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Impact of Abattoir Wastewater Discharge on the Physicochemical Properties and Heavy Metal Levels of Dei-Dei Stream, Abuja, Nigeria

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Abstract:** This study aimed to determine the impact of abattoir wastewater discharge on the physicochemical properties and heavy metal levels of Dei-Dei Stream, Abuja, Nigeria. Water samples were randomly collected from the upstream and downstream sections of Dei-Dei Stream, while soil samples were collected from the farm behind the abattoir. Sampling was carried out at two-week intervals from March to April 2026. The physicochemical properties were determined using the American Public Health Association (APHA) standard methods and other standard analytical procedures. Wet digestion was performed on the water and soil samples, after which the samples were analyzed for heavy metals. The results of the physicochemical analysis showed that temperature, conductivity, turbidity, TS, TSS, TDS, pH, alkalinity, acidity, hardness, chloride, COD, and BOD were 27.87 ± 0.04 °C, 1395.78 ± 272.59 µS/cm, 12.59 ± 1.50 NTU, 888.41 ± 180.64 mg/L, 43.61 ± 6.72 mg/L, 844.8 ± 173.92 mg/L, 7.30 ± 0.06, 349.76 ± 39.11 mg/L, 23.5 ± 7.10 mg/L, 335.45 ± 52.95 mg/L, 2006.60 ± 286.56 mg/L, 104.66 ± 4.32 mg/L, and 72.2 ± 4.18 mg/L, respectively. The concentrations of the assessed heavy metals in the stream water ranged (mg/L) as follows: Fe (0.03–2.25), Zn (0.01–0.32), Pb (0.004–0.15), Cd (0.001–0.09), and Cu (0.001–0.99). The Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF), and Pollution Load Index (PLI) consistently indicated that the farm soil was only slightly affected by heavy metal contamination. Overall, the findings revealed that abattoir wastewater discharge has impacted the physicochemical quality of Dei-Dei Stream, with elevated concentrations of some heavy metals, while the adjoining farm soil remained only slightly contaminated.

***Keywords:** Abattoir, Dei-Dei, Downstream, Geoaccumulation Index, Physicochemical, Wastewater.*

I. INTRODUCTION

Water quality deterioration resulting from the discharge of untreated wastewater into aquatic environments remains a major environmental challenge in developing countries (Asibor *et al*., 2019; Osibanjo & Adie, 2007). Among the various sources of wastewater pollution, abattoir activities contribute substantially to the contamination of surface water bodies due to the direct discharge of untreated effluents containing organic and inorganic pollutants into rivers and streams (Asibor *et al*., 2019; Mohammed *et al*., 2020; Adeyemi-Ale, 2014). The abattoir industry is an important component of Nigeria's livestock sector, providing meat supply to over 150 million people and generating employment opportunities for a large proportion of the population (Asibor *et al*., 2019; Oladipo *et al*., 2022). However, the rapid growth of slaughterhouse activities has been accompanied by inadequate waste management practices in Nigeria. In many Nigerian abattoirs, wastewater generated during slaughtering, dehairing, hide removal, paunch handling, rendering, trimming, processing, and cleaning operations is discharged directly into nearby rivers and streams without prior treatment (Asibor *et al*., 2019; Mohammed *et al*., 2020; Madukasi *et al*., 2026). The abattoirs are mostly located close to water bodies, primarily to ensure easy access to water for processing and disposal of wastes; this has further increased the risk of environmental contamination (Asibor *et al*., 2019; Mohammed *et al*., 2020).

Abattoir wastewater is characterized by high concentrations of blood, fats, grease, suspended solids, fecal materials, animal trimmings, paunch contents, urine, undigested feed materials, bones, and other organic matter (Elemile *et al*., 2019; Mohammed *et al*., 2020; Oladipo *et al*., 2022; Madukasi *et al*., 2026). Fresh abattoir wastewater mainly consists of diluted blood, fats, and suspended solids (Mohammed *et al*., 2020). These wastes contain substantial organic and nutrient loads that can alter the physicochemical characteristics of receiving water bodies and cause environmental degradation (Asibor *et al*., 2019; Friday *et al*., 2025).

Several studies have reported that untreated abattoir effluents significantly influence important water quality parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids, pH, temperature, turbidity, nitrate, phosphate, dissolved oxygen (DO), and electrical conductivity (Asibor *et al*., 2019; Adeyemi-Ale, 2014; Mohammed *et al*., 2020). According to Asibor *et al*. (2019), the discharge of abattoir wastewater into the Orogodo River resulted in marked increases in downstream BOD, suspended solids, COD, total nitrogen, total phosphorus, dissolved solids, dissolved oxygen, and nitrate concentrations, indicating significant deterioration of river water quality. In the same line, Adeyemi-Ale (2014) reported elevated concentrations of BOD, COD, phosphate, sulfate, and several heavy metals in Gbagi Stream, with most parameters exceeding the discharge limits established by the National Environmental Standards and Regulations Enforcement Agency (NESREA). An assessment of wastewater from three major abattoirs in Sagamu, Ogun State, Nigeria, detected a suite of heavy metals, demonstrating that the effluent acts as a direct vector for their release into the environment (Jegede *et al*., 2022). Similar research on the Kara Abattoir effluent's impact on the Ogun River revealed that all twelve heavy metals analyzed were present, with many chemical parameters exceeding accepted environmental standards (Adesina *et al*., 2018).

Studies also show that the environmental implications of abattoir wastewater pollution extend beyond physicochemical deterioration (Anzene *et al*., 2024). Biodegradable organic matter discharged into receiving waters creates intense competition for dissolved oxygen among aquatic organisms, leading to elevated BOD levels and reductions in dissolved oxygen concentrations that may threaten aquatic life and affect surrounding sediments and soils (Asibor *et al*., 2019; Dewi *et al*., 2020). Consequently, the nutrient-rich nature of abattoir wastes contributes to excessive nitrate and phosphate loading, which may promote eutrophication and further compromise aquatic ecosystem health (Madukasi *et al*., 2026; Friday *et al*., 2025).

