Environmental and Health Impacts of Abattoir Activities on the Water Quality of River Systems in Warri and Its Environs

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Abstract—*The unregulated release of industrial wastewater from specific points into freshwater ecosystems, along with the subsequent degradation of water quality, remains widely undocumented in numerous developing nations, including Nigeria. This study aims to assess the concentrations of physicochemical, heavy metals and microbiological load around water bodies in 3 abattoirs in Warri using analytical techniques. Samples were collected during the wet and dry season. The physicochemical concentrations during the wet and dry season were of the following range: pH (6.5-7.5), Turbidity (2-2.5 NTU), Total dissolved solids (120-315.9 mg/L), Total suspended solids (10-40 mg/L), Biochemical oxygen demand (3-15 mg/L), Ammonia (0.2-1.2 mg/L), Nitrate (0.4-3 mg/L), Total Nitrogen (0.3-2 mg/L), Electrical conductivity (220-400 µS/cm), and Dissolved Oxygen (5.2-6.5 mg/L). The heavy metal concentrations in water samples from abattoir areas around Warri during both the wet and dry seasons revealed alarming levels surpassing WHO standards. The concentrations of Cadmium (Cd), Chromium (Cr), Nickel (Ni), Zinc (Zn), Lead (Pb), and Copper (Cu) ranged from 0.8 to 15 mg/L. These elevated concentrations were attributed to runoff from abattoir activities, particularly the use of car tires for defurring animals, and inadequate waste management practices. The results also reveal heightened levels of total coliform Count, Escherichia Coliform, Enterococci, and Total Heterotrophic Bacteria, surpassing established safety thresholds and emphasizing the urgent need for effective pollution control measures. The findings in this study shows the necessity for integrated environmental management practices, regulatory frameworks, and community awareness initiatives to mitigate the adverse effects of the effluents*.

Keywords— *Abattoir wastewater, Water pollution, Heavy metal contamination, Microbiological load, Environmental management*.

I. Introduction

Abattoirs stand as crucial components in the urban food supply chain, addressing the escalating demand for meat products globally and in Developing nations (Descovich et al., 2019; Patel et al., 2022; Schneidewind et al., 2023). Despite their importance, abattoirs pose significant environmental and health challenges, highlighting the need for comprehensive understanding to guide sustainable practices (Ozdemir and Yetilmezsoy, 2019; Ovuru et al., 2024). With urbanization and population growth surging in Warri, the increased demand for meat products has led to the proliferation of abattoirs, introducing complex environmental and health challenges (Godwin and Oborakpororo, 2019; Omoregie and Ikhajiagbe, 2021). The discharge of pollutants into water bodies and soil, coupled with energy consumption and emissions, necessitates a thorough assessment of these consequences (Olaniran et al., 2019; Asibor et al., 2020).

Simultaneously, abattoir workers and nearby residents face health risks associated with daily occupational hazards, including injuries and exposure to zoonotic diseases (Vonesch et al., 2019; Obidegwu et al., 2019; Winders and Abrell, 2021; Rodarte et al., 2023). Proximity to abattoirs raises concerns about zoonotic disease transmission and other health risks, necessitating a holistic understanding of potential health impacts (Espinosa et al., 2020; Agbalaya et al., 2020; Khan et al., 2023). Ensuring compliance with regulations is crucial for environmental and public health protection (Costa et al., 2020; Gutema et al., 2021). Therefore, a comprehensive evaluation of regulatory adherence in Warri's abattoirs is vital to identify areas for strengthening enforcement (De Luca et al., 2021).

The surge in abattoirs in Warri, driven by urbanization and population growth, poses environmental and public health challenges requiring in-depth investigation. This study aims to investigate the environmental and health impacts of abattoir activities on the water quality of river bodies around three abattoirs in Warri. It will scrutinize the release of pollutants and waste materials from abattoirs, assessing contamination levels and implications for the local ecosystem. Additionally, health risks faced by abattoir workers and nearby residents will be examined to inform measures for safeguarding their well-being. Evaluating regulatory compliance is pivotal for developing effective frameworks governing abattoirs in Warri.

In the pursuit of understanding the environmental and health impacts of abattoir activities, this research focuses on investigating the water quality of river bodies around three abattoirs in Warri. The study will assess the release of pollutants, contamination levels, and health risks associated with abattoir activities. Existing literature emphasizes the substantial impact of abattoirs on water quality parameters in Nigeria (Wizor and Nwankwoala, 2019; Ighalo and Adeniyi, 2020; Ibrahim et al., 2021), highlighting the interconnectedness of abattoir processes and water quality. These studies underscore the urgent need for effective pollution control measures, guiding the current research in its pursuit of a comprehensive understanding of the complexities involved.

