web of semantic
Journal of Interdisciplinary Science | ISSN: 2960-9550
Research Article
Peer-review, Open Access

Impact of Seasonal Variation of Heavy Metal Concentrations in Abattoir Effluents on Groundwater Quality in Port Harcourt Metropolis, Rivers State

Amaechi - Onyerimma, C. A. [1]

Abstract: This study investigates the impact of seasonal variation of heavy metal concentrations in abattoir effluents on groundwater quality in Port Harcourt metropolis, Rivers State, over 12 months. Forty-nine water samples (48 groundwater and 1 surface water) were collected from four abattoirs and a control site between May 2023 and April 2024 for this study. Heavy metals like Chromium, Cadmium, Zinc, Copper, Iron, and Lead were analyzed in the lab and compared with the Control using an experimental design and a completely randomized block design. The study revealed that Eagle Island had the highest chromium level (0.52 mg/l) during the wet season, which exceeded NSDWQ limits, and may pose risks of skin irritation and long-term organ damage. Copper levels exceeded the 0.004 mg/l NSDWQ limit at all sites during the wet season, and elevated copper in drinking water may, over time, lead to liver and kidney damage. Similarly, zinc levels far exceeded the NSDWQ limit (0.01 mg/l) at all sites during the dry season, indicating significant contamination. Lead levels at the control (36 mg/l) during the dry season exceeded the NSDWQ limit, as well as expected environmental and regulatory thresholds. The study recommended, amongst others, that the Ministries of Health, Environment, and Agriculture, in collaboration with Veterinary and environmental professionals, should establish continuous groundwater monitoring and enforce best management practices (BMPs) at all abattoir locations to mitigate the long-term accumulation of toxic metals such as lead and iron in nearby water sources.

Keywords: Seasonal Variations, Heavy Metal, Abattoir Effluents, Groundwater Quality, Port Harcourt Metropolis.

[1] *Department of Biology, Ignatius Ajuru University of Education, Port Harcourt, Rivers State, Nigeria, leobenz@yahoo.com*

Introduction

Abattoirs, through their routine operations across different seasons, are known for generating and discharging untreated or inadequately treated wastewater directly into the surrounding environment. This wastewater among other materials, often contains high concentrations of pollutants, notably heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), and zinc (Zn), originating from sources like animal blood, waste, cleaning agents, and corroded equipment. Thus, the continuous release of these effluents into the environment contributes to seasonal fluctuations in groundwater quality, posing a significant environmental and public health risk, particularly in Port Harcourt metropolis, Rivers State.

Seasonal variations, primarily the wet and dry seasons characteristic of the Niger Delta region, play a critical role in modulating the behaviour and concentration of these heavy metals in the environment. During the dry season, lower water tables and reduced rainfall result in a higher concentration of effluents in the immediate environment due to limited dilution (Okon et al., 2019. As such, heavy metals tend to accumulate in soil and leach more readily into shallow groundwater systems. In contrast, the rainy season, marked by intense and frequent rainfall, may cause increased runoff, which spreads contaminants across a wider area (Edward & Adamu, 2023). However, the dilution effect of rainwater can temporarily lower the observed concentrations of heavy metals in surface effluents, even though the cumulative infiltration into aquifers may still pose long-term contamination risks (Okerulu & Offor, 2019; Edward, 2020; Ekpechi & Okori, 2022).

Studies conducted in Port Harcourt have shown that groundwater sources, particularly shallow wells and boreholes situated near abattoirs, often exceed World Health Organization (WHO) permissible limits for heavy metals during both seasons, with slight variations depending on the volume of effluents discharged and the prevailing hydrological conditions (Nduka et al., 2022; Okoye & Amadi, 2021; WHO, 2022). The proximity of groundwater sources to points of effluent discharge exacerbates the risk of contamination, especially in unlined or poorly constructed wells. This implies that the seasonal fluctuation in heavy metal concentrations in abattoir effluents can significantly influence groundwater quality in Port Harcourt metropolis.

