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Assessment of Physicochemical Properties of Abattoir Effluents on Groundwater Quality in Port Harcourt Metropolis, Rivers State, Nigeria

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Abstract:
This study examines the impact of the physicochemical properties of abattoir effluents on groundwater quality in Port Harcourt metropolis, Rivers State, over 12 months. In doing this, forty-nine (49) water samples (comprising 48 groundwater samples and 1 surface water sample) were collected between May 2023 and April 2024 from 4 abattoirs, namely Iwofe, Eagle Island, Eliozu, and Woji (i.e., 4 sampling points) and the Control (1500m away from the Iwofe abattoir). Physicochemical parameters like pH, conductivity, temperature, salinity, DO, TDS, and turbidity were measured in-situ, while COD, BOD, alkalinity, and hardness were determined through laboratory analysis and compared with the Control. The study revealed that the pH, EC, and TDS range fell within NSDWQ (2008) standard for drinking water quality. Also, in both seasons, turbidity levels at all abattoir sites were extremely high (49.08-71.17 NTU), far above the 5 NTU standard, indicating heavy contamination from suspended particles like blood and solid waste. Alkalinity exceeded the 20 mg/l benchmark at Eliozu and Eagle Island, suggesting carbonate presence likely from organic waste. Chemical Oxygen Demand (COD) levels were elevated at all sites, indicating organic pollution from decomposing waste. The study recommended amongst others that the Ministry of Environment should ensure stricter enforcement of environmental regulations by implementing effluent treatment systems at abattoir sites, and introducing year-round groundwater quality monitoring programmes, to prevent environmental degradation, safeguard groundwater resources and ensure sustainable public health outcomes in Port Harcourt.

Keywords: Physicochemical Properties, Abattoir Effluents, Groundwater Quality, Port Harcourt.

1. Introduction

Water is indispensable for human survival, public health, food production, and economic progress. In urban centers such as Port Harcourt, groundwater is extensively utilized for domestic and industrial purposes due to its perceived cleanliness and availability. However, activities in slaughterhouses frequently result in the uncontrolled release of untreated organic waste—including blood, fats, and fecal matter—into nearby environments, thereby contaminating both surface and subsurface water bodies [1]. This contamination, though abattoirs fulfill essential roles in food supply and economic livelihoods, poses a growing environmental challenge.

Abattoir effluent, comprising a complex mixture of blood, protein residues, fats, and cleaning agents, significantly alters groundwater chemistry when it infiltrates through percolation or discharge. Key water quality parameters such as pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), and total suspended solids (TSS) are often disrupted, alongside rising levels of hydrocarbons and nutrients [2]. More alarmingly, heavy metals including chromium, cadmium, lead, copper, and zinc are introduced, which in excessive concentrations, become toxic and may cause severe physiological harm including gastrointestinal ailments, organ failure, or carcinogenic effects [3], [4].

A study conducted in Port Harcourt highlighted the seasonal accumulation of petroleum-related hydrocarbons—polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons (TPHs)—in groundwater surrounding abattoirs, with elevated levels particularly during the wet season [5]. Similarly, an investigation into surface water quality in the Iwofe River found dangerously high levels of pollutants such as TDS, TSS, DO, BOD_5, COD, and heavy metals, exceeding international safety limits, further raising concerns about potential seepage into groundwater [6].

Findings from other Nigerian regions corroborate these risks. For instance, groundwater sources in Southeast Nigeria revealed bacteriological contamination and disrupted physicochemical balance during the dry season [7], [8]. Furthermore, studies in Omu-Aran showed that pollution from abattoirs led to increased BOD, reduced DO, trace metal presence, and microbial contaminants, with contamination severity reducing as borehole distance increased—implying radial spread through the aquifer [9]. Such consistent evidence across multiple regions confirms that abattoir waste discharge significantly degrades water quality, reflected in lower pH, higher nutrient loads, and rising levels of TSS, hydrocarbons, and pathogenic organisms. Given that shallow aquifers supply nearly 45% of urban water in Port Harcourt, and are highly susceptible to leachate intrusion, these concerns warrant urgent investigation [10].

This research addresses these concerns by examining the physicochemical effects of abattoir effluents on groundwater under Port Harcourt's unique hydrogeological conditions—marked by permeable sandy soils, intense rainfall, and shallow water tables [11]. The infiltration of slaughterhouse waste introduces diverse contaminants, including nitrates, phosphates, chlorides, ammonia, and toxic metals like lead and chromium [12], with direct implications for human health, economic activities, and environmental sustainability.