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II. MATERIALS AND METHODS

2.1 Sampling Area

Water samples were systematically collected from three distinct sampling areas within the Warri metropolis, including the Effurun Market Abattoir (Samples A1, A2, A3), where sampling points strategically covered upstream, discharge, and downstream locations; the Ugbolokposo Market Abattoir (B1, B2, B3) using a similar approach; and the Osubi Abattoir, represented by a single sample (C), due to its unique characteristics as a perennial wetland that dries up during the dry season. The areas of sample collection are shown in Figure 1 below.

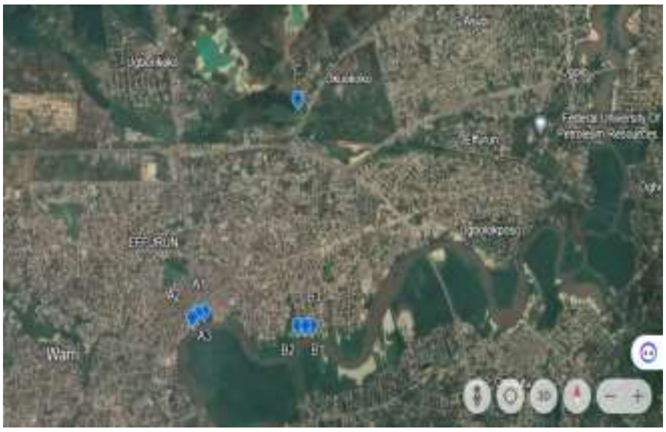

Figure 1: Map showing sample collection points in this study

2.2 Sampling Dates and Times

The samples were collected on October 3rd, 2023, to represent the rainy season, and on December 16th, 2023, to represent the dry season. Sampling was conducted at 50-meter intervals, ensuring a comprehensive coverage of the study area. All sampling procedures were carried out in the morning to as this was the time were slaughtering of animals at the abattoir generally occurs.

2.3 Sample Collection Method

To ensure the integrity of the collected samples, plastic containers were used. These containers were pre-treated with 3-4 mL of nitric acid and rinsed with the respective water samples before collection. The samples were obtained by dipping a bottle mid-way into the water at the designated sampling points along the stream. Following collection, the samples were promptly stored in a cooler containing ice blocks to maintain a temperature of 3-4 ºC, ensuring preservation until laboratory analysis.

2.4 Physicochemical Analysis of Water Samples

Water samples (A1, A2, A3, B1, B2, B3, C) were analyzed at Jacio Environmental Limited, Refinery Road, Warri, using APHA, (2017) standard protocols. Key physicochemical parameters were determined as follows:

- pH: Measured potentiometrically in situ using a calibrated Hanna handheld pH meter.
- Turbidity: Assessed in situ with a handheld turbidimeter (Nephelometer), calibrated using prepared standards.
- Electrical Conductivity (EC): Determined in situ using a handheld conductivity meter, calibrated with pre-determined standards.
- Total Suspended Solids (TSS) and Total Dissolved Solids (TDS): Gravimetrically determined using 0.45µm pore size membrane filter paper and standardized solutions.
- Dissolved Oxygen (DO): Measured using a DO-meter probe, immersed approximately 1.25 inches into the samples.
- Biochemical Oxygen Demand (BOD): Determined with a BOD OxiTop meter following incubation at 20°C for 5 days.
- Ammonia (NH3): Analyzed by the indophenol method involving oxidation with sodium hypochlorite and phenol solution.
- Nitrates ($NO3^{-}$): Analyzed by cadmium reduction and diozoic complex followed by spectrophotometric analysis.
- Chlorides (Cl^{-}): Analyzed using a cadmium reduction approach, adopting principles from the Chloridetest kit.
- Nitrite: Assessed through colorimetric reaction initiated by cadmium sulfate and sodium diethyldithiocarbamate (dithiocarbamate), with quantification using a spectrophotometer.

2.5 Analysis of Heavy Metals in Water Samples

Hydrochloric acid digestion was employed for the determination of heavy metals, including Lead (Pb), Cadmium (Cd), Copper (Cu), Nickel (Ni), Zinc (Zn) and Chromium (Cr). Metal ion concentrations were subsequently analyzed using an atomic absorption spectrophotometer (AA-6300 SHIMAOZU Model) equipped with a hollow cathode lamp and operated under a fuel-rich flame (air acetylene).