The nature of abattoir waste containing animal feeds and water affects the lead (Pb) loads, which constitute an environmental hazard to plants, animals, and human beings that come in contact with groundwater sources (Elemile et al., 2020). The implications of toxic heavy metals such as lead and cadmium, even at low concentrations, and long-term exposure can cause significant contamination, leading to severe health issues, including kidney damage, neurological disorders, and developmental impairments in children (Amaechi-Onyerimma, 2021). The presence of toxic substances in abattoir effluents has the propensity to incite carcinogens that can cause harm, especially to humans (Wokoma et al., 2022). Furthermore, the presence of these metals in drinking water affects not only human health but also soil fertility and ecosystem stability, threatening food safety and livelihoods in affected communities, including those in Port Harcourt metropolis (Ndukwe et al., 2023). These scholarly standpoints corroborate with Akinnibosun and Ayejuyoni (2015) earlier assertion that heavy metals like Lead, Zinc, Chromium, Copper, and Cadmium constitute the parameters that are greatly impacted by abattoir waste effluents.

Beyond the evident health and ecological risks, the seasonal impact of heavy metal-laden effluents on groundwater in Port Harcourt underscores broader challenges in urban planning, environmental governance, and sustainable resource management (Wokoma et al., 2022). The high density of informal and unregulated abattoirs across the metropolis, especially in areas such as Trans-Amadi, Diobu, and Rumuokoro, further complicates the containment of pollution sources. These abattoirs often lack proper drainage infrastructure, leading to the indiscriminate disposal of wastewater, which seeps into surrounding soils and shallow aquifers, particularly vulnerable during the dry season when groundwater recharge is minimal and pollutant concentrations become more pronounced (Akaninwor & Ijeoma, 2020).

During the rainy season, however, although dilution may reduce immediate toxicity levels in surface water, the risk of groundwater contamination through vertical leaching increases due to enhanced percolation (Umeuduji & Okezie, 2022). The saturated soils become more permeable, and heavy metals, especially those with low adsorption capacity, such as cadmium and lead, can migrate into aquifers over time (Edward, 2020). This dynamic highlight the importance of understanding seasonal hydrogeological behaviour when designing mitigation and monitoring programmes (Edward & Adamu, 2023). This issue reflects a complex interaction between environmental factors, human activity, and governance gaps. Recent studies underscore the considerable seasonal variation in heavy metal concentrations in abattoir effluents and the downstream effects on groundwater quality in the Port Harcourt metropolis, Rivers

State, Nigeria. Wokoma et al. (2022) conducted a six-month analysis (encompassing both dry and wet seasons) on creek waters receiving abattoir discharges. They found significantly elevated levels of calcium, zinc, manganese, cadmium, iron, and lead across multiple locations compared to control sites.

While the Wokoma et al. (2022) study focused on surface water, other researchers have highlighted the hydrological connectivity between surface runoff and groundwater systems in similar contexts. For instance, Ndukwe et al. (2023) documented persistent traces of lead, cadmium, chromium, copper, iron, manganese, nickel, and arsenic in the Iwofe River, an effluent-receiving channel, finding that although concentrations differed by season, many parameters exceeded World Health Organization guidelines. Their analysis suggested that during the wet season, increased runoff and dilution may lower concentration levels in stream water but simultaneously raise the risk of percolation into shallow aquifers. Parallel results have been observed across Nigeria. Yahaya et al. (2009) reported in Yauri (northwestern Nigeria) that soil heavy metal concentrations varied significantly between rainy and dry seasons, though levels often exceeded typical background values in both settings.

Similarly, Abdul-Adeleke et al. (2022) noted that exposure to rainfall-driven runoff in Benin City resulted in higher concentrations of copper, lead, chromium, and zinc in effluents during the wet season compared to the dry season. In Port Harcourt metropolis, the combination of Wokoma et al.'s (2022) and Ndukwe et al.'s (2023) findings suggests a cyclical pattern: wet-season runoff carries heavier metal loads into surface waterways, some of which infiltrate into underlying aquifers, while dry-season stagnation may result in groundwater accumulation of contaminants. As these heavy metals, such as cadmium and lead, accumulate in groundwater, they pose chronic health risks (including kidney damage, cholera, neurological deficits, and carcinogenic effects) for communities relying on boreholes and hand-dug wells for their water consumption.

Problem Specification

Groundwater is a major water source in the Port Harcourt metropolis. However, its quality can be threatened by untreated abattoir effluents containing organic waste and heavy metals, which seep into soil and shallow aquifers, especially in high water table areas. Seasonal variations further complicate the situation, as rainfall in the wet season increases runoff and infiltration, raising contaminant levels in groundwater, while the dry season reduces dilution, causing higher concentrations of heavy metals in the water table. More problematic is that despite growing awareness of environmental pollution in Port Harcourt, limited attention has been given to the seasonal dynamics of heavy metal contamination from abattoirs and their direct impact on groundwater quality.

