toxicity assessment of heavy metals in the abattoir soils

Table 3 reveals that the concentrations of the examined heavy metals (Pb, Cd, Co and Cr) were significantly higher in the contaminated abattoir soils than that of the control ($p \leq 0.05$). The dominant contaminating heavy metal in this study was Pb whose concentrations were in the order Oluku abattoir > Ikpoba slope abattoir > Control (Table 3). Lead has the potential of bioaccumulation in plants and humans. It can cause serious health problems to children and adults (Elemile et al., 2019). Therefore, it is unsafe to consume Pb contaminated abattoir products. The high concentrations of Pb in the abattoir sites, when eroded, may contaminate nearby surface waters thereby posing public health risk. This should be especially noted in Ikpoba abattoir site at the city center because of the proximity to Ikpoba river (Figure 1). The higher Pb content in abattoir soils of this study is consistent with the study by Useh et al. (2022). However, the mean value for Pb which was lower than the WHO (2006) and DPR (2002) reference value of 85.00 mg/kg implies that it was within permissible range. The contamination factor (CF_i) for Pb concentrations in the two abattoirs and across soil depths indicated low contamination which implied that the abattoir soils were not enriched with Pb especially as the enrichment factor (EF) and geo-accumulation index (Igeo) values were less than 1 and 0 respectively (Table 3). This implied no ecological and public health threat.

Table 3: Toxicity assessment of heavy metals in the abattoir soils

Heavy metals	Soil depth	Oluku abattoir						Ikpoba slope abattoir						Control site			p-value
		Range	Mean	CV (%)	CF_i	EF	Igeo	Range	Mean	CV (%)	CF_i	EF	Igeo	Range	Mean	CV (%)	
Cd (mg/kg)	Topsoil	0.04 - 0.06	0.05	16.33	0.06	0.00	−4.64	0.02 - 0.03	0.02	23.09	0.02	0.00	−6.64	0.02 - 0.04	0.02	40.00	0.00*
	Subsoil	0.03 - 0.04	0.04	13.33	0.05	0.00	−5.05	0.02 - 0.04	0.03	29.46	0.03	0.00	−5.64	0.01 - 0.04	0.02	51.64	0.24
Pb (mg/kg)	Topsoil	1.30 - 1.39	1.35	2.98	0.01	0.01	−6.64	1.25 - 1.36	1.29	4.00	0.01	0.01	−6.64	0.36 - 0.45	0.39	9.72	0.00*
	Subsoil	1.30 - 1.38	1.34	2.44	0.01	0.07	−6.64	1.20 - 1.31	1.26	4.11	0.01	0.01	−6.79	0.34 - 0.65	0.43	33.14	0.00*
Co (mg/kg)	Topsoil	0.36 - 0.49	0.43	14.55	0.00	0.00	−7.64	0.18 - 0.39	0.28	39.44	0.00	0.00	−8.38	0.00 - 0.00	0.00	0.00	0.00*
	Subsoil	0.32 - 0.49	0.40	17.73	0.00	0.00	−7.64	0.16 - 0.37	0.25	43.06	0.00	0.00	−8.38	0.00 - 0.00	0.00	0.00	0.00*
Cr (mg/kg)	Topsoil	0.04 - 0.06	0.05	16.33	0.00	0.00	−11.70	0.05 - 0.07	0.06	19.25	0.00	0.00	−11.28	0.00 - 0.00	0.00	0.00	0.00*
	Subsoil	0.04 - 0.06	0.40	17.73	0.00	0.00	−8.96	0.16 - 0.37	0.25	43.06	0.00	0.00	−9.96	0.00 - 0.00	0.00	0.00	0.00*
C_{deg}	Topsoil					0.07						0.03					
	Subsoil					0.06						0.04					
PLI	Topsoil					0.00						0.00					
	Subsoil					0.00						0.00					

Cd = cadmium, Pb = lead, Co = cobalt, Cr = chromium, CV = coefficient of variation, CF_i = contamination factor, EF = enrichment factor, C_{deg} = degree of contamination, PLI = pollution load index, * = significant at 0.05 level, Topsoil = 0-15 cm depth, Subsoil = 15-30 cm depth.