2.6 Microbiological Analysis

Microbiological analysis was conducted in water samples (A1, A2, A3, B1, B2, B3, C) collected from abattoirs in Warri were analyzed using standard methods as follows:

- Total Coliform Count (MPN/100mL): Enumerated using the Most Probable Number (MPN) technique based on APHA Standard Method 9221 D (APHA, 2017). Samples were cultured in Lauryl Tryptose Broth (LTB) at 35°C for 48 hours and confirmed using Brilliant Green Lactose Bile Broth (BGLB) at 37°C for 24 hours. The detection limit for this method is 1 MPN/100mL.
- Escherichia Coli (MPN/100mL): Specifically quantified using the MPN method based on EPA Method 1681 (USEPA, 2012). Samples were cultured in Lactose Broth at 35°C for 48 hours and confirmed using E. coli chromogenic agar at 44.5°C for 24 hours. The detection limit for this method is 1 MPN/100mL.
- Enterococci (CFU/100mL): Evaluated through Colony Forming Units (CFU) using ISO 7890 (ISO, 2000). Samples were filtered through a membrane and cultured on Membrane-Tetralin-Indole Agar (MTIA) at 37°C for 48 hours. The detection limit for this method is 1 CFU/100mL.

- Total Heterotrophic Bacteria (CFU/mL): Assessed by counting Colony Forming Units per milliliter using APHA Standard Method 10030 B (USEPA, 2018). Samples were spread plated on Plate Count Agar (PCA) and incubated at 35°C for 48 hours. The detection limit for this method is 1 CFU/mL.

2.7 Statistical analysis

Computer software Microsoft Excel 2016 was used for record, compiling, organizing and analysis of numerical and statistical data, for different calculation like average, mean, and standard deviation. The data and graphical representation were presented using MS-Word.

III. RESULTS AND DISCUSSION

3.1 Physicochemical parameters of the water samples during the wet and dry season

The physicochemical parameters of the water samples gathered from various points within the river systems in Warri metropolis, both during the wet and dry seasons, elucidate the discernible influence of the nearby abattoir on the water quality, as detailed in Table 1 below.

TABLE 1: Physicochemical characterization of water samples from river bodies around abattoirs in Warri metropolis

	Sampled points														
	A1		A2		A3		B1		B2		B3		C		
Parameter	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**WHO Standard**
pH	6.8	6.7	7	6.9	6.5	6.3	7.2	7	7.1	7.2	6.9	6.8	7.5	7.3	7.0-8.5
DO (mg/L)	6	5.8	6.5	6.2	5.8	5.5	7	6.5	6.2	6	5.5	5.2	8	7	5
EC (µS/cm)	320	350	350	330	350	300	380	280	300	260	380	240	250	220	500
Turbidity (NTU)	25	20	20	18	15	22	10	15	8	12	5	8	2	5	1
TDS (mg/L)	315.9	280	280	260	250	240	180	200	160	180	140	160	120	140	600
TSS (mg/L)	40	30	35	25	30	20	20	15	18	12	15	10	10	8	-
BOD (mg/L)	15	12	12	10	10	8	8	6	6	5	5	4	3	2	25
Ammonia (NH3-N) (mg/L)	1.2	0.9	1	0.8	0.8	1	0.5	0.6	0.7	0.5	0.3	0.4	0.6	0.2	0.15
Nitrate (mg/L)	3	2.5	2.5	2	2	1.8	1.5	1.2	1.2	1	1	0.8	0.5	0.4	50
Nitrite (mg/L)	0.2	0.15	0.1	0.12	0.1	0.18	0.08	0.1	0.07	0.08	0.05	0.06	0.02	0.03	50
Chlorides (mg/L)	150	130	140	120	130	140	120	110	110	100	100	80	90	70	250

3.1.1 pH

The pH levels in water samples (A1, A2, A3) during the wet season ranged from 6.5 to 7.0, and in the dry season, from 6.3 to 6.9. Notably, all recorded pH levels within this area during both seasons fall within the WHO standard range of 7.0-8.5, except for the dry season samples. Similarly, samples (B1, B2, B3) exhibited pH levels between 6.8 and 7.2 in the wet season, and from 6.8 to 7.2 in the dry season, all within WHO's acceptable range. Distinctively, Sample C showed a pH level of 7.5 in the wet season and 7.3 in the dry season, both aligning with the recommended WHO range (Bwire et al., 2020). These findings mirror those of Kenechukwu et al., (2023) in the Ezu river near an abattoir. Water with pH outside the specified range may adversely affect aquatic life and be unsuitable for drinking (Mushtaq et al., 2020). The observed pH values are attributed to abattoir activities, waste disposal, and sewage in water bodies, highlighting anthropogenic impacts on water quality.