There is a lack of comprehensive, location-specific data on how these seasonal changes influence contaminant levels in groundwater, particularly in densely populated and peri-urban areas dependent on boreholes and wells for drinking water. This gap in knowledge hinders the development of effective regulatory and public health interventions. Consequently, residents may unknowingly consume water with heavy metal concentrations that exceed permissible limits. This could pose serious health risks such as cholera, kidney damage, neurological disorders, and cancer. It is based on this premise that this study investigated the seasonal variations in heavy metal concentrations in abattoir effluents on the groundwater quality in Port Harcourt Metropolis, Rivers State, Nigeria.

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

1. What is the heavy metal concentration of abattoir effluents in groundwater during the wet season in the study area?
2. What is the heavy metal concentration of abattoir effluents in groundwater during the dry season in the study area?
3. What is the impact of the wet and dry season average concentration of heavy metals in abattoir effluents on groundwater quality in the study area?

Objectives of the Study

The objectives of the study are to:

1. Determine the heavy metal concentration of abattoir effluents in groundwater during the wet season in the study area.
2. Identify the heavy metal concentration of abattoir effluents in groundwater during the dry season in the study area.
3. Ascertain the impact of the wet and dry season average concentration of heavy metals in abattoir effluents on groundwater quality in the study area.

Significance of the Study

1. The study will aid environmental monitoring and raise awareness of health risks, like cancer, kidney damage, and neurological disorders, associated with contamination of drinking water.
2. The study supports agencies in formulating and enforcing abattoir waste and groundwater policies. This will help local authorities develop sustainable groundwater management by revealing aquifer vulnerability to seasonal heavy metal contamination.
3. The results can guide community leaders and residents in making informed decisions about water use, treatment, and alternative sources, especially during peak contamination seasons.

Materials and Methods

Study Area: The study was conducted in the Port Harcourt metropolis. Geographically, Port Harcourt metropolis, which comprises two local government areas (Port Harcourt and Obio-Akpor), is located on longitude 6°55' – 7°05' E and latitude 4°55' – 6°55'N. It is located 25 km from the Atlantic. Port Harcourt lies between Bonny and Amadi Creeks at 12 m above sea level (Chiadikobi et al., 2011). According to Uwalaka (2014), Port Harcourt metropolis spans 369 km², with 360 km² land and 9 km² water coverage.

Sample Site Location: Forty-nine (49) water samples (comprising 48 groundwater samples and 1 surface water sample) were collected over 12 months (i.e., between May 2023 to April 2024) from 4 abattoirs. The sampling was in four phases. Firstly, the cluster sampling technique was used to delineate the study area into 12 clusters for the collection of groundwater samples. The 12 cluster classification include: (1) May, (2) June, (3) July, (4) August, (5) September, (6) October, (7) November, (8) December, (9) January, (10) February, (11) March, and (12) April. Secondly, random sampling was used to select 4 out of 20 abattoirs in Port Harcourt metropolis, namely Eagle Island, Eliozu, Egbelu, and Woji, while Iwofe abattoir was chosen as the control site for comparison (see Figure 1 for study area and sample location map). Thirdly, purposive sampling was used to select 1 groundwater sample from the 4 selected abattoirs. In the fourth and final phase, purposive sampling was used to select one groundwater source within 1500 m of the Iwofe abattoir (i.e., control) for focused environmental assessment. In all, twelve monthly groundwater samples were collected from each of four abattoirs (48 total), plus one control surface water sample, making 49 samples across the Port Harcourt metropolis for the study.