The health ramifications are substantial. Groundwater tainted with organic waste and microbial pathogens is linked to outbreaks of waterborne diseases such as typhoid, cholera, and dysentery, especially in densely populated locales where untreated groundwater is widely consumed [13]. Chronic exposure to nitrates and heavy metals may lead to conditions such as methemoglobinemia or long-term organ damage [14]. Hence, poor effluent management from abattoirs constitutes a major environmental health hazard in Nigeria and similar low- to middle-income countries.

Contaminants from slaughterhouse discharges negatively influence key water parameters such as pH, turbidity, conductivity, and DO, ultimately reducing water quality and suitability for consumption [15]. Although environmental agencies such as NESREA provide regulatory guidelines for effluent discharge, enforcement remains ineffective due to institutional weaknesses and lack of political commitment [16]. Consequently, many abattoirs continue to operate without waste treatment infrastructure, disposing of waste directly into streams, open drains, or the ground surface, from where contaminants percolate into aquifers [17].

Given these widespread impacts, this study seeks to evaluate the magnitude of groundwater pollution near abattoirs by analyzing parameters including pH, EC, TDS, DO, BOD, COD, nitrates, phosphates, chlorides, sulfates, and heavy metals, comparing findings with both national and WHO standards [18], [19]. The insights gained are expected to inform more effective policies, monitoring strategies, and remediation efforts essential to protecting public health and ensuring sustainable urban water management in Nigeria.

Statement of the Problem

Groundwater serves as a major source of potable water for many residents of Port Harcourt Metropolis, particularly in areas where municipal water supply is inadequate or unreliable. However, the quality of this essential resource is increasingly threatened by the unregulated disposal of waste from abattoirs operating within the city. Most of these slaughterhouses lack proper wastewater treatment facilities, resulting in the direct discharge of untreated effluents onto open lands, into drains, or into nearby water bodies. These effluents, rich in organic matter, blood, fats, detergents, and potentially hazardous substances such as heavy metals and pathogens, have a high potential to infiltrate the soil and contaminate underlying aquifers.

Despite growing awareness of the environmental and health implications of this practice, there remains a significant gap in empirical data on how these effluents specifically alter the physicochemical characteristics of groundwater within the metropolis. Prior studies in other Nigerian urban centres have documented elevated levels of biological oxygen demand (BOD), chemical oxygen demand (COD), nitrates, phosphates, total dissolved solids (TDS), and heavy metals in groundwater sources near abattoirs, often exceeding SON, WHO and NESREA safety thresholds. However, few comprehensive studies have been conducted within Port Harcourt, a city with high population density, significant reliance on boreholes, and shallow, sandy aquifers that are particularly vulnerable to contamination.

Furthermore, the absence of strict monitoring and enforcement of environmental regulations allows these abattoirs to continue discharging effluents without consequences. As a result, residents may be unknowingly exposed to contaminated groundwater, leading to increased risks of waterborne diseases and long-term health effects such as organ toxicity or cancer due to chronic ingestion of heavy metals or nitrates. The lack of localized, data-driven assessments has limited the ability of policymakers, public health officials, and environmental agencies to develop effective strategies for managing and mitigating this threat. Therefore, this study seeks to address the problem of potential groundwater contamination by systematically assessing the physicochemical properties of abattoir effluents and their impacts on the quality of groundwater in Port Harcourt metropolis, Rivers State Nigeria.

This prompted the articulation of the following questions that guided this research.

1. What is the wet season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area?
2. What is the dry season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area?
3. What is the impact of the wet and dry seasons mean composition of physicochemical properties of abattoir effluents in groundwater in the study area?

Objectives of the Study

The objectives of the study are to:

1. Determine the wet season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area.
2. Ascertain the dry season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area.
3. Identify the impact of the wet and dry seasons mean composition of physicochemical properties of abattoir effluents in groundwater in the study area.

Significance of the Study

1. The study offers critical data on how abattoir effluents impact groundwater quality, supporting environmental monitoring and raising awareness of related public health risks such as waterborne diseases and toxic exposure from impaired groundwater.
2. Its findings provide a scientific basis for environmental regulations and guide both government agencies and abattoir operators in improving policies on effluent or waste management practices in the study area.
3. The study contributes to academic knowledge on groundwater contamination and provides baseline data for future research on environmental pollution and water safety in urban Nigeria.
4. By informing communities and stakeholders, the research empowers citizenry and promotes advocacy for clean water access and supports broader goals of sustainable urban and industrial development.
5. The findings are expected to provide critical insights into the extent of pollution, identify specific contaminants of concern, and serve as a basis for environmental policy formulation, urban planning, and public health protection.