3.1.2 Dissolved Oxygen (DO)

In the collected water samples, particularly A1, A2, A3, DO levels during the wet season ranged from 5.8 to 6.5, while in the dry season, they varied from 5.5 to 6.2 mg/L. Remarkably, all recorded DO levels for Effurun Market Abattoir, during both seasons, fall within the World Health Organization (WHO) standard range of 5.0-8.0 mg/L (Leta and Dibaba, 2019). Similarly, for samples B1, B2, B3, DO levels during the wet season ranged between 5.8 and 6.5, with dry season values varying from 5.5 to 6.2 mg/L. Significantly, all DO levels for sample C were within the acceptable range defined by WHO, with recorded DO levels at 8.0 mg/L during the wet season and 7.0 mg/L during the dry season. In a similar report on DO in water samples, Neboh et al. (2013) noted an increase in DO levels as the effluent flowed from one point to the next and further away from the abattoir facility. Dissolved Oxygen levels serve as crucial indicators of water quality, reflecting the amount of oxygen available for aquatic life. Adequate DO levels are vital for sustaining aquatic ecosystems, and the findings imply that the studied abattoirs do not significantly compromise the oxygen content in the water during both wet and dry seasons. It is important to note that DO levels below 5.0 mg/L adversely affect aquatic biological life, while concentrations below 2.0 mg/L may lead to death for most fishes (Abdel-Tawwab et al., 2019; Leta and Dibaba, 2019).

3.1.3 Electrical Conductivity (EC)

The concentration of EC, in water samples especially in samples A1, A2, A3, during the wet season ranged from 320 to 350 µS/cm, while in the dry season, they varied from 330 to 350 µS/cm. Crucially, all recorded EC, in both seasons, fell within the WHO standard of 500 µS/cm. Similarly, in samples B1, B2, B3, EC levels during the wet season were observed between 350 and 300 µS/cm, with dry season values ranging from 380 to 280 µS/cm. Importantly, all EC values for Ugbolokposo Market Abattoir are within the acceptable range. Sample C recorded EC levels of 380 µS/cm during the wet season and 240 µS/cm during the dry season. Significantly, both dry and wet EC levels fall within the recommended WHO range. The results agreed with the reports of Magaji and Chup (2012) and Akan et al., (2010), where EC values were within the maximum permissible limits and were highest at the point of discharge of effluents into the water body. The results in this study indicated that the water samples are not salty because the concentration of salts dissolved in the water was as little as possible. Conductivity levels, indicative of a water sample's ability to conduct an electric current, are often associated with the presence of dissolved ions. These findings imply that the abattoirs studied do not significantly contribute to elevated levels of conductivity in the water during both wet and dry seasons.

3.1.4 Turbidity

Turbidity levels in water samples detected in samples A1, A2, A3 during the wet season, ranged from 25 to 20 NTU, while in the dry season, values varied from 20 to 18 NTU. Importantly, all recorded Turbidity levels for Effurun Market Abattoir, in both seasons, align with the WHO standard of 5 NTU (Kumar and Puri, 2012). Similarly, samples B1, B2, B3, recorded turbidity levels during the wet season between 15 and 22 NTU, with dry season values ranging from 10 to 15 NTU which were within the acceptable range defined by WHO. In sample C, the recorded Turbidity levels were 5 during the wet season and 8 during the dry season. Turbidity, serving as an indicator of water clarity, reflects the presence of suspended particles. The turbidity levels in this study were higher than what was recorded by Adesina et al., (2018) who analysed water samples from the Ogun River close to the Kara abattoir were effluents from the abattoir were being discharged. High levels of turbidity can impede photosynthesis by preventing penetration of sunlight into the river, which in turn would result in decreased dissolved oxygen output and decrease in plant survival (Adesina et al., 2018).

3.1.5 Total Dissolved Solids (TDS)

The levels of TD in water samples A1, A2, A3, during the wet season ranged from 315.9 to 280 mg/L, while in the dry season, concentration levels varied from 280 to 260 mg/L which were below the WHO standard of 600 mg/L (Ndefo et al., 2011). Similarly, samples B1, B2, B3, TDS levels during the wet season were observed between 250 and 240 mg/L, with dry season values ranging from 180 to 200 mg/L. which were also all well below the WHO standard. Sample C recorded TDS levels were 140 during the wet season and 160 during the dry season, which also fell within the recommended WHO range. The TDS levels in this study was higher than that recorded in river water at Anwai were abattoir effluents were being discharged into with concentration range of 14.78-48.48 mg/L. Total Dissolved Solids encompass a variety of inorganic and organic substances dissolved in water. The implication of a high TDS is that the water becomes ‘undrinkable’ and it can corrode water storage tanks and containers.