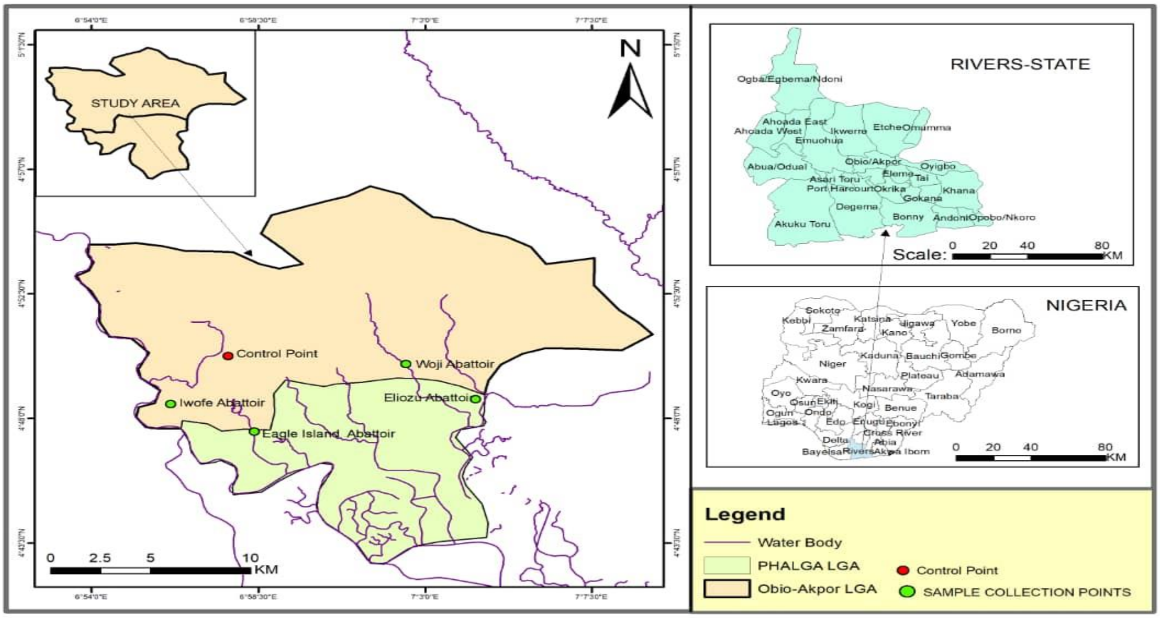

Figure 1: Study Area and Sample Location Map

Research Design: This study employed an experimental design, which involves manipulating and controlling one or more intervening variables based on the subjects, the researcher, experimental tools, and key environmental conditions (Nwankwo, 2016).

Method of Data Collection: Groundwater samples were collected monthly for 12 months from four abattoirs and one control. The period covered both wet (May-October 2023) and dry (November 2023-April 2024) seasons for seasonal comparison of the heavy metals like Chromium, Cadmium, Zinc, Copper, Iron, and Lead.

Data Analysis: Relevant statistical tools such as mean, standard error, line and bar charts, and graphs were employed to analyze data and address the study's stated objectives.

Results

Table 1: Heavy metal concentration of abattoir effluents in groundwater during the wet season in the study area

Parameters/Unit	Woji	Iwofe	Eliozu	Eagle Island	Control	NSDWQ (2008)
Chromium, Cr (mg/l)	.30±.01	.20±.02	.27±.02	.52±.04	.11±.02	0.30
Cadmium, Cd (mg/l)	.21±.01	.31±.02	.27±.02	.40±.04	.19±.02	0.5
Zinc, Zn (mg/h)	3.20±.06	3.00±.06	3.01±.05	4.47±.06	1.46±.06	0.01
Copper Cu (mg/Kg)	.27±.02	.36±.01	.31±.01	.19±.00	.11±.02	0.004
Iron, Fe (mg/l)	54.04±.07	53.66±.01	52.00±.04	50.56.±.04	42.44±.05	0.42
Lead, Pb (mg/l)	.46±.04	.23±.02	.20±.04	.41±.03	.27±.02	1.00

Source: Researchers' Fieldwork, 2024.

Table 1 shows heavy metal concentrations in groundwater from four abattoir sites, Woji, Iwofe, Eliozu, Eagle Island, and a control site during the wet season in Port Harcourt metropolis. Eagle Island had the highest chromium level (0.52 mg/l), exceeding NSDWQ limits may pose risks of skin irritation and long-term organ damage. Woji met the limit, while Iwofe, Eliozu, and the control site showed lower, acceptable concentrations. Cadmium levels at all sites, including the control, were below the 0.5 mg/l NSDWQ limit, with Eagle Island and Iwofe recording the highest concentrations. Cadmium's presence suggests carcinogenic risk and potential chronic exposure concerns. Zinc levels exceeded the 0.01 mg/l NSDWQ limit at all sites. Eagle Island had the highest (4.47 mg/l), and Iwofe the lowest (3.00 mg/l); control was 1.46 mg/l. However, excessive zinc intake may lead to health complications such as gastrointestinal distress. Copper levels exceeded the 0.004 mg/l NSDWQ limit at all sites, with Iwofe highest (0.36 mg/kg) and the control site lowest (0.11 mg/kg). Elevated copper in drinking water may, over time, lead to liver and kidney damage. Iron levels greatly exceeded the 0.42 mg/l NSDWQ limit at all sites; Woji, Iwofe, and Eliozu were highest, with the control also significantly above safe levels. The widespread iron contamination may cause unpleasant taste, staining, and possible health complications. Lead levels were highest at Woji (0.46 ± 0.04 mg/l) and Eagle Island (0.41 ± 0.03 mg/l). All values remained below the NSDWQ maximum of 1.00 mg/l, with the control site showing 0.27 ± 0.02 mg/l. However, the presence of lead is concerning due to its cumulative toxicity, especially in children.