Heavy metals are naturally occurring elements, but their concentrations in the environment can be elevated through anthropogenic activities such as waste disposal and industrial processes (Friday *et al*., 2025). Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), and zinc (Zn) are of particular concern because of their toxicity, persistence, and bioaccumulation potential (Friday *et al*., 2025). The study conducted by Mohammed *et al*. (2020) at Kasuwan Shanu Abattoir in Maiduguri revealed that concentrations of Cd, Hg, Ni, and Cr in wastewater exceeded World Health Organization (WHO) permissible limits. Likewise, Adeyemi-Ale (2014) detected measurable concentrations of Pb, Cu, Fe, Zn, Ni, and Cd in the receiving stream, while Friday *et al*. (2025) highlighted the environmental significance of heavy metal contamination around abattoir effluent discharge points. The contamination potential of abattoir effluent is also induced by the likely presence of pathogenic bacteria. Abattoir effluents may contain *Salmonella*, *Escherichia coli*, *Shigella*, parasite eggs, amoebic cysts, and other pathogenic microorganisms capable of posing serious public health risks through contamination of surface and groundwater resources (Oladipo *et al*., 2022). Such contamination can affect communities that rely on nearby rivers for domestic, agricultural, commercial, and irrigation purposes (Asibor *et al*., 2019; Mohammed *et al*., 2020; Madukasi *et al*., 2026).

Despite increasing awareness of the environmental consequences of abattoir operations, inadequate waste treatment, weak regulatory enforcement, and ineffective monitoring systems continue to characterize many slaughterhouses in Nigeria (Asibor *et al*., 2019; Oladipo *et al*., 2022; Madukasi *et al*., 2026). Consequently, continuous assessment of receiving water bodies is essential to determine the extent of physicochemical alterations and heavy metal contamination resulting from abattoir wastewater discharge (Anzene *et al*., 2024). Therefore, this study investigates the impact of abattoir wastewater on the physicochemical properties and heavy metal

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contamination of the Dei Dei stream to provide information that will support environmental monitoring, pollution control, and the development of effective wastewater management strategies.

II. MATERIALS AND METHODS

2.1 Study Area Description

Abuja, the capital city of Nigeria, is located in the central part of the country, north of the confluence of the Niger and Benue Rivers. Abuja lies at latitude 9.07°N and longitude 7.48°E, at an elevation of 840 m (2,760 ft) above sea level. In the Federal Capital Territory (FCT), the Dei-Dei Abattoir is located within the Abuja International Livestock Market and is the biggest and busiest of such facilities in the FCT. Abattoirs are designated facilities where food animals are received, inspected, and slaughtered under approved conditions for the production of meat intended for human consumption (Buhari *et al*., 2020).

However, the Dei-Dei Abattoir was constructed in such a way that it has drainage channels through which wastewater generated from washing and cleaning animals flows into the stream behind the abattoir. Water from this stream is used by many farmers and abattoir workers for irrigation, washing clothes, and bathing after the day's work.

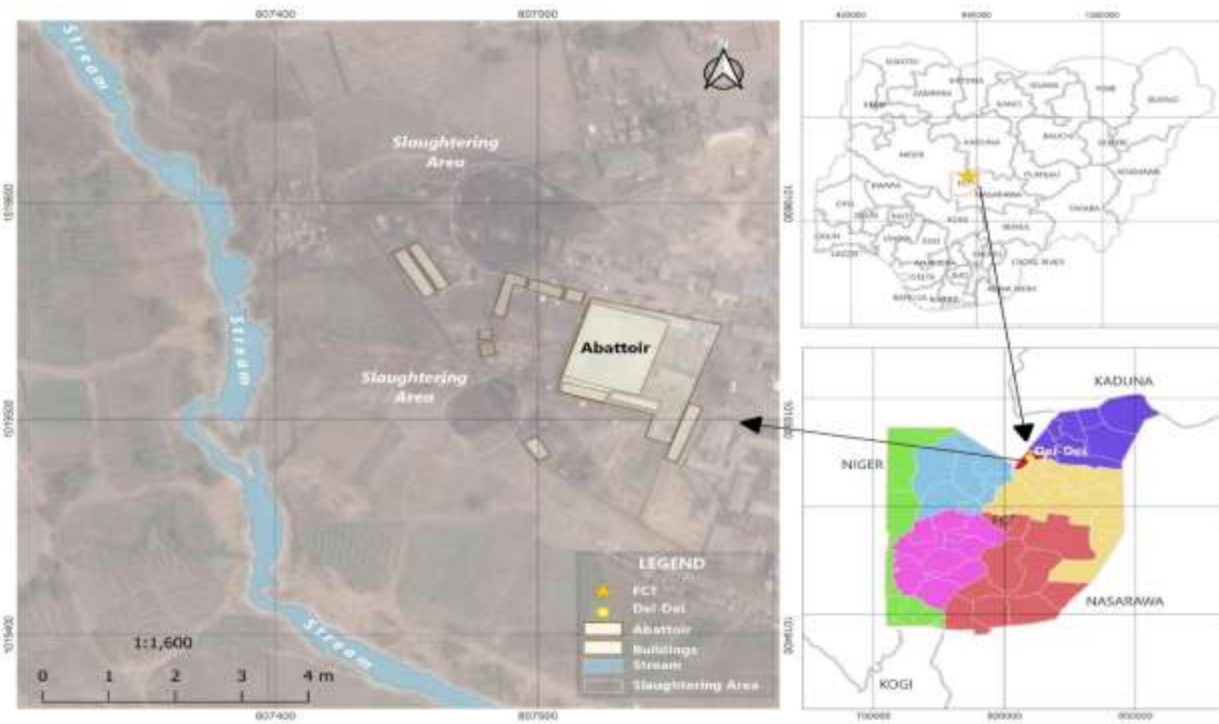

Figure 1. Map showing the location of the Dei Dei Abattoir and surrounding slaughtering areas in Abuja, Nigeria

2.2 Sample Collection and Preservation

2.2.1 Water Samples

Two sampling points were established along the Dei-Dei Stream within the study area. The upstream sampling point, located approximately 80 m before the abattoir wastewater discharge point, served as the control, while the downstream sampling point was located approximately 300 m after the discharge point. At each sampling point, water samples were collected by the grab sampling method from three randomly selected locations across the width of the stream to obtain representative samples.

Two sets of water samples were collected for laboratory analyses. The first set, designated for physicochemical analyses, was collected into clean polyethylene bottles without acidification, kept at

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approximately 4 °C, and transported to the laboratory for analysis. The second set, intended for heavy metal determination, was collected into acid-washed polyethylene bottles, immediately acidified with concentrated nitric acid (HNO_3) to pH < 2, and stored at approximately 4 °C until analysis. The coordinates of the water sampling locations are given in Table 1.