3.1.6 Total Suspended Solids (TSS)

The TSS levels, in samples A1, A2, A3 during the wet season, ranged from 40 to 30 mg/L, while in the dry season, the concentrations varied from 35 to 25 mg/L. Samples B1, B2, B3 had TSS levels during the wet season between 30 and 20 mg/L, with dry season values ranging from 20 to 15 mg/L. Sample C in the wet season had TSS levels at 10 and 8 during the dry season. Total Suspended Solids represent the levels of solid particles that remain suspended in water, influencing water clarity. The concentration of TSS in this study was lesser when compared to TSS concentrations of water quality of the River Benue that were receiving untreated abattoir effluents in Wurukum, Wadata, and Northbank of Makurdi with levels of 62.6-92.0 mg/L (Omoni et al., 2023).

The elevated TSS concentrations in water bodies can have significant health and ecological effects. Excessive TSS levels can reduce water clarity, affecting light penetration and hindering photosynthesis in aquatic plants (Pang et al., 2023). This, in turn, can disrupt the aquatic ecosystem and impact the health of fish and other organisms dependent on a balanced and clear water environment. Additionally, suspended solids may carry contaminants, including pathogens and pollutants, posing potential risks to human health if the water is used for domestic purposes or recreational activities (du Plessis and du Plessis, 2019).

3.1.7 Biochemical Oxygen Demand (BOD)

The concentration of BOD in samples A1, A2, A3, BOD levels during the wet season ranged from 15 to 12 mg/L, while in the dry season, values varied from 12 to 10 mg/L. Importantly, all recorded BOD levels for Effurun Market Abattoir, in both seasons, fall within the World Health Organization (WHO) standard of 25 mg/L (Kenechukwu et al., 2023). BOD in water samples B1, B2, B3, during the wet season were between 10 and 8 mg/L, with dry season values ranging from 8 to 6 mg/L which were still below permissible limits. Biochemical Oxygen Demand is a critical parameter indicating the level of organic pollutants in water. Osayomwanbo et al., (2019) recorded BOD levels in river water samples from the Ikpoba river very close to an open waste drain emanating from an active abattoir sited in close proximity to the river at 139.98 to 390.3 mg/L. Higher concentrations of BOD indicates higher organic matter content which can lead to eutrophication of any river water.

3.1.8 Ammonia

The Ammonia (NH_3) levels, in water samples A1, A2, A3 during the wet season ranged from 1.2 to 0.9 mg/L, while in the dry season, values varied from 1 to 0.8 mg/L. Importantly, all recorded Ammonia levels for Effurun Market Abattoir, in both seasons, were above the WHO standard of 0.15 mg/L (Li et al., 2020). Samples B1, B2, B3 had Ammonia levels during the wet season between 0.8 and 1 mg/L, with dry season values ranging from 0.5 to 0.6 mg/L. Crucially, all Ammonia values for in this points were also above the recognized WHO standard. Sample C, recorded Ammonia levels were 0.3 during the wet season and 0.4 during the dry season. Notably, both Ammonia values from also above the recommended WHO range. Ammonia levels are crucial indicators of water quality, reflecting nitrogen pollution. During the slaughtering and processing of animals in abattoirs, blood, urine, and other organic materials rich in nitrogen are released into wastewater (Nazifa et al., 2021). These findings affirm that the abattoirs studied do significantly contribute to elevated levels of ammonia in the water during both wet and dry seasons, ensuring water quality may not be within recommended levels for environmental and human health.

3.1.9 Nitrate

The Nitrate levels, in samples A1, A2, A3, during the wet season ranged from 3 to 2.5 mg/L, while in the dry season, values varied from 2.5 to 2 mg/L. Importantly, all recorded Nitrate levels for Effurun Market Abattoir, in both seasons, fall within the WHO standard of 50 mg/L (Kenechukwu et al., 2023). Similarly, samples B1, B2, B3, had Nitrate levels during the wet season and were observed between 2 and 1.8 mg/L, with dry season values ranging from 1.5 to 1.2 mg/L which were also significantly below the specified WHO standard. Sample C, a single sample was collected, and the recorded Nitrate levels were 1 during the wet season and 0.8 during the dry season which were also below the WHO standard. Nitrate levels are crucial indicators of water quality, reflecting potential contamination by agricultural and human activities. The observed Nitrate levels in all abattoirs suggest that the water quality, based on this parameter, is within acceptable limits according to the WHO standard. In the study by Adesina et al., (2018) they recorded concentrations of Nitrate levels in range of 7.7 to 2,395 mg/L in the Ogun River receiving effluents discharge from abattoirs close by which is higher in concentration to that recorded in this study. Research studies have reported that high values of nitrate in water could result to excessive aquatic plant growth and algal bloom, and in the Blue-baby syndrome in children and pregnant women (Hashimi and Hashimi, 2020; Verma et al., 2023; Riaz et al., 2024).