2. Materials and Methods

Study Area: The study was conducted in the Port Harcourt metropolis. Geographically, Port Harcourt metropolis, encompassing the Port Harcourt and Obio-Akpor Local Government Areas (i.e., two local governments in Rivers State, South-South Nigeria), is situated between latitudes 4°55’N and 6°55’N, and longitudes 6°55’E and 7°05’E. Also, Port Harcourt metropolis is positioned approximately 25 kilometers from the Atlantic Ocean, the city lies at an elevation of 12 meters above sea level, nestled between the Bonny and Amadi Creeks (Chiadikobi et al., 2011). Additionally, Uwalaka (2014) stated that Port Harcourt metropolis covers a total area of 369 km², comprising 360 km² of land and 9 km² of water.

Sample Site Location: A total of forty-nine (49) water samples, comprising 48 groundwater samples and one surface water sample, were collected over 12 months, from May 2023 to April 2024, across four abattoir sites. The sampling was conducted in four distinct phases. In the first phase, a cluster sampling technique was employed to divide the study period into 12 monthly clusters corresponding to each month from May 2023 to April 2024. In the second phase, random sampling was used to select 4 abattoirs out of the 20 identified in Port Harcourt Metropolis, namely Eagle Island, Eliozu, Egbelu, and Woji, while Iwofe abattoir was purposively selected as the control site for comparative analysis (see Figure 1 for the study area and sample location map). The third phase involved purposive sampling to collect one groundwater sample per month from each of the four selected abattoirs. In the final phase, purposive sampling was again applied to select one groundwater source within a 1500 m radius of the Iwofe control abattoir for targeted environmental assessment. Altogether, 12 groundwater samples were obtained from each of the four abattoirs (totaling 48), along with one control surface water sample, culminating in a total of 49 samples collected throughout Port Harcourt Metropolis for this study.