Table 1. GPS Coordinates of the Water Sampling Locations in the Dei Dei Stream, Abuja

Locations	Coordinates	
	Latitude	Longitude
Upstream (control)	9°7′9.408″N	7°15′11.520″E
Discharge point	9°7′11.748″N	7°15′11.376″E
Downstream	9°7′21.500″N	7°15′11.700″E

2.2.2 Soil samples

Soil samples were randomly collected from three sampling points within the study farm, designated as SSA, SSB, and SSC, at a depth of 0–20 cm using a soil auger, following the procedure described by Emmanuel *et al.* (2018). Composite soil samples were prepared by thoroughly homogenizing the soil collected from each sampling point, and approximately 400 g of each composite sample was obtained for analysis. A control soil sample (SSD) was collected from an uncontaminated location approximately 350 m away from the farm behind the Dei-Dei abattoir. All samples were placed in clean polyethylene bags, appropriately labeled immediately after collection, and transported to the laboratory for sample preparation and subsequent analysis.

2.3 Sample Preparation

2.3.1 Determination of Physicochemical Properties

The physicochemical properties of the water and soil samples were determined using standard analytical methods. Temperature was measured immediately after sample collection using a mercury thermometer. Turbidity was determined using a standardized digital turbidity meter (Hach 2100Q). Electrical conductivity was measured with a conductivity meter (Jenway Model 4510, UK), while pH was determined using a pH meter (Jenway Model 3510, UK). Total solids (TS), total suspended solids (TSS), and total dissolved solids (TDS) were determined by the gravimetric method involving filtration and evaporation (AOAC, 2000). Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were determined using the standard methods recommended by APHA (1998). The concentration of total hardness was determined by the ethylenediaminetetraacetic acid (EDTA) titrimetric method.

2.3.2 Digestion of Water and Soil Samples

i. Water

Wet digestion was employed using concentrated nitric acid (65% HNO_3). A 100 mL aliquot of the acid-preserved downstream water sample was measured into a beaker, and 5 mL of concentrated HNO_3 was added. The mixture was covered with a watch glass, placed on a hot plate, and heated gently until the volume was reduced to about 20 mL. Another 5 mL of concentrated HNO_3 was then added, and heating was continued until the digestion was complete, as indicated by the formation of a clear solution. The digest was allowed to cool and then filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask and made up to the mark with deionized

ii. Soil

The method of Obasi *et al*. (2022), with slight modification, was employed for the soil sample digestion. One gram (1 g) of the homogenized soil sample was weighed into a pre-washed 250 mL beaker, and 20 mL of freshly prepared aqua regia ($HCl:HNO_3$, 3:1, v/v) was added.

The beaker was covered and placed on a hot plate, where the mixture was gently heated at 150°C for approximately 2 h. The digestion was considered complete when the solution turned light in colour. The digest was allowed to cool and then filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask. The filtrate was made up to the mark with

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deionized water, transferred into clean sample containers, and stored in a refrigerator prior to analysis.

2.4 Calibration Curve

Calibration curves were prepared for each target metal, including iron (Fe), zinc (Zn), lead (Pb), cadmium (Cd), and copper (Cu), using standard solutions of the respective metals. For analytical quality assurance, a reagent blank and triplicate determination were carried out for each sample.

2.5 Heavy Metals Analysis

All the digested water and soil samples were analyzed for the concentrations of iron (Fe), zinc (Zn), lead (Pb), cadmium (Cd), and copper (Cu) using a Flame Atomic Absorption Spectrometer (Thermo Scientific iCE 3300, UK). The analyses were performed according to the manufacturer's recommended operating conditions for each metal using an air–acetylene flame.

III. RESULTS AND DISCUSSION

3.1 Physicochemical Properties of Water

The physicochemical properties of water are important indicators of environmental quality because they reflect the extent to which anthropogenic activities, particularly abattoir operations, influence aquatic ecosystems. As presented in Table 2, the stream water samples exhibited elevated values for most physicochemical parameters compared with the control sample, indicating considerable deterioration of water quality due to abattoir activities.

Table 2. Physicochemical Properties of Control and Downstream Water Samples

Parameters	Upstream (Control)	Downstream
Temperature (°C)	27.58±0.07	27.87±0.04[a] (27.40-28.30)[b]
Conductivity (µs/cm)	79.75±5.24	1395.78±272.59[a] (72.00-4500.00)[b]
Turbidity NTU	7.00±1.87	12.59±1.50[a] (0.03-26.90)[b]
TS (mg/l)	60.13±8.40	888.41±180.64[a] (46.00-3033.00)[b]
TSS (mg/l)	13.68±1.77	43.61±6.72[a] (10.00-133.00)[b]
TDS (mg/l)	46.45±6.63	844.8±173.92[a] (36.00-2910.00)[b]
pH	7.12±0.04	7.30±0.06[a] (6.75-8.65)[b]
Alkalinity (mg/l)	137.1±29.50	349.76±39.11[a] (65.40-764.00)[b]
Acidity (mg/l)	86.20±1.00	23.5±7.10[a] (0.002-139.60)[b]
Hardness (mg/l)	77.87±11.80	335.45±52.95[a] (32.50-1250.00)[b]
Chloride (mg/l)	774.0±39.00	2006.60±286.56[a] (1.00-6816.00)[b]
COD (mg/l)	68.00±9.91	104.66±4.32[a] (42.00-163.32)[b]
BOD (mg/l)	50.43±12.94	72.2±4.18[a] (24.00-128.00)[b]

a = Values are mean ± standard deviation of triplicate determinations (n = 3); b = Range
KEY: BOD = Biological Oxygen Demand; COD = Chemical Oxygen Demand; TS = Total Solid; TSS = Total Suspended Solid; TDS = Dissolved Solid

The mean water temperature recorded in the present study was 27.87 ± 0.04°C (range: 27.40–28.30°C), which was only slightly higher than the control value (27.58 ± 0.07°C). This temperature falls within the range of 27.00–29.00°C reported by Madukasi *et al.* (2026) for Ekpan abattoir and is also comparable with the 27.40–38.00°C observed by Friday *et al.* (2025) in Yola and Numan abattoirs. Similarly, it lies within the broader range of 25.26–33.30°C documented by Asibor *et al.* (2020) in Orogodo River. The relatively stable temperature suggests that the discharged effluent did not cause significant thermal pollution. However, temperatures approaching 28°C may accelerate microbial metabolism and organic matter decomposition, thereby increasing oxygen consumption in receiving waters (Mohammed *et al.,* 2020; Ahmadu *et al.*, 2020). Electrical conductivity averaged 1395.78 ± 272.59 µS/cm (range: 72.00–4500.00 µS/cm), indicating a high ionic content in the wastewater. This value was considerably higher than the conductivity ranges of 105–196 µS/cm reported by Madukasi *et al.* (2026) and 72.80–841.00 µS/cm observed by Asibor *et al.* (2020). However, it was also lower than the 1784 µS/cm reported by Mohammed *et al.* (2020) and fell within the broader range of 18.01–13,360 µS/cm documented by Ogbonna and Ideriah (2014). The elevated electrical conductivity reflects the presence of high concentrations of dissolved ions, primarily inorganic salts originating from blood, intestinal contents, urine, cleaning agents and animal wastes commonly discharged from abattoirs operations.