3.1.10 Nitrite

The Nitrite levels in water samples A1, A2, A3 during the wet season ranged from 0.2 to 0.15 mg/L, while in the dry season, values varied from 0.1 to 0.12 mg/L. Importantly, all recorded Nitrite levels for Effurun Market Abattoir, in both seasons were above the WHO standard of 0.03 mg/L. For samples B1, B2, B3, Nitrite levels during the wet season were observed between 0.1 and 0.18 mg/L, with dry season values ranging from 0.08 to 0.1 mg/L. Crucially, all Nitrite values for Ugbolokposo Market Abattoir are significantly also above the specified WHO standard. Sample C recorded Nitrite levels at 0.05 mg/L during the wet season and 0.06 mg/L during the dry season. Nitrite levels are crucial indicators of water quality, reflecting potential contamination by agricultural and human activities. nitrite concentrations were found to be comparable to those observed in water samples collected at five different locations along the Eleme River in Rivers state, particularly in areas with abattoir operations with recorded nitrite levels of 0.41 to 1.14 mg/L (Egobueze et al., in 2011). Elevated Nitrite levels in water pose health risks such as methemoglobinemia, reducing blood's oxygen transport capacity (Balejčíková et al., 2020; Banerjee et al., 2023). Additionally, Nitrite contamination disrupts aquatic ecosystems, harming fish and other organisms (Paul et al., 2019). High concentrations, often tied to organic matter decomposition and runoff from agriculture and industry, threaten overall aquatic environment health.

3.1.11 Chlorides

The Chlorides levels in samples A1, A2, A3 ranged from 150 to 130 mg/L during the wet season, while in the dry season, values varied from 140 to 120 mg/L. Importantly, all recorded Chlorides levels for Effurun Market Abattoir, in both seasons, fall within the World Health Organization (WHO) standard of 250 mg/L (Kenechukwu et al., 2023). Samples B1, B2, and B3 had Chloride levels during the wet season were observed between 130 and 140 mg/L, with dry season values ranging from 120 to 110 mg/L which were also below the specified WHO standard. Sample C recorded Chlorides levels at 100 during the wet season and 80 mg/L during the dry season. Chlorides levels are crucial indicators of water quality, reflecting potential contamination and salinity. Chloride concentration in this study was similar to concentrations in water samples from a section of the Ogun River were there was the discharge of abattoir effluents at concentrations of 15.33 to 183.58 mg/L (Uwadiae and Agagbo, 2018). The health implications of chloride levels in water are significant. Elevated chloride concentrations can adversely impact human health and have ecological consequences, and those dependent on water resources. Such complications include including gastrointestinal distress, hypertension, and potential renal complications (Oyagbemi et al., 2019; Preuss, 2020). They also pose a potential threat to aquatic ecosystems by disrupting the balance of salinity, which can adversely affect aquatic organisms, their habitats, and overall ecosystem health (Szklarek et al., 2022).

3.2 Heavy Metal Contamination from Abattoir Activities Around Warri

The analysis of heavy metal concentrations (Cd, Cr, Ni, Zn, Pb, and Cu) in water samples collected from river bodies receiving abattoir effluents is detailed in Table 2. The results reveal alarming levels of contamination, with concentrations surpassing permissible limits at all sampled points, indicative of severe pollution. The consequences of these elevated concentrations extend beyond environmental thresholds, posing significant ecological and health impacts.

TABLE 2: Concentrations of Heavy Metals in Water Samples from Abattoir-Impacted River Bodies in Warri

	Sampled points														
	A1		A2		A3		B1		B2		B3		C		
Parameter	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**WHO**
Cadmium (mg/L)	5	4	3.5	3	2	2.5	1	1.8	1.5	1.2	1.5	1.2	0.8	1	0.2
Chromium (mg/L)	12	9	9	7	7.5	6	5.5	4.5	3.5	4	3	2.5	2	1.8	0.05
Nickel (mg/L)	14	11	11	9	9	7.5	7	6	5	6	4	3.5	2.5	2	0.02
Zinc (mg/L)	15	13	13	11	11	9	9	8	7	8	6	5.5	3.5	3	3
Lead (mg/L)	6	5	5	4	4	3.5	3	2.5	2	2	2	1.8	1	1.5	0.03
Copper (mg/L)	7	6	6.5	5.5	5.5	4.5	4.5	3.5	3	4	3	2.2	2	1.8	3

The concentration ranges of heavy metals varied across the sampled points and seasons. Cd showed levels ranging from 0.2 to 5 mg/L, Cr exhibited concentrations from 1.8 to 12 mg/L, Ni ranged from 2 to 14 mg/L, Zn displayed concentrations of 3 to 15 mg/L, Pb had levels from 1.5 to 5 mg/L, and Cu demonstrated concentrations of 1.8 to 7 mg/L. All these concentrations surpassed permissible limits set by regulatory standards, highlighting the severity of contamination.