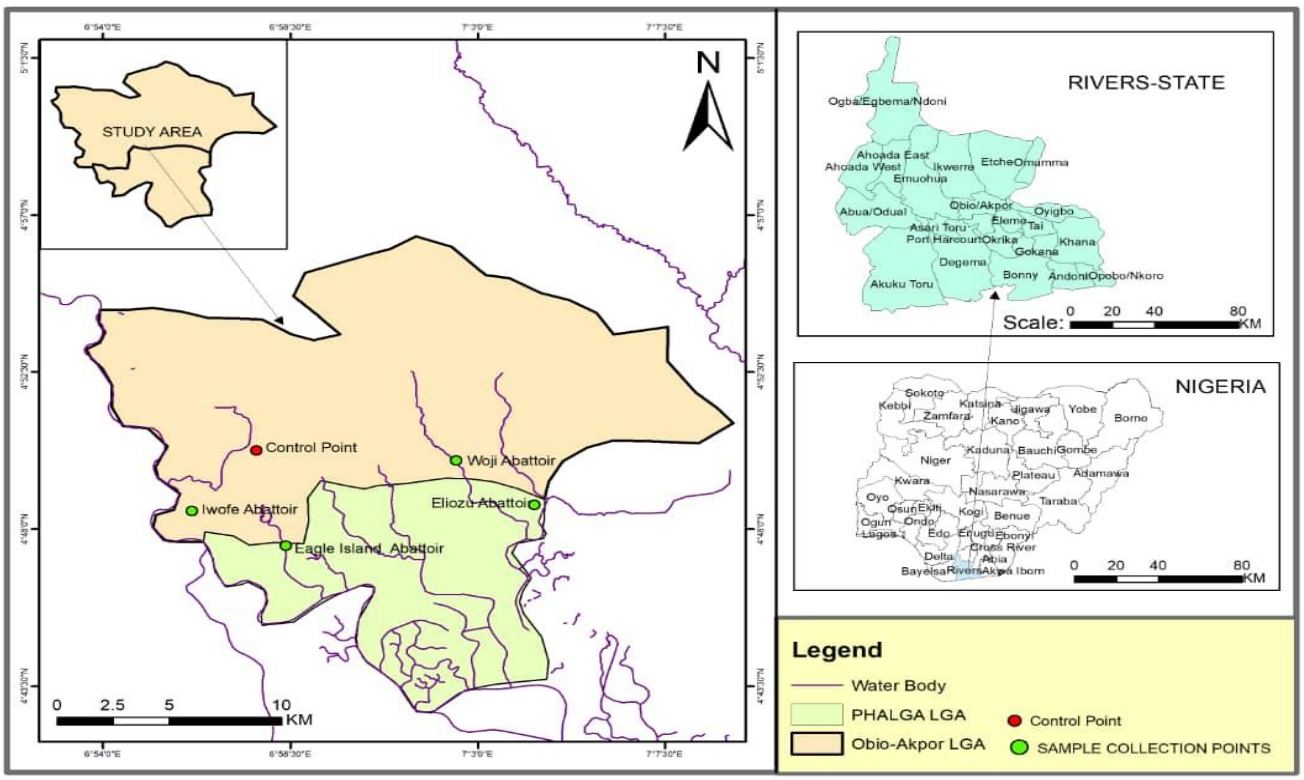

Figure 1: Study Area and Sample Location Map

Research Design: This study adopted an experimental design, which entails the manipulation and control of one or more intervening variables to the subjects, the researcher, experimental instruments, and essential environmental conditions (Nwankwo, 2016).

Method of Data Collection: Groundwater samples were collected monthly over a 12-month period from four abattoirs and one control site, covering both the wet season (May to October 2023) and dry season (November 2023 to April 2024). This allowed for seasonal comparison of physicochemical parameters such as pH, conductivity, temperature, salinity, dissolved oxygen (DO), total dissolved solids

(TDS), turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD), alkalinity, and hardness.

Data Analysis: Relevant statistical tools, including mean, standard error, line charts, bar charts, and other graphical representations, were utilized to analyze the data and effectively address the study's stated objectives.

3. Results

Results

Table 1. The wet season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area

Parameters/Unit	Abattoir				Control	NSDWQ (2008) & WHO (2022)
	Woji	Iwofe	Eliozu	Eagle Island		
pH	6.71±.037	7.20±.021	6.78±.014	6.49±.004	6.63±.024	6.5-8.5
EC (µs/cm)	99.60±.11	112.79±.07	102.86±.08	114.99±.08	54.14±.22	500
TDS (mg/l)	43.43±.13	46.16±.05	42.73±.14	68.47±.06	27.31±.06	1000
Temp (°C)	27.81±.047	27.71±.044	27.72±.097	27.54±.046	27.31±.061	< 40
Salinity (ppt)	1.23±.005	1.17±.002	1.17±.004	1.13±.003	1.14±.013	-
DO (mg/l)	3.40±.017	3.90±.009	5.30±.018	1.80±.008	2.18±.013	14.00
Turbidity (NTU)	71.17±.03	68.31±.06	70.17±.09	49.08±.04	24.76±.04	5.00
Hardness (%)	34.93±.21	46.02±.22	36.05±.24	45.21±.22	34.52±.20	80
Alkalinity (mg/l)	18.85±.12	14.87±.11	24.94±.16	25.66±.12	12.67±.07	20
Calcium Ca (%)	25.76±.12	42.27±.27	27.86±.11	11.65±.10	6.63±.03	NA
Magnesium Mg (mg/l)	1.75±.13	1.52±.10	1.52±.10	1.52±.10	1.72±.08	0.5
COD (mg/l)	14.24±.09	2.84±.02	5.94±.04	5.28±.04	3.95±.03	N/A
BOD (mg/l)	14.06±.08	16.23±.10	14.81±.10	3.22±.09	3.81±.03	30

Source: Researchers' Fieldwork, 2024.

Table 1 presents the mean values of groundwater physicochemical parameters during the wet season near abattoirs, compared with those at a control site and the NSDWQ/WHO standard benchmarks. Groundwater pH at the abattoir sites ranged from 6.49 to 7.20, indicating slightly acidic to neutral conditions within the acceptable range (6.5–8.5) for drinking water. Electrical Conductivity (EC) values were well below the 500 µs/cm limit, suggesting low salinity, with the highest at Eagle Island (114.99 µs/cm). Total Dissolved Solids (TDS) ranged from 42.73 to 68.47 mg/l, also below the 1000 mg/l standard, indicating minimal dissolved substances. Temperature across sites was stable (27.54°C–27.81°C), consistent with typical tropical groundwater conditions. Salinity ranged from 1.13 to 1.23 ppt, slightly above the control (1.14 ppt), with no specific WHO/NSDWQ guideline, implying limited saline intrusion but potential localized contamination. Dissolved Oxygen (DO) was significantly low across sites, especially at Eagle Island (1.80 mg/l), below the 14 mg/l ideal, indicating organic pollution likely from abattoir effluent discharges.