Similar to Pb, the values of Cd were in decreasing order of Oluku abattoir > Ikpoba slope abattoir > Control (Table 3). The concentrations of Cd obtained in this study were lower than the toxicity limit of 0.80 mg/kg. While the CF_i and Igeo for Cd concentrations in the abattoir soils indicated low contamination and uncontaminated respectively, EF revealed that the soils were not enriched with Cd. These results imply that the abattoir soils were not overloaded with Cd and therefore had no potential ecological risks and public health effects. The range of values of Co were between 0.16 and 0.49 mg/kg and those of Cr were between 0.04 and 0.37 mg/kg in the abattoir soils respectively. Whereas, in the control soils, Co and Cr were below detection limit. The concentrations of Co and Cr in the abattoir soils were much lower than their toxicity limits of 50.00 and 100.00 mg/kg respectively (WHO, 2006; DPR, 2002). This means that they were within safe range.

Similar to the results of Pb and Cd, Co and Cr were rated low contamination/uncontaminated and no soil enrichment. Therefore, their concentrations in the soil had no potential ecological and public health risks. However, Co and Cr have been linked with allergic dermatitis in humans (Wuana & Okieimen, 2011), and may easily be transported from soil to surface waters through runoffs. Therefore, the accumulation of Cr and Co in abattoir soils of Benin City must be checked. Generally, the higher concentrations of all the heavy metals in the abattoir sites than in the control could be attributed to the elevated organic matter content (Table 2) and the metals being components of animal feeds and processing methods. Organic matter is an important soil property that can influence heavy metal availability in soils (Kirmani et al., 2011). The degree of contamination (C_{deg}) and pollution load index (PLI) of heavy metals in top- and sub- soils of the two abattoirs were classified as low degree of contamination and unpolluted respectively. These classifications indicate that the abattoir soils pose no ecological threat and ultimately no risk on public health.

Relationships between the soil properties in the abattoir sites

Soil properties relate with one another because each soil property influences one or more of the other properties (Arshad & Martin, 2002). Correlation analysis has been widely used in soil studies (Balogun et al., 2023b; Ekpenkhio & Ugwa, 2023). It is an effective statistical technique to understand the relationships between soil properties and evaluate possible common sources of heavy metals. The correlation coefficient matrix for the physical, chemical, microbial and heavy metals contents in the abattoir soils are shown in Table 4. A total of 39 pairs of significant relationships were detected within the correlation matrix. The results revealed 21 pairs of significant positive correlations and 18 pairs of significant negative correlations (Table 4).

Significant positive relationships were observed between sand and pH, Fe; silt and TP, K, Cr, THFC; TP and K, Pb, Cr; pH and Zn; OC and Avl. P, Cr; Avl. P and Cr; K and Cr, THFC; Ca and Mg; TN and Mg; Zn and Pb; Cu and Pb, Cd; and Co and Cd respectively. From the results, it could be inferred that silt significantly and positively influenced the highest number of soil properties in the abattoir sites. This means that an increase in silt contents may result in a corresponding increase in TP, K, Cr and fungi populations (Table 4). The positively correlated soil properties may be due to the fact that they were formed from similar parent materials which is sandstone. Organic carbon positively correlated with Cr which supports the assertion that OC is a major influence on heavy metals. The positive correlation between Co and Cd indicated that they were from similar sources. The micronutrients (Zn and Cu) positively influenced the concentration of Pb. In this study, pH only positively affected Zn but had a negative correlation with TN, Mn and Cr.

The significant negative correlations that were found in this research was between sand and silt, TP, K, Cr, THFC; silt and pH, Ca, Fe; BD and Fe; pH and Cr, Mn, TN; Ca and Pb, Cu; Mg and Cu, Pb; Fe and Cr; and Zn and Mn. From the results, sand was the major negative influential soil property within the correlation matrix. An increase in sand fractions caused a decline in the values of silt, TP, K, Cr and THFC. This was also the findings of Ekpenkhio (2022) in Odighi, Edo State who reported significant negative correlation between sand and silt, TP. At high pH values, Mn and TN were less concentrated while Cr did not pose any risk to the soil. There were significant negative associations between some of the micronutrients and heavy metals (Mg and Cu, Pb; Fe and Cr; and Zn and Mn). Generally, silt and sand were

Table 4: Correlation coefficient matrix of the physical, chemical, microbial and heavy metals concentration of soils in the abattoir sites