The elevated heavy metal concentrations are attributed to various anthropogenic activities. E-waste components from dumpsites around the river shores, runoff from burnt ash tires used in defurring animals, car washing, vehicle and motorcycle repairs, as well as faecal droppings from cattle and sheep contribute to these pollution levels (Tekenah et al., 2014; Adeyemo et al., 2019; Mohammed et al., 2020). Furthermore, the burning of oils in the abattoir adds another dimension to the sources of heavy metal contamination.

The elevated heavy metal concentrations pose a severe threat to aquatic ecosystems. These contaminants can accumulate in sediments, affecting benthic organisms and disrupting the overall balance of the aquatic food chain (Ugochukwu et al., 2019). The persistence of these metals may lead to long-term ecological damage, impacting fish populations and other aquatic organisms (Pelić et al., 2023). The potential bioaccumulation of heavy metals in aquatic organisms and subsequent consumption by humans poses health risks. Chronic exposure to these metals through contaminated water or aquatic products may lead to various health issues, including neurological disorders, kidney damage, and carcinogenic effects (Rehman et al., 2018; Isangedighi and David, 2019). Research by Vershima et al., (2015) who took water samples from the Katsina-Ala River to ascertain impact of abattoir effluents on the river found similar elevated concentrations of heavy metals in the water body, suggesting a broader pattern of pollution.

3.3 Microbial Contamination in Water Samples from River Bodies in Abattoir Operational Areas, Warri

Microbiological analyses were conducted on water samples collected from abattoir-affected areas as shown in Table 3, revealing varying concentrations of microbial parameters during both wet and dry seasons. The high counts of Total Coliforms (2400 to 10 MPN/100ml), Escherichia Coliforms (1600 to 3 MPN/100ml), Enterococci (180 to 3 CFU/100ml), and Total Heterotrophic Bacteria (520 to 10 CFU/ml) shows the potential health risks associated with the contamination of these water bodies.

TABLE 3: Microbiological Assessment of Water Samples from Abattoir-Influenced River Bodies

Parameter	Sampled points													
	A1		A2		A3		B1		B2		B3		C	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Total Coliform Count (MPN/100ml)	2400	1800	1800	1500	1200	1000	200	150	110	80	90	70	10	5
Escherichia Coliform (MPN/100ml)	1600	1200	1200	1000	800	700	120	100	70	50	50	40	5	3
Enterococci (CFU/100ml)	180	150	150	120	120	100	30	25	25	20	20	15	5	3
Total Heterotrophic Bacteria (CFU/ml)	520	480	480	450	400	350	100	80	75	60	60	50	15	10

Elevated Total Coliform and Escherichia Coliform counts indicate faecal contamination, suggesting the potential presence of waterborne pathogens (Odonkor and Mahami, 2020; Nascimento Santos et al., 2023). This poses a direct health risk to individuals who may come into contact with or consume the contaminated water, leading to gastrointestinal illnesses and other waterborne diseases (Madhav et al., 2020). The presence of high levels of Total Heterotrophic Bacteria, while not necessarily harmful, can indicate organic pollution. This may lead to oxygen depletion in aquatic ecosystems, adversely affecting the health of aquatic organisms and overall ecosystem balance.

The elevated microbial loads in these water bodies may be attributed to various anthropogenic activities. The runoff from abattoir effluents, including animal waste, carcass residues, and cleaning processes, contributes to the Total Coliform and Escherichia Coliform counts (Ng et al., 2022). Additionally, faecal droppings from cattle and sheep further amplify microbial contamination. The coexistence of these microbial loads with heavy metal concentrations suggests a complex relationship of pollution sources, necessitating comprehensive strategies for water quality management. Esemu et al., (2022) conducted a study Limbe municipality, Cameroon, and found comparable microbial concentrations in water bodies impacted by industrial effluents. This suggests a common pattern of contamination, emphasizing the need for targeted interventions and improved water quality management in abattoir-affected regions.

3.4 Pearson Correlation Matrix for Water Quality Parameters

The Pearson correlation results for the physicochemical parameters during dry and wet seasons in the study are depicted in the correlation matrix in Table 4 below.