Furthermore, Turbidity levels at all abattoir sites were extremely high (49.08–71.17 NTU), far above the 5 NTU standard, indicating heavy contamination from suspended particles like blood and solid waste. Hardness ranged from 34.93% to 46.02%, within safe limits, showing moderately hard water. Alkalinity exceeded the 20 mg/l benchmark at Eliozu and Eagle Island, suggesting carbonate presence likely from organic waste. Calcium was highest at Iwofe (42.27%) and lowest at Eagle Island (11.65%), while magnesium levels across all sites exceeded the WHO limit of 0.5 mg/l, indicating possible effluent or mineral contamination. COD peaked at Woji (14.24 mg/l), reflecting high organic load, with lower values at the control site. BOD values, though under the 30 mg/l limit, were notably elevated at Iwofe (16.23 mg/l), confirming significant organic pollution. In summary, while many parameters fall within permissible limits, elevated turbidity, low DO, and moderate BOD and COD levels in the abattoir sites point to organic contamination likely caused by effluent infiltration during the wet season. These findings suggest a potential risk to groundwater quality and public health, warranting urgent attention and improved waste management at abattoir sites.

Table 2. The dry season mean composition of the physicochemical properties of abattoir effluents in groundwater in the study area

Parameters/Unit	**Abattoir**				**Control**	**NSDWQ (2008) & WHO (2022)**
	Woji	**Iwofe**	**Eliozu**	**Eagle Island**		
pH	6.92±.015	7.28±.017	6.37±.015	6.46 ±.011	7.10± .027	6.5-8.5
EC (µs/cm)	145.67±.17	141.01±.09	139.65±.15	134.09±.18	62.9±.25	500
TDS (mg/l)	27.60±.01	21.53±.12	28.96±.12	62.30±.26	27.88±.06	1000
Temp (°C)	28.75±.109	28.56±.201	29.21±.119	28.95±.013	27.88 ± .173	< 40
Salinity (ppt)	1.22±.011	1.38±.014	1.22±.013	1.14 ±.003	1.16±.0.08	-
DO (mg/l)	5.70±.015	5.59±.014	4.36±.013	2.54 ±.011	3.08±.003	14.00
Turbidity (NTU)	57.63±.17	62.30±.26	63.61±.20	26.18±.07	27.89±.08	5.00
Hardness (%)	34.63±.20	43.12±.22	33.87±.10	32.15±.15	27.65±.14	80
Alkalinity (mg/l)	21.60±.11	14.32±.11	22.82±.10	14.93±.07	15.30±.10	20
Calcium Ca (%)	14.16±.18	28.69±.13	25.48±.21	13.58±.24	7.10±.05	NA
Magnesium Mg (mg/l)	1.78±.18	4.62±.16	2.68±.02	2.75±.24	3.44±.12	0.5
COD (mg/l)	16.68±.11	3.25±.02	11.15±.09	4.37±.04	5.40±.045	N/A
BOD (mg/l)	12.11±.03	16.20±.09	15.11±.10	3.47±.02	6.24±.03	30

Source: Researchers' Fieldwork, 2024.

Table 2 shows dry season average concentrations of groundwater physicochemical parameters from four abattoir sites and a control, compared with NSDWQ (2008) and WHO (2022) standards. The pH values (6.37–7.28) indicate slightly acidic to neutral groundwater, all within the safe range (6.5–8.5). Electrical Conductivity (134.09–145.67 µS/cm) and Total Dissolved Solids (up to 62.30 mg/L) were higher in abattoir sites than the control (62.9 µS/cm and 27.88 mg/L, respectively) but below standard limits, indicating moderate contamination from dissolved ions and organics. Water temperatures (28.56°C–29.21°C) were slightly higher than the control (27.88°C) but within the safe limit, suggesting biological or chemical activity linked to organic waste. Salinity (1.14-1.38 ppt) was fairly stable but marginally above control, indicating possible salt leaching from abattoir waste. Dissolved Oxygen (2.54–5.70 mg/L) was well below the WHO limit (14 mg/L), reflecting significant oxygen depletion likely due to microbial breakdown of organic pollutants from the effluents, signaling potential environmental stress in affected groundwater sources.