The average value of turbidity was 12.59 ± 1.50 NTU (range: 0.03–26.90 NTU), exceeding the control value but remaining lower than the 22.40–150.00 NTU reported by Asibor *et al.* (2020) and the 34 NTU reported by Mohammed *et al*. (2020). Increased turbidity is commonly associated with suspended organic particles, blood, fat residues, and fine solids discharged during slaughtering operations. Substantial increases were observed in total solids (TS), total dissolved solids (TDS), total suspended solids (TSS), electrical conductivity, hardness, alkalinity, and chloride concentration. The mean TS value (888.41 ± 180.64 mg/L) and TDS (844.80 ± 173.92 mg/L) were markedly higher than the control values, indicating a considerable influx of dissolved and suspended materials into the stream. The TDS range (36.00–2910.00 mg/L) exceeded the ranges reported by Madukasi *et al*. (2026) (360.70–1071.50 mg/L), Oladipo *et al*. (2022) (103.40–272.80 mg/L), Asibor *et al*. (2020) (65.00–750.00 mg/L) and Mohammed *et al*. (2020) (260 mg/L). However, the values remained far below the extremely high concentrations (450–15,600 mg/L) reported by Ogbonna and Ideriah (2014) in abattoir wastewater. Elevated TDS and TS are generally associated with blood residues, dissolved proteins, fats and decomposing organic materials released during slaughtering and carcass washing.

The pH of the stream water was averaged 7.30 ± 0.06 (range: 6.75–8.65), indicating a nearly neutral to slightly alkaline condition. This value is comparable to the pH range of 6.20–8.60 reported by Oladipo *et al.* (2022) and 6.94–7.00 reported by Adeyemi-Ale (2014). It is also similar to the 6.60–7.40 recorded by Taiwo *et al.* (2025), although lower than the more alkaline values (7.51–10.11) observed by Friday *et al.* (2025). Asibor *et al.* (2020) reported lower pH values of 5.34–6.76, while Mohammed *et al.* (2020) recorded a slightly acidic pH of 5.661.

Water hardness (335.45 ± 52.95 mg/L) and chloride concentration (2006.60 ± 286.56 mg/L) were also considerably elevated relative to the control. The chloride concentration recorded in this study greatly exceeded the 47.31–53.10 mg/L reported by Adeyemi-Ale (2014) and the 0.623–49.30 mg/L observed by Asibor *et al*. (2020). The exceptionally high chloride level can be attributed to the discharge of animal blood, urine, gastrointestinal contents, and cleaning chemicals into the stream, all of which increase the ionic composition of the receiving waters.

The mean biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were 72.20 ± 4.18 mg/L and 104.66 ± 4.32 mg/L, respectively. The BOD value exceeded the 40.00–70.00 mg/L reported by Madukasi *et al*. (2026) but was lower than the 82.44–90.46 mg/L observed by Adeyemi-Ale (2014) and within the wider range (6.87–112.50 mg/L) documented by Asibor *et al*. (2020). The COD value was lower than the 150.00–375.00 mg/L reported by Madukasi *et al.* (2026), the 338.42–382.09 mg/L observed by Adeyemi-Ale (2014), and the 61.14–1045.00 mg/L reported by Asibor *et al.* (2020). The elevated BOD and COD values indicate a high organic pollution load in the downstream water. The higher COD relative to BOD suggests the presence of both biodegradable and non-biodegradable organic substances, while the BOD/COD ratio of approximately 0.69 indicates that the organic matter is predominantly biodegradable.

The elevated physicochemical parameters observed in the present study demonstrate that untreated abattoir wastewater substantially alters the quality of receiving surface waters, corroborating the findings from previous studies that identified abattoir effluent as a

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significant source of aquatic environmental pollution (Madukasi *et al*., 2026; Oladipo *et al*., 2022; Adeyemi-Ale, 2014; Asibor *et al*., 2020).

3.2 Heavy Metal Concentrations in Stream Water

Heavy metals are among the most persistent environmental pollutants because they are non-biodegradable, accumulate in aquatic ecosystems, and may pose significant risks to human health and aquatic organisms when present above permissible concentrations. The concentrations of iron (Fe), zinc (Zn), lead (Pb), cadmium (Cd), and copper (Cu) determined in the stream water are presented in Table 3. Generally, the mean concentrations of Fe, Pb, Cd, and Cu were higher than those of the control sample, indicating that abattoir activities contribute to the enrichment of these metals in the receiving water body.

Table 3. Heavy Metal Concentrations in Control and Downstream Water Samples

Metals	Upstream (Control) (mg/l)	Downstream (mg/l)
Fe	0.06±0.01	0.28±0.11[a] (0.03-2.25)[b]
Zn	0.21±0.04	0.10±0.01[a] (0.01-0.32)[b]
Pb	0.01±0.00	0.06±0.008[a] (0.004-0.15)[b]
Cd	0.002±0.001	0.02±0.004[a] (0.001-0.09)[b]
Cu	0.003±0.001	0.10±0.03[a] (0.001-0.99)[b]

a = Values are mean ± standard deviation of triplicate determinations (n = 3); b = Range

Iron (Fe) recorded the highest mean concentration among the analyzed metals, with a value of 0.28 ± 0.11 mg/L (range: 0.003–2.25 mg/L), compared with the control value of 0.06 ± 0.01 mg/L. Although Fe was the dominant metal in the present study, its concentration was considerably lower than the values reported by Oladipo *et al*. (2022), who recorded 0.402–122.85 mg/L in water around an abattoir in Ado-Ekiti. Likewise, Adeyemi-Ale (2014) reported higher concentrations ranging from 1.79–4.84 mg/L in Gbagi Stream, while Friday *et al*. (2025) documented substantially elevated Fe concentrations of 6.934–47.095 mg/L in abattoir effluents from Yola and Numan. Similarly, Taiwo *et al*. (2025) reported Fe concentrations ranging from 0.59–14.16 mg/L, with wastewater samples containing 9.05–14.16 mg/L. The comparatively lower Fe concentration observed in the present study can be attributed to dilution by stream water, differences in slaughtering intensity, or variations in waste management practices. Nevertheless, the occurrence of Fe reflects the discharge of blood, animal tissues, rusted metallic equipment, and other iron-containing materials associated with abattoir operations (Taiwo *et al*., 2025). The relatively low Zn concentration observed in this study suggests limited zinc contamination and may reflect reduced inputs from galvanized equipment, animal feed supplements, or other anthropogenic sources commonly associated with abattoir activities. Zinc (Zn) had a mean concentration of 0.10 ± 0.01 mg/L (range: 0.01–0.32 mg/L), which was lower than the control value of 0.21 ± 0.00 mg/L. The concentration was also lower than the 0.1255–0.525 mg/L reported by Oladipo *et al.* (2022) and substantially below the 0.87–4.43 mg/L reported by Adeyemi-Ale (2014). Taiwo *et al*. (2025) recorded much higher Zn concentrations ranging from 0.92–14.05 mg/L, particularly in untreated abattoir wastewater.