	Sand	Silt	Clay	BD	TP	pH	OC	Avl P	K	Ca	Mg	N	Fe	Zn	Cu	Mn	Pb	Co	Cr	Cd	THBC	THFC
Sand	1																					
Silt	-0.982**	1																				
Clay	-0.447	0.271	1																			
BD	0.281	-0.276	-0.124	1																		
TP	-0.729**	0.738**	0.219	-0.338	1																	
pH	0.533*	-0.510*	-0.303	-0.401	-0.324	1																
OC	-0.203	0.206	0.060	-0.072	0.316	-0.329	1															
Avl. P	-0.035	0.072	-0.162	-0.226	0.346	0.006	0.880**	1														
K	-0.778**	0.804**	0.158	-0.244	0.520*	-0.481	0.443	0.269	1													
Ca	0.487	-0.512*	-0.058	0.079	-0.443	0.189	0.086	0.106	-0.488	1												
Mg	0.423	-0.466	0.052	0.020	-0.437	0.082	0.119	0.046	-0.372	0.879	1											
TN	-0.455	0.396	0.445	0.391	0.255	-0.923**	0.204	-0.106	0.436	-0.234	-0.087	1										
Fe	0.596*	-0.579*	-0.295	0.245	-0.332	0.224	-0.369	-0.275	-0.486	0.205	0.179	-0.206	1									
Zn	-0.188	0.180	0.105	-0.537*	0.357	0.501*	-0.062	0.180	0.019	-0.399	-0.379	-0.413	-0.405									
Cu	-0.065	0.168	-0.463	-0.233	0.374	0.274	0.130	0.362	0.355	-0.560*	-0.612*	-0.278	0.006	0.495	1							
Mn	-0.236	0.213	0.195	0.281	0.091	-0.717**	0.214	-0.029	0.422	0.076	0.228	0.758**	0.052	-0.663**	-0.260	1						
Pb	-0.152	0.216	-0.249	-0.358	0.546*	0.333	0.076	0.401	0.058	-0.501*	-0.534*	-0.325	-0.188	0.802**	0.719**	-0.480	1					
Co	0.063	-0.016	-0.243	0.066	0.191	-0.136	-0.149	-0.008	0.024	-0.479	-0.481	0.304	-0.040	0.230	0.430	0.007	0.429	1				
Cr	-0.734**	0.726**	0.305	-0.303	0.692**	-0.541*	0.635**	0.512*	0.605*	-0.301	-0.172	0.383	-0.534*	0.167	0.039	0.251	0.276	-0.087	1			
Cd	0.320	-0.273	-0.337	0.087	-0.057	0.185	-0.006	0.054	-0.053	-0.387	-0.353	-0.057	0.136	0.322	0.618*	-0.288	0.383	0.649**	-0.326	1		
THBC	-0.120	0.138	-0.040	0.038	0.203	0.104	0.215	0.274	0.125	-0.333	-0.455	-0.170	0.044	-0.013	0.245	-0.092	0.260	-0.180	0.128	-0.089	1	
THFC	-0.509*	0.553*	-0.025	-0.023	0.488	-0.439	0.489	0.371	0.592*	-0.079	-0.076	0.400	-0.236	-0.187	0.101	0.380	0.060	0.041	0.422	-0.018	0.239	1

BD = bulk density, TP = total porosity, OC = organic carbon, TN = total nitrogen, Avl. P = available phosphorous, Mg = magnesium, Ca = calcium, Na = sodium, K = phosphorous, Fe = iron, Cu = copper, Mn = manganese, Zn = zinc, THBC = total heterotrophic bacteria count, THFC = total heterotrophic fungi count, ** = correlation is significant at the 0.01 level (2-tailed), * = correlation is significant at the 0.05 level (2-tailed).

important influencing factors in this study as their increase resulted in the positive and negative response of the highest number of other soil properties. This finding is consistent with the argument that texture is a crucial soil characteristic that influences other soil properties (Ugwa et al., 2016).

Conclusion

This study presented the morphological, physicochemical and microbial properties of abattoir contaminated soils in Benin City, Edo State Nigeria. The soil colour was affected by the abattoir activities as they were more silty loam and fragile. Soils in the abattoir sites were slightly alkaline in nature and deficient in micronutrients. The organic rich soil in the abattoir sites was an indication that it could serve as a good source of manure for agricultural purposes. The bacteria and fungi counts were found to be higher in abattoir soils which could destabilize the soil ecology. However, the contamination indices revealed no ecological threat to the soil environment and health of the public. Silt and sand were important influencing factors in this study as their increase resulted in both positive and negative response from the highest number of the other soil properties. From this study, siting of abattoir near a water body, as the case in the Ikpoba hill site, may cause water pollution and ecological consequences over time. Though, the heavy metal concentrations were all within safe limit, proper management of abattoir wastes should be adopted to mitigate the accumulation of heavy metals in the soil.

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