Furthermore, Turbidity levels at all abattoir sites exceeded the 5 NTU limit, peaking at Eliozu (63.61 NTU), indicating poor clarity and health risks. Water hardness ranged from 32.15% to 43.12%, within the 80% limit, but was potentially problematic for domestic use. Alkalinity was highest at Eliozu (22.82 mg/L), slightly above the 20 mg/L WHO standard, while Iwofe remained within limits. High calcium at Iwofe (28.69%) and Eliozu (25.48%) suggests mineral leaching from abattoir activity. Magnesium levels exceeded the 0.5 mg/L limit across all sites, notably at Iwofe (4.62 mg/L), indicating contamination. Chemical Oxygen Demand (COD) levels were elevated at all sites, especially Woji (16.68 mg/L), compared to 5.40 mg/L at the control. Biological Oxygen Demand (BOD) was highest at Iwofe (16.20 mg/L) and Eliozu (15.11 mg/L), below the 30 mg/L WHO limit, but indicating organic pollution from decomposing waste. Overall, groundwater samples from abattoir sites during the dry season displayed elevated values in turbidity, salinity, magnesium, DO, COD, and BOD compared to the control and WHO/NSDWQ standards. These findings indicate that abattoir operations are contributing to the physicochemical degradation of groundwater quality, posing potential risks to human and environmental health.

Table 3: The impact of the wet and dry seasons mean composition of some physicochemical properties of abattoir effluents in groundwater in the study area

Parameter/Unit	**Abattoirs**								**Control**		**NSDWQ (2008)**
	Woji		**Iwofe**		**Eliozu**		**Eagle Island**				
	WET	**DRY**	**WET**	**DRY**	**WET**	**DRY**	**WET**	**DRY**	**WET**	**DRY**	
pH	6.71±.037	6.92±.015	7.20±.021	7.28±.017	6.78±.014	6.37±.015	6.49±.004	6.46±.011	6.63±.024	7.10±.027	6.5-8.5
EC (µs/cm)	99.60±.11	145.67±.17	112.79±.07	141.01±.09	102.86±.08	139.65±.15	114.99±.08	134.09±.18	54.14±.22	62.9±.25	500
TDS (mg/l)	43.43±.13	27.60±.01	46.16±.05	21.53±.12	42.73±.14	28.96±.12	68.47±.06	62.30±.26	27.31±.06	27.88±.06	1000
Temp (°C)	27.81±.047	28.75±.109	27.71±.044	28.56±.201	27.72±.097	29.21±.119	27.54±.046	28.95±.013	27.31±.061	27.88±.173	< 40
Salinity (ppt)	1.23±.005	1.22±.011	1.17±.002	1.38±.014	1.17±.004	1.22±.013	1.13±.003	1.14±.003	1.14±.013	1.16±.0.08	-
DO (mg/l)	3.40±.017	5.70±.015	3.90±.009	5.59±.014	5.30±.018	4.36±.013	1.80±.008	2.54±.011	2.18±.013	3.08±.003	14.00

Source: Researchers' Fieldwork, 2024.

Table 3 compares seasonal groundwater quality near abattoirs and a control site using physicochemical parameters against NSDWQ (2008) standards. The pH levels remained within NSDWQ limits (6.5-8.5), with slightly lower values in the wet season at Eliozu and Eagle Island, indicating mild acidity. Electrical Conductivity (EC) levels were higher in the dry season, especially at Woji, indicating reduced dilution and increased ion concentration due to limited recharge and evaporation. Total Dissolved Solids (TDS) levels were higher at Eagle Island during the wet season, likely due to sediment-laden runoff and organic infiltration from rainfall. Dry season temperatures were higher (28.56°C–29.21°C) than wet season (~27.7°C), due to increased ambient heat and solar radiation. Salinity remained stable seasonally, with slight dry-season rise at Iwofe, suggesting consistent ionic intrusion from surrounding waste sources. Dissolved Oxygen (DO) levels were higher in dry season but remained below WHO standards, indicating poor oxygenation and possible organic pollution, especially at Eagle Island (1.80 mg/L) during the wet season at Eagle Island (1.80 mg/L).

Table 4. The impact of the wet and dry seasons mean composition of some physicochemical properties of abattoir effluents in groundwater in the study area

Parameter/Unit	**Abattoirs**								**Control**		**NSDWQ (2008)**
	Woji		**Iwofe**		**Eliozu**		**Eagle Island**				
	WET	**DRY**	**WET**	**DRY**	**WET**	**DRY**	**WET**	**DRY**	**WET**	**DRY**	
Turbidity (NTU)	71.17±.03	57.63±.17	68.31±.06	62.30±.26	70.17±.09	63.61±.20	49.08±.04	26.18±.07	24.76±.04	27.89±.08	5.00