Lead (Pb) was detected at a mean concentration of 0.06 ± 0.008 mg/L (range: 0.004–0.15 mg/L), which exceeded the control concentration (0.01 ± 0.00 mg/L). This concentration was lower than the 0.0155–0.3675 mg/L reported by Oladipo *et al*. (2022) and the 0.19–0.44 mg/L reported by Adeyemi-Ale (2014). It was also markedly lower than the 0.67–1.06 mg/L documented by Taiwo *et al*. (2025). Friday *et al*. (2025) did not detect Pb in any of their wastewater samples. These differences may be attributed to variations in environmental background levels, sampling locations, surrounding anthropogenic activities, and waste disposal practices. Although the Pb concentration in the present study was relatively

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low compared with several previous reports, its presence remains environmentally significant because lead is highly toxic, persistent, and capable of bioaccumulating in aquatic food chains.

Cadmium (Cd) recorded the lowest mean concentration among the analyzed metals, with a value of 0.02 ± 0.004 mg/L (range: 0.001–0.09 mg/L), compared with 0.002 ± 0.00 mg/L in the control sample. The concentration exceeded the 0.001–0.004 mg/L detected by Oladipo *et al*. (2022) and the 0.005–0.009 mg/L reported by Friday et al. (2025) but was comparable to the 0.01–0.02 mg/L documented by Adeyemi-Ale (2014). Conversely, Mohammed *et al*. (2020) reported a considerably higher Cd concentration of 0.12667 mg/L, while Taiwo *et al*. (2025) observed concentrations ranging from 0.10–0.23 mg/L. Cadmium contamination is of particular concern because even low concentrations can accumulate in aquatic organisms and pose chronic health risks to humans through prolonged exposure.

Copper (Cu) had a mean concentration of 0.10 ± 0.03 mg/L (range: 0.001–0.99 mg/L), which was substantially higher than the control value (0.003 ± 0.01 mg/L). However, this concentration was lower than the 0.277–1.070 mg/L reported by Oladipo et al. (2022) but comparable with the 0.18–0.20 mg/L reported by Adeyemi-Ale (2014). The occurrence of Cu in the present study may be associated with corrosion of metallic slaughtering equipment, plumbing materials, and animal feed residues. Although copper is an essential trace element, elevated concentrations can become toxic to aquatic organisms by impairing physiological and enzymatic functions.

The heavy metal profile of the Dei-Dei abattoir stream water indicates that Fe was the predominant metal, followed by Cu, Zn, Pb, and Cd. Compared with most of the reviewed studies, the concentrations observed in this study were generally lower, suggesting relatively lower heavy metal loading. The elevated concentrations relative to the control sample confirm that abattoir effluent contributes to heavy metal contamination of the receiving stream. Continuous discharge of untreated wastewater could lead to gradual accumulation of these metals in aquatic sediments and biota, thereby posing long-term ecological and public health concerns (Oladipo *et al*., 2022; Adeyemi-Ale, 2014; Mohammed *et al*., 2020; Friday *et al*., 2025; Taiwo *et al*., 2025).

3.3 Physicochemical Properties of Soil

The physicochemical properties of soil serve as important indicators of soil quality and provide insight into the extent of environmental alterations resulting from anthropogenic activities such as abattoir operations. The continuous discharge of untreated abattoir effluent introduces organic matter, dissolved salts, blood, fats, intestinal contents, and other waste materials into surrounding soils, thereby modifying their physical and chemical characteristics. As shown in Table 4, the soil samples collected from the farm behind the Dei-Dei abattoir generally exhibited higher values for temperature, pH, porosity, chloride, total alkalinity, and total acidity than the control soil, suggesting that prolonged exposure to abattoir wastes has influenced the physicochemical condition of the soil.

Table 4. Physicochemical Properties of the Control Soil and Farm Soil

Parameters	Control Soil	Farm Soil
Temperature (°C)	35.30±0.18	37.31±1.45[a] (35.00-39.50)[b]
pH	6.74±0.20	6.96±0.69[a] (6.78-7.95)[b]
Porosity (%)	15.60±1.85	26.27±9.76[a] (10.80-40.90)[b]
Chloride (mg/kg)	29.60±9.76	51.49±43.49[a] (10.21-129.7)[b]
Total alkalinity (mg/kg)	10.93±3.52	18.79±14.92[a] (3.00-43.60)[b]
Total acidity (mg/kg)	10.42±6.37	12.65±14.44[a] (2.52-39.30)[b]

a = Values are mean ± standard deviation of triplicate determinations (n = 3); b = Range

The mean soil temperature recorded in this study was 37.31 ± 1.45°C (range: 35.00–39.50°C), slightly higher than the control value of 35.30 ± 0.18°C. This temperature falls within the 27.40–38.00°C reported by Friday *et al*. (2025) for abattoir effluents and is also comparable with the 25.26–33.30°C observed by Asibor *et al*. (2020) and the broader range of 20.00–30.50°C reported by Ogbonna and Ideriah (2014). The relatively higher soil temperature may result from microbial decomposition of organic wastes deposited on the soil surface, a process that generates heat and accelerates biochemical reactions. Elevated soil temperatures can stimulate microbial activity and nutrient mineralization but may also alter soil moisture dynamics and affect the growth of sensitive plant species. The soil pH had a mean value of 6.96 ± 0.69 (range: 6.78–7.95), indicating a slightly acidic to nearly neutral soil environment. This pH was comparable to the 6.20–8.60 reported by Oladipo *et al*. (2022), the 6.94–7.00 documented by Adeyemi-Ale (2014), and the 6.60–7.40 recorded by Taiwo *et al*. (2025). It was, however, lower than the 7.05–9.37 reported by Ogbonna and Ideriah (2014) and the 7.51–10.11 observed by Friday *et al*. (2025). The near-neutral pH observed in the present study suggests that although abattoir waste contributes organic and inorganic substances to the soil, it has not caused excessive acidification or alkalinization. Such pH conditions are generally favourable for microbial activity and nutrient availability, although prolonged waste accumulation could gradually alter the soil chemistry.