Table 2: Heavy metal concentration of abattoir effluents in groundwater during the dry season in the study area

Parameters/Unit	Woji	Iwofe	Eliozu	Eagle Island	Control	NSDWQ (2008)
Chromium, Cr (mg/l)	.69±.05	.80±.01	.91±.02	.73±.04	.27±.02	0.30
Cadmium, Cd (mg/l)	.28±.02	.24±.04	.14±.02	.53±.10	.46±.05	0.5
Zinc, Zn (mg/h)	9.65±.05	13.16±.04	10.38±.11	4.94±.07	1.89±.04	0.01
Copper Cu (mg/Kg)	.26±.01	.50±.03	.34±.03	.19±.04	.52±.05	0.004
Iron, Fe (mg/l)	68.50±.04	69.03±.06	66.89±.02	57.80±.09	46.25±.04	0.42
Lead, Pb (mg/l)	.50±.04	.53±.04	.55±.04	.50±.06	3.6±.05	1.00

Source: Researchers' Fieldwork, 2024.

Table 2 shows dry season concentrations of selected heavy metals in groundwater from four abattoir sites and a control, compared with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2008). Chromium levels exceeded NSDWQ limits at all abattoir sites, highest at Eliozu (0.91 mg/l); even the control site (0.27 mg/l) neared the threshold, suggesting broader environmental contamination. Cadmium levels were mostly within the NSDWQ limit (0.5 mg/l), except Eagle Island (0.53 mg/l) and the control site (0.46 mg/l), indicating potential health risks. Zinc levels far exceeded the NSDWQ limit (0.01 mg/l) at all sites, with Iwofe highest (13.16 mg/l); even the control (1.89 mg/l) showed significant contamination. Copper levels exceeded NSDWQ limits (0.004 mg/l) at all sites. Iwofe had the highest (0.50 mg/kg), Eagle Island the lowest (0.19 mg/kg); the control also showed elevated contamination (0.52 mg/kg). Iron levels exceeded NSDWQ limits at all sites. Iwofe had the highest (69.03 mg/l), followed by Woji, Eliozu, and Eagle Island; the control also showed elevated levels (46.25 mg/l), suggesting persistent iron pollution. Lead levels at all abattoir sites were within the NSDWQ limit, with Eliozu highest (0.55 mg/l). The control value (3.6 mg/l) appears to have exceeded the expected environmental and regulatory thresholds.

Table 3: The impact of the wet and dry season average concentration of heavy metals in abattoir effluents on groundwater quality in the study area

Parameters /Unit	Woji		Iwofe		Eliozu		Eagle Island		Control		NSDWQ (2008)
	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	
Chromium, Cr (mg/l)	.30±.01	.69±.05	.20±.02	.80±.01	.27±.02	.91±.02	.52±.04	.73±.04	.11±.02	.27±.02	0.30
Cadmium, Cd (mg/l)	.21±.01	.28±.02	.31±.02	.24±.04	.27±.02	.14±.02	.40±.04	.53±.10	.19±.02	.46±.05	0.5
Zinc, Zn (mg/h)	3.20±.06	9.65±.05	3.00±.06	13.16±.04	3.01±.05	10.38±.11	4.47±.06	4.94±.07	1.46±.06	1.89±.04	0.01
Copper Cu (mg/Kg)	.27±.02	.26±.01	.36±.01	.50±.03	.31±.01	.34±.03	.19±.00	.19±.04	.11±.02	.52±.05	0.004
Iron, Fe (mg/l)	54.04±.07	68.50±.04	53.66±.01	69.03±.06	52.00±.04	66.89±.02	50.56.±.04	57.80±.09	42.44±.05	46.25±.04	0.42
Lead, Pb (mg/l)	.46±.04	.50±.04	.23±.02	.53±.04	.20±.04	.55±.04	.41±.03	.50±.06	.27±.02	3.6±.05	1.00

Source: Researchers' Fieldwork, 2024.