Hardness (%)	34.93±.21	34.63±.20	46.02±.22	43.12±.22	36.05±.24	33.87±.10	45.21±.22	32.15±.15	34.52±.20	27.65±.14	80
Alkalinity (mg/l)	18.85±.12	21.60±.11	14.87±.11	14.32±.11	24.94±.16	22.82±.10	25.66±.12	14.93±.07	12.67±.07	15.30±.10	20
Calcium Ca (%)	25.76±.12	14.16±.18	42.27±.27	28.69±.13	27.86±.11	25.48±.21	11.65±.10	13.58±.24	6.63±.03	7.10±.05	NA
Magnesium Mg (mg/l)	1.75±.13	1.78±.18	1.52±.10	4.62±.16	1.52±.10	2.68±.02	1.52±.10	2.75±.24	1.72±.08	3.44±.12	0.5
COD (mg/l)	14.24±.09	16.68±.11	2.84±.02	3.25±.02	5.94±.04	11.15±.09	5.28±.04	4.37±.04	3.95±.03	5.40±.045	N/A
BOD (mg/l)	14.06±.08	12.11±.03	16.23±.10	16.20±.09	14.81±.10	15.11±.10	3.22±.09	3.47±.02	3.81±.03	6.24±.03	30

Source: Researchers' Fieldwork, 2024.

Table 4 presents a comparison of seasonal groundwater quality at abattoir and control sites, evaluating physicochemical parameters against NSDWQ (2008) standards. Turbidity was highest in the wet season at Eliozu and Woji, exceeding limits due to runoff and suspended solids, indicating poor water clarity. Water hardness stayed below NSDWQ limits, peaking in wet season at Iwofe and Eagle Island due to mineral-rich runoff. Alkalinity rose in the wet season at Eliozu (24.94 mg/L) and Eagle Island (25.66 mg/L), exceeding limits due to increased buffering from organic and inorganic runoff. Calcium levels increased substantially during the wet season, especially at Iwofe (42.27%), while magnesium levels spiked in the dry season, particularly at Iwofe (4.62 mg/L) and Eagle Island (2.75 mg/L), both surpassing the WHO limit of 0.5 mg/L. This suggests seasonal leaching of minerals intensified by abattoir waste infiltration. Chemical Oxygen Demand (COD) levels peaked in the dry season, especially at Woji (16.68 mg/L), indicating more organic accumulation due to reduced flow and less dilution. Biological Oxygen Demand (BOD) levels exceeded 14 mg/L at all abattoir sites (except Eagle Island, wet season), peaking at Iwofe, (16.23 mg/L in wet and 16.20 mg/L in dry seasons), indicating strong microbial activity and notable organic contamination, though below WHO's 30 mg/L limit.

4. Discussion

Table 1 illustrates the compromised quality of groundwater near abattoir sites during the wet season. Although parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature remained within regulatory limits, several others—including dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), calcium, alkalinity, and magnesium—exceeded safe thresholds, suggesting contamination. Turbidity values ranging from 49.08 to 71.17 NTU were recorded, significantly surpassing the recommended 5 NTU limit and indicating the presence of suspended materials such as blood, fats, and microorganisms [20]. These elevated turbidity levels increase the risk of waterborne infections by supporting microbial survival and impeding disinfection processes. Furthermore, reduced DO levels point to organic pollution, which depletes oxygen levels, hinders aquatic survival, and diminishes the groundwater's natural self-purification ability [21].

Elevated concentrations of BOD (14.06–16.23 mg/L) and COD (up to 14.24 mg/L) near these sites signify the discharge of high organic loads from untreated slaughterhouse waste, which poses a long-term risk to groundwater sustainability [22]. Additionally, elevated levels of magnesium, especially above the World Health Organization (WHO) permissible limit of 0.5 mg/L, point to leaching intensified by rainfall and percolation, which may result in chronic laxative effects or other health hazards upon consumption [23]. Although EC, TDS, and hardness remained within acceptable ranges, their consistent elevation indicates cumulative contamination from repeated effluent discharge. Continuous exposure to even low-level contaminants can lead to persistent groundwater pollution that becomes increasingly difficult to remediate, as previously documented [24]. The combined effect of elevated BOD, COD, turbidity, and magnesium concentrations validates prior reports on urban water quality degradation from abattoir waste [25], [26]. Left unregulated, such contamination poses a threat to communities relying on shallow wells. Thus, waste treatment systems and regular groundwater monitoring are urgently needed.