Soil porosity increased from 15.60 ± 1.85% in the control to 26.27 ± 9.76% (range: 10.80–40.90%) in the contaminated soil. Although porosity was not reported in the reviewed studies, the increase observed may be attributed to the incorporation of decomposing organic matter from abattoir waste, which can improve soil aggregation and create additional pore spaces. Enhanced porosity promotes water infiltration and aeration; however, excessive accumulation of organic residues may eventually clog soil pores and reduce permeability if decomposition is incomplete. The chloride concentration of the contaminated soil averaged 51.49 ± 43.49 mg/kg (range: 10.21–129.70 mg/kg), exceeding the control value of 29.60 ± 9.76 mg/kg. This concentration was comparable to the range of 47.31–53.10 mg/L reported by Adeyemi-Ale (2014) but higher than the 0.623–49.30 mg/L observed by Asibor *et al*. (2020). Conversely, it was considerably lower than the extremely high chloride concentrations (100.1–252,600 mg/L) reported by Ogbonna and Ideriah (2014) in soils impacted by prolonged abattoir wastewater discharge. Elevated chloride levels are commonly associated with blood, urine, intestinal contents, and cleaning chemicals released during slaughtering activities, all of which contribute to increased soil salinity over time.

The mean total alkalinity (18.79 ± 14.92 mg/kg; range: 3.00–43.60 mg/kg) and total acidity (12.65 ± 14.44 mg/kg; range: 2.52–39.30 mg/kg) were also higher than those of the control soil, reflecting alterations in the soil buffering system following continuous waste deposition. Although these parameters were not directly reported in most of the reviewed studies, Ogbonna and Ideriah (2014) documented alkalinity values ranging from 100 to 2300 mg/L in abattoir-impacted environments, indicating that prolonged wastewater disposal can substantially modify soil chemical characteristics. The relatively lower alkalinity observed in the present study may suggest a less severe level of contamination or a shorter duration of waste accumulation. The physicochemical properties of the soil indicate that the continuous discharge of abattoir waste has altered the chemical composition of the surrounding soil, particularly through increases in temperature, porosity, chloride concentration, alkalinity, and acidity. Although most parameters remained within the ranges reported by previous studies, the observed elevations relative to the control confirm the influence of abattoir activities on soil quality. These findings agree with the reports of Oladipo *et al*. (2022), Ogbonna and Ideriah (2014), and Asibor *et al*. (2020), who similarly concluded that long-term disposal of untreated abattoir waste modifies the physicochemical properties of soils and may adversely affect their environmental quality and agricultural productivity.

3.4 Heavy Metal Concentrations in Soil

The accumulation of heavy metals in soil is a major environmental concern because these elements are persistent, non-biodegradable, and capable of

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accumulating in plants, animals, and humans through the food chain. Abattoir activities contribute to soil contamination through the indiscriminate disposal of blood, animal tissues, wastewater, manure, and other organic wastes containing trace metals. As presented in Table 5, the concentrations of zinc (Zn), lead (Pb), cadmium (Cd), and copper (Cu) in soils around the Dei-Dei abattoir were consistently higher than those in the control soil, indicating enrichment of the surrounding soil by abattoir-derived wastes.

Table 5. Heavy Metal Concentrations in Control and Farm Soil

Metals	Control (mg/kg)	Farm Soil (mg/kg)
Zn	0.62±0.10	1.15±0.13[a] (0.52-1.72)[b]
Pb	0.22±0.02	0.57±0.20[a] (0.07-2.02)[b]
Cd	0.002±0.00	0.02±0.00[a] (0.01-0.06)[b]
Cu	0.001±0.00	0.45±0.10[a] (0.02-0.86)[b]

a = Values are mean ± standard deviation of triplicate determinations (n = 3); b = Range

Zinc recorded the highest mean concentration among the analyzed metals, with a value of 1.15 ± 0.13 mg/kg (range: 0.52–1.72 mg/kg), compared with the control value of 0.62 ± 0.10 mg/kg. Although Zn was the predominant metal in the study area, its concentration was considerably lower than those reported by previous studies. For example, Oladipo *et al*. (2022) reported Zn concentrations ranging from 0.1255–0.525 mg/L in contaminated water around an abattoir, while Adeyemi-Ale (2014) recorded much higher values of 0.87–4.43 mg/L in surface water affected by abattoir effluent. Similarly, Taiwo *et al*. (2025) reported Zn concentrations of 0.92–14.05 mg/L in abattoir wastewater, indicating substantially greater zinc contamination than observed in the present study. Lead had a mean concentration of 0.57 ± 0.20 mg/kg (range: 0.07–2.02 mg/kg), which was higher than the control value (0.22 ± 0.02 mg/kg). This concentration exceeded the 0.19–0.44 mg/L reported by Adeyemi-Ale (2014) and the range of 0.0155–0.3675 mg/L documented by Oladipo *et al*. (2022) but lower than the 0.67–1.06 mg/L reported by Taiwo *et al.* (2025). The presence of Pb in the soil may be associated with prolonged deposition of abattoir wastes, vehicular emissions around the abattoir environment, and atmospheric deposition.

Cadmium recorded the lowest concentration, with a mean value of 0.02 ± 0.005 mg/kg (range: 0.01–0.06 mg/kg), compared with 0.002 ± 0.00 mg/kg in the control soil. This concentration was comparable to the 0.01–0.02 mg/L reported by Adeyemi-Ale (2014) but higher than the 0.001–0.004 mg/L detected by Oladipo *et al*. (2022) and the 0.005–0.009 mg/L reported by Friday *et al*. (2025). Conversely, it was substantially lower than the 0.10–0.23 mg/L observed by Taiwo *et al*. (2025). Although cadmium occurred at relatively low concentrations, its high toxicity and tendency to accumulate in soil makes it a contaminant of environmental concern, particularly where wastewater is continuously discharged. Copper had a mean concentration of 0.45 ± 0.10 mg/kg (range: 0.02–0.86 mg/kg), markedly higher than the control value (0.001 ± 0.00 mg/kg). The concentration exceeded the 0.18–0.20 mg/L reported by Adeyemi-Ale (2014) but was lower than the 0.277–1.070 mg/L documented by Oladipo *et al.* (2022). Copper contamination may originate from corrosion of metallic slaughtering equipment, plumbing systems, feed additives, and other operational materials associated with abattoir activities. Although Cu is an essential micronutrient for plants and microorganisms, excessive accumulation may impair soil microbial processes and adversely affect crop productivity.