The correlation matrix reveals significant relationships between various water quality parameters. Significantly, turbidity exhibits a strong negative correlation with pH (-0.75), suggesting that as turbidity increases, pH tends to decrease. This inverse relationship is indicative of potential contamination, impacting the water's acidity. Moreover, DO shows a strong positive correlation with Nitrite (0.82), implying that higher Nitrites are associated with increased DO levels. However, certain correlations, such as those between Nitrate and Ammonia (-0.57), indicate complex interactions within the water system.

3.5 Heavy metals correlation analysis

The Pearson correlation coefficients for heavy metals during both dry and wet seasons reveal significant relationships among the concentrations of various elements as shown in Table 5.

In the dry season, the coefficients are as follows: Cd (1), Cr (0.294884), Ni (-0.80175), Zn (-0.97251), Pb (0.326679), and Cu (-0.21779). Similarly, in the wet season, the coefficients are consistent, with Cd (1), Cr (0.294884), Ni (-0.80175), Zn (-0.97251), Pb (0.326679), and Cu (-0.21779). These coefficients serve as indicators of the connections between different heavy metal concentrations in the water samples, offering valuable information into potential pollution sources and inter-metal associations. The negative values, particularly for Ni and Zn, suggest potential inverse relationships with

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other heavy metals, highlighting the complexity of environmental dynamics in the studied areas.

TABLE 4: Pearson Correlation Coefficients for Physicochemical paramters in Water Samples

	Turbidity	Total Dissolved Solids	Total Suspended Solids	BOD	Ammonia	Nitrate	Chlorides	Total Nitrogen	Nitrite	Conductivity	Dissolved Oxygen	
pH	1											
Turbidity	-0.75	1										
Total Dissolved Solids	0.65	-0.48	1									
Total Suspended Solids	-0.52	0.68	-0.83	1								
BOD	0.31	-0.21	0.15	-0.32	1							
Ammonia	-0.6	0.78	-0.69	0.55	-0.23	1						
Nitrate	0.48	-0.64	0.45	-0.38	0.5	-0.57	1					
Chlorides	-0.42	0.57	-0.48	0.42	-0.31	0.49	-0.57	1				
Total Nitrogen (TN)	0.78	-0.55	0.62	-0.7	0.33	-0.52	0.59	-0.5	1			
Nitrite	0.66	-0.78	0.74	-0.68	0.43	-0.6	0.55	-0.49	0.79	1		
Conductivity	0.43	-0.59	0.51	-0.45	0.35	-0.48	0.4	-0.3	0.68	0.7	1	
Dissolved Oxygen	-0.63	0.82	-0.76	0.21	-0.33	0.62	0.38	-0.28	0.59	0.52	0.64	1

TABLE 5: Pearson Correlation Coefficients for Heavy Metals in Water Samples

	Chromium	Nickel	Zinc	Lead	Copper	Cadmium
Cadmium	1					
Chromium	0.294884	1				
Nickel	-0.80175	0.175412	1			
Zinc	-0.97251	-0.26234	0.723121	1		
Lead	0.326679	0.369274	-0.45343	-0.16607	1	
Copper	-0.21779	0.553912	0.194325	0.276783	0.636364	1

The correlation coefficient of 1 for Cd in both dry and wet seasons indicates a perfect positive linear relationship, suggesting that Cd concentrations are consistently related to each other. This may signify a common source of Cd pollution or similar environmental conditions affecting its presence in the water. On the other hand, negative correlation coefficients for Ni and Zn, such as -0.80175 and -0.97251, reveal an inverse relationship with other heavy metals. This suggests that as concentrations of Ni and Zn increase, other heavy metals tend to decrease, indicating potential antagonistic interactions or distinct sources of contamination.

IV. CONCLUSION

This study analyzed physicochemical parameters, heavy metals, and microbiological indicators in water around three abattoirs in Warri and its environs during both wet and dry seasons. The study showed that physicochemical parameters were below WHO standards, especially during the wet season. Although, there is a need for consistent monitoring to avoid water body contamination in the areas studied. Furthermore, worrying levels of heavy metals like Cadmium, Chromium, and Nickel highlight the need for stricter pollution control to prevent ecological and health risks. Additionally, the alarming presence of coliforms and heterotrophic bacteria exceeding safety thresholds necessitates improved waste management within abattoirs. These findings indicate the critical need for integrated environmental management, strengthened regulations, and community awareness campaigns to mitigate the adverse impacts of abattoir activities. There is a need for regular sanitation exercise and a need to ensure the treatment of wastewater before discharge from these facilities. By taking a holistic approach, stakeholders can foster sustainable practices that safeguard both the environment and public health in this region.

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