Table 3 presents seasonal variations in average concentrations of selected heavy metals in groundwater from four abattoir sites and a control, compared with NSDWQ (2008) permissible limits. Chromium levels were higher in the dry season across all sites, notably at Eliozu (0.91 mg/l) and Iwofe (0.80 mg/l), exceeding NSDWQ limits. Even the control showed seasonal increases. Cadmium levels fluctuated seasonally, mostly within NSDWQ limits. Eagle Island (0.53 mg/l) in the dry season and the control (0.46 mg/l) neared or slightly exceeded the threshold. Zinc levels were consistently high, peaking at Iwofe during the dry season (13.16 mg/l). All sites exceeded NSDWQ limits, indicating widespread and severe zinc contamination. Copper levels exceeded the NSDWQ limit year-round at all sites, with Iwofe recording the highest (0.50 mg/kg). Seasonal variation was minimal, indicating persistent and consistent contamination. Iron concentrations were consistently high year-round, far exceeding the NSDWQ limit of 0.42 mg/l. Iwofe (69.03 mg/l) and Woji (68.50 mg/l) showed peak levels, indicating persistent iron pollution. Lead levels stayed within the NSDWQ limit (1.00 mg/l) across abattoir sites in both seasons. However, the control site's dry season value (3.6 mg/l) for Lead appears to have exceeded the regulatory threshold.

Discussion of Findings

The results in Tables 1-3 revealed that Chromium in Eagle Island exceeded the NSDWQ limit (0.30 mg/L), recorded at 0.52 ± 0.04 mg/L, indicating heightened carcinogenic risks due to long-term exposure (Olusegun et al., 2023). Woji, Iwofe, and Eliozu remained within acceptable bounds, but their proximity to the threshold indicates potential for deterioration. Cadmium levels were below the standard across all sites, though Eagle Island (0.40 ± 0.04 mg/L) nears unsafe concentrations. Even low-level cadmium exposure raises concerns over kidney and bone health (Okafor et al., 2024). Zinc stood far above the NSDWQ limit, ranging from 3.01 to 4.47 mg/L, highlighting significant metal loading. Similar trends were reported by Okafor and Omokpariola in Southeast Nigeria, with zinc concentrations posing ecological and water safety threats.

Also, copper, recorded between 0.11 and 0.36 mg/Kg, exceeded permissible levels by over 80-fold, a trend echoed in studies of Nigerian groundwater with chronic copper presence (Tajudeen et al., 2021). Persistently high copper may impair liver and gastrointestinal health. Additionally, iron contamination was severe: 50-54 mg/L, exceeding the 0.42 mg/L limit. Consistent with findings in oil-contaminated areas (Olalekan et al., 2018), this indicates extensive leaching or corrosion, impacting taste, infrastructure, and raising potential microbial growth. The lead concentrations (0.20-0.46 mg/L) did not breach the NSDWQ limit of 1.0 mg/L, but they remain within a range associated with adverse neurodevelopmental effects in children (WHO, 2023).

Summarily, the result in Table 3 shows elevated levels of heavy metals in groundwater, notably chromium, cadmium, zinc, copper, iron, and lead over the dry and wet seasons. These pose risks ranging from organ damage, gastrointestinal distress, and carcinogenic effects to neurological harm, especially in children. The findings highlight potential chronic exposure from drinking water polluted by abattoir effluents and underline the need for monitoring and remediation to protect public health. Also, the findings of this study agree with previous studies by Oyeku and Eludoyin (2019), which found that the groundwater from a solid waste landfill contained heavy metal levels in Lagos, Nigeria. Also, Adekola and Salami (2020) found that trace or heavy metal pollution from abattoir effluents impacted groundwater resources as well as posed environmental risks in Ilorin, Nigeria. While Adamu et al. (2021) observed heavy metal pollution in groundwater around abattoir wastes in Gombe, Northeastern Nigeria.

Overall, these elevated heavy metal levels, particularly zinc, iron, copper, and chromium, suggest that wet-season percolation exacerbates contamination in groundwater systems. This finding aligns with Ihenyen and Otaru's (2022) study on the seasonal variations in heavy metal concentrations in abattoir-impacted groundwater in Benin City, Nigeria. Similar trends were reported by Wokoma et al. (2023) in Port Harcourt metropolis, Nigeria, where abattoir effluents contained heavy metals (zinc, iron, copper, cadmium, lead, and chromium) that polluted groundwater quality, posing health risks to humans. Thus, the contamination of the groundwater system compromises water potability, raising ecological, infrastructural, and health risks such as organ damage and carcinogenic