3.5 Comparison with FAO/USEPA Irrigation Water Standards

Comparison of the measured physicochemical parameters and heavy metal concentrations with FAO (1985) and USEPA (2012) irrigation water guidelines showed that the suitability of the Dei-Dei stream water for agricultural irrigation varied considerably among the measured parameters (Table 6). While some parameters were within acceptable limits, others exceeded the recommended standards and may pose environmental or agronomic concerns.

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The mean pH (7.30 ± 0.06) fell within the recommended irrigation range of 6.5–8.0, indicating that the water is neither excessively acidic nor alkaline and is therefore unlikely to adversely affect nutrient availability or soil pH, and that abattoir wastewater generally maintains pH values suitable for irrigation despite high organic pollution. The recorded temperature (27.87 ± 0.04°C) was slightly higher than the recommended irrigation range of 20–25°C.

Table 6. Comparison of the Physicochemical Properties and Heavy Metal Concentrations in This Study with Water Quality Standards for Agricultural Use

Parameters / metals	This study	Water quality for agriculture
pH	7.3±0.06	6.5 – 8.0
BOD (mg/l)	72.2±4.18	2.0
Temperature (^{0}C)	27.87±0.04	20 – 25
TDS (mg/l)	844.8±173.92	450 – 2000
EC (µs)	1395.78±272.59	0.7 – 30
Cd (mg/l)	0.02±0.004	0.01
Cu (mg/l)	0.10±0.03	0.2
Zn (mg/l)	0.10±0.01	2.0
Pb (mg/l)	0.06±0.008	5.0
Fe (mg/l)	0.28±0.11	5.0

Source: Water quality for Agriculture irrigation and drainage. FAO, 1985 and guidelines for water re-use USEPA, 2012

The TDS concentration (844.8 ± 173.92 mg/L) is within the FAO recommended range of 450–2000 mg/L, indicating moderate salinity that may not immediately affect most crops. Electrical conductivity (1395.78 ± 272.59 µS/cm) also falls within the FAO permissible salinity classification, although the water exhibits relatively high ionic strength, reflecting increased dissolved salts associated with abattoir wastes. BOD (72.2 ± 4.18 mg/L) greatly exceeded the recommended irrigation limit of 2 mg/L, indicating severe organic pollution. High BOD reflects excessive biodegradable organic matter that may deplete oxygen and promote microbial proliferation in receiving water bodies.

Among the heavy metals, Cd (0.02 ± 0.004 mg/L) exceeded the FAO guideline of 0.01 mg/L, suggesting potential long-term ecological and agricultural risks because cadmium readily accumulates in soils and edible crops. Cu (0.10 mg/L) remained below the permissible limit of 0.20 mg/L, while Zn (0.10 mg/L), Pb (0.06 mg/L) and Fe (0.28 mg/L) were also well below their respective irrigation guideline values.

3.6 Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF) and Pollution Load Index (PLI)

Pollution assessment indices provide a more reliable evaluation of heavy metal contamination than concentration values alone because they distinguish between natural geological contributions and anthropogenic inputs. In the present study, the Enrichment Factor (EF), Geoaccumulation Index (Igeo), Contamination Factor (CF), and Pollution Load Index (PLI) consistently indicated that the agricultural soil behind the Dei-Dei abattoir is presently only slightly affected by heavy metal contamination.

The enrichment factor showed marked differences among the analysed metals. Iron recorded an EF of 1.00, (Table 7), indicating deficiency to minimal enrichment, suggesting that its occurrence is largely controlled by natural geological sources rather than anthropogenic activities. Zinc (19.3), lead (33.1) and copper (374) exhibited varying degrees of enrichment attributable to anthropogenic inputs associated with abattoir activities. Cadmium showed an EF of approximately 90, indicating the highest enrichment among all analysed metals and confirming that cadmium represents the most environmentally sensitive contaminant in the study area. Similar observations have been reported by Taiwo *et al.* (2025), who identified cadmium as one of the most enriched toxic metals in abattoir wastewater due to its persistence and mobility.

Despite the elevated EF values, the Geoaccumulation Index (Igeo) remained very low for all metals, with Fe (2.0×10^{-5}), Zn (2.4×10^{-3}), Pb (6.8×10^{-3}), Cd (1.2×10^{-2}) and Cu (1.4×10^{-3}) all falling within the $0 < Igeo \leq 1$ category, which corresponds to uncontaminated to moderately contaminated soils. These results indicate that although anthropogenic enrichment exists, the overall metal accumulation has not yet reached levels capable of causing severe soil contamination.

Table 7. Classification of the Soil from the Farm Behind the Dei-Dei Abattoir Using Enrichment Factor, Geoaccumulation Index, Contamination Factor, and Pollution Load Index

Parameters	This study	Class	Description
EFFe	$1.00\pm.00^{a}$ $(1.00\text{-}1.00)^{b}$	EF< 2	Deficiency to mineral enrichment.
EFZn	$1.93x10^{1}\pm1.93x10^{1\,a}$ $(3.08x10^{-9}\text{-}1.57x10^{3})^{b}$	EF < 2 – 5	Moderate enrichment.
EFPb	$3.31x10^{1}\pm3.31x10^{1\,a}$ $(4.72x10^{-9}\text{-}1.65x10^{3})^{b}$	EF < 2 – 5	Moderate enrichment.
EFCd	$9.00x10^{1}\pm9.00x10^{1\,a}$ $(3.15x10^{-8}\text{-}4.50x10^{2})^{b}$	EF < 5 – 20	Significant enrichment
EFCu	$3.74x10^{2}\pm1.43x10^{2a}$ $(3.33x10^{1}\text{-}6.99x10^{2})^{b}$	EF < 2 – 5	Moderate enrichment
IgeoFe	$2.00x10^{-5}\pm9.80x10^{-6\,a}$ $(4.25x10^{-8}\text{-}5.30x10^{-5})^{b}$	0 <Igeo< 1	Uncontaminated to moderately uncontaminated.
IgeoZn	$2.40x10^{-3}\pm3.30x10^{-4a}$ $(1.31x10^{-3}\text{-}3.30x10^{-3})^{b}$	0 <Igeo< 1	Uncontaminated to moderately uncontaminated.
IgeoPb	$6.80x10^{-3}\pm2.10x10^{-3a}$ $(2.01x10^{-3}\text{-}1.29x10^{-2})^{b}$	0 <Igeo< 1	Uncontaminated to moderately uncontaminated.
IgeoCd	$1.20x10^{-2}\pm2.90x10^{-3a}$ $(1.34x10^{-3}\text{-}1.74x10^{-2})^{b}$	0 <Igeo< 1	Uncontaminated to moderately uncontaminated.
IgeoCu	$1.40x10^{-3}\pm6.20x10^{-4a}$ $(2.87x10^{-5}\text{-}3.70x10^{-3})^{b}$	0 <Igeo< 1	Uncontaminated to moderately uncontaminated.
CfFe	$3.6x10^{-5}\pm2.7x10^{-5a}$ $(2.10x10^{-8}\text{-}1.41x10^{-4})^{b}$	CF < 1	Low contamination
CfZn	$1.2x10^{-2}\pm1.7x10^{-3a}$ $(6.50x10^{-3}\text{-}1.70x10^{-2})^{b}$	CF < 1	Low contamination
CfPb	$5.2x10^{-2}\pm1.5x10^{-2a}$ $(1.90x10^{-2}\text{-}1.0x10^{-1})^{b}$	CF < 1	Low contamination
CfCd	$7.3x10^{-2}\pm5.2x10^{-3a}$ $(6.30x10^{-2}\text{-}8.70x10^{-2})^{b}$	CF < 1	Low contamination
CfCu	$6.7x10^{-3}\pm3.1x10^{-3a}$ $(1.43x10^{-5}\text{-}1.83x10^{-2})^{b}$	CF < 1	Low contamination
PLI	$5.80x10^{-4}\pm4.20x10^{-4a}$ $(2.00x10^{-13}2.19x10^{3})^{b}$	PL < 1	Low contamination