During the dry season, data in Table 2 reveal significant groundwater quality fluctuations. Although certain values stayed within standards, other parameters exhibited signs of increasing pollution due to the absence of rainfall and minimal dilution. For example, pH ranged between 6.37 and 7.28, remaining mostly within the safe range, although the low reading at Eliozu (6.37) suggests local acidification due to organic decomposition. EC values rose significantly (134.09–145.67 µS/cm) at abattoir sites, indicating elevated ionic concentrations from concentrated waste infiltration [27]. Temperatures were slightly elevated, promoting microbial growth and organic decomposition—factors that can further degrade oxygen levels [28]. DO readings across the sites remained low, particularly at Eagle Island, pointing to ongoing oxygen stress and sustained pollution [29].

Moreover, turbidity remained high, ranging from 26.18 to 63.61 NTU, further indicating suspended waste particles and microbial risk [30]. Magnesium levels were consistently above WHO limits across all locations, with Iwofe recording the peak (4.62 mg/L) [31]. COD and BOD values, particularly at Woji (16.68 mg/L) and Iwofe (16.20 mg/L), respectively, affirm ongoing organic waste contamination from slaughterhouse discharge [32].

Seasonal analyses in Table 3 show similar concerning trends. While pH values remained within the Nigerian Standard for Drinking Water Quality (NSDWQ) range of 6.5–8.5, their variation between seasons reflects dilution effects and organic decomposition [33]. EC and TDS levels, especially at Eliozu and Woji, were higher in the dry season, suggesting increased ionic and organic loads due to reduced water recharge and accumulation of pollutants [34]. Though within permissible thresholds, such sustained increments may pose chronic contamination risks. Dry season temperatures, reaching up to 29.21°C, can intensify microbial decomposition and chemical activity, hastening groundwater quality decline [35]. Additionally, salinity rose at certain sites, notably Iwofe, indicating possible salt intrusion from organic matter decomposition. DO dropped as low as 1.80 mg/L in the wet season, indicating severe oxygen stress and potential anaerobic conditions [36].

Table 4 supports these findings, with turbidity levels exceeding 70 NTU at Woji and Eliozu in the wet season, signifying heavy contamination and increased treatment burden [37]. Although hardness remained within the 80% limit, alkalinity levels during the wet season at Eliozu and Eagle Island surpassed safe margins, likely due to organic matter buffering effects [2]. Elevated calcium and magnesium levels, consistent across seasons, suggest contamination through leaching of decomposing animal waste into the aquifers [12].

High COD values (up to 16.68 mg/L) and BOD readings (above 15 mg/L) confirm sustained organic pollution and potential anaerobic groundwater conditions [15]. Overall, these patterns strongly indicate that abattoir waste in Port Harcourt significantly impacts groundwater quality, with more acute effects during the dry season. These findings highlight the urgent need for enhanced regulatory oversight and improved waste management practices [1]. The risk is especially serious for low-income communities relying on untreated groundwater for daily use, reinforcing the necessity of institutionalized monitoring and the adoption of sustainable abattoir operations [19].

5. Conclusion

In summary, the result demonstrates pronounced seasonal variations in groundwater quality near abattoir sites. The wet season generally showed higher turbidity, alkalinity, and calcium levels due to increased surface runoff, while the dry season recorded elevated EC, COD, and magnesium levels due to concentration effects. Across both seasons, many parameters, turbidity, DO, magnesium, and BOD, deviated from safe standards, reflecting the continuous impact of abattoir effluents on groundwater quality and potential public health risks.

Overall, the dry season measurements show that groundwater in proximity to abattoirs remains impacted by organic and chemical waste, with elevated turbidity, magnesium, BOD, and COD levels being of particular concern. The reduced dilution capacity of the dry season likely exacerbates the effects of pollutant infiltration, calling for stricter effluent management and groundwater protection strategies to prevent long-term environmental degradation and health risks for surrounding communities.

6. Recommendations

Based on the findings of the study, the following recommendations were made:

1. The Ministry of Environment should ensure stricter enforcement of environmental regulations by implementing effluent treatment systems at abattoir sites, and introducing year-round groundwater quality monitoring programmes. These measures are necessary to prevent environmental degradation, safeguard groundwater resources and ensure sustainable public health outcomes in Port Harcourt metropolis.
2. Regulatory bodies like the Standard Organization of Nigeria (SON), National Environmental Standards Enforcement and Regulatory Agency (NESERA), etc., should intensify monitoring of effluent discharges from abattoirs during the rainy season and enforce pre-treatment measures such as sedimentation and filtration before effluent seeps into the surrounding groundwater systems.
3. The government should embark on regular seasonal assessments that are institutionalized to identify pollutant concentration trends and initiate early remedial action, including controlled discharge practices and community awareness campaigns, to prevent the short and long-term health risks associated with toxic chemicals exposure on humans and biodiversity.

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