a = Mean ± SD; b = Range

Key: EF = Enrichment Factor; Igeo = Geoaccumulation Index; CF = Contamination Factor;
PLI = Pollution Load Index

Similarly, contamination factor (CF) values for Fe (3.6×10^{-5}), Zn (1.2×10^{-2}), Pb (5.2×10^{-2}), Cd (7.3×10^{-2}) and Cu (6.7×10^{-3}) were all below 1, classifying the study area as having low contamination. The Pollution Load Index (PLI) was 5.8×10^{-4}, which is considerably less than 1, indicating that the overall soil quality has not deteriorated due to heavy metal pollution. A PLI value below unity generally signifies the absence of cumulative heavy metal pollution and suggests that the site remains environmentally stable. Similar conclusions have been drawn by Ogbonna and Ideriah (2014), who noted that although abattoir wastewater introduces heavy metals into soils, the severity of pollution depends largely on the duration and volume of waste discharge.

The apparent discrepancy between the relatively high enrichment factors and low contamination indices may be explained by the mathematical principles underlying these indices. The EF is highly sensitive to deviations from background concentrations and therefore detects anthropogenic contributions even when absolute metal concentrations remain low. In contrast, The Igeo, CF and PLI evaluate the magnitude of accumulated contamination relative to established background values. Consequently, the soils can exhibit evidence of anthropogenic enrichment while still remaining within the low contamination category.

3.7 Correlation Analysis

Pearson correlation analysis was employed to evaluate the relationships among heavy metals in water and soil and to infer possible common sources, transport pathways and environmental behaviour. Significant positive correlations generally indicate that metals originate from similar pollution sources or undergo comparable geochemical processes, whereas negative correlations suggest different origins or contrasting environmental behaviour.

Among the water samples, zinc showed a strong positive correlation with lead ($r = 0.706$, $p < 0.01$), suggesting that both metals likely originate from similar anthropogenic activities associated with abattoir operations, including animal wastes, blood, discarded tissues and wastewater discharge. Zinc also exhibited a significant positive relationship with soil zinc ($r = 0.611$, $p < 0.05$) and soil lead ($r = 0.795$, $p < 0.01$), indicating possible transfer of these metals from wastewater into surrounding agricultural soils through continuous irrigation, runoff or infiltration. Zinc in water was negatively correlated with cadmium ($r = –0.497$, $p < 0.01$) and copper ($r = –0.368$, $p < 0.05$) in water, suggesting that these metals may originate from different sources or possess different mobilities within the aquatic environment. Zinc in water showed a strong negative correlation with soil copper ($r = –0.714$, $p < 0.01$), indicating contrasting accumulation behaviour between these metals.

Lead in water displayed a significant negative correlation with cadmium ($r = –0.566$, $p < 0.01$), implying that their environmental distributions are influenced by different physicochemical processes. Cadmium exhibited generally weak and insignificant relationships with most soil metals, supporting the observation from the enrichment factor analysis that cadmium behaves independently and may originate from localized anthropogenic sources. This finding is environmentally important because cadmium is highly mobile, persistent and capable of accumulating in agricultural soils even when present at relatively low concentrations. Within the soil samples, zinc was positively correlated with lead ($r = 0.595$, $p < 0.05$), indicating similar accumulation pathways, whereas copper showed strong negative relationships with zinc ($r = –0.693$, $p < 0.05$) and lead ($r = –0.811$, $p < 0.01$). These inverse relationships suggest differences in adsorption, mobility and soil retention mechanisms among the metals.

The observed correlations support the conclusion that the detected heavy metals are not entirely of natural origin but are influenced by anthropogenic inputs from abattoir activities. Similar source relationships have been discussed by Oladipo *et al*. (2022), Ogbonna and Ideriah (2014) and Taiwo *et al.* (2025), who attributed positive correlations among heavy metals around abattoirs to common waste sources, while negative correlations reflected differences in environmental transport, adsorption and metal speciation.

IV. CONCLUSION

This study showed that the continuous discharge of abattoir wastewater has adversely affected the physicochemical quality of the Dei-Dei stream and the surrounding farm soil. The significant increases in solids, electrical conductivity, hardness, alkalinity, chloride, BOD, and COD indicate deterioration of water quality due to organic and inorganic pollutants. The heavy metal concentrations in the stream, although generally lower than those reported in many previous studies, were higher than those in the control sample, confirming that abattoir effluent contributes to heavy metal contamination.

Similarly, the surrounding soil exhibited changes in its physicochemical properties and elevated concentrations of Zn, Pb, Cd, and Cu compared with the control soil, indicating enrichment from abattoir activities. However, the near-neutral soil pH suggests that the soil has not yet undergone severe chemical degradation. The pollution indices (EF, Igeo, CF, and PLI) revealed that the agricultural soil is currently only slightly affected by heavy metal contamination, with overall contamination remaining at a low level. Nevertheless, the observed enrichment highlights the potential for long-term accumulation if untreated abattoir waste continues to be discharged into the environment.

Overall, the findings indicate that although heavy metal pollution is presently low, abattoir activities have already altered the quality of the receiving water and surrounding soil. Therefore, proper treatment and management of abattoir wastewater, together with regular environmental monitoring, are essential to prevent further environmental degradation and protect public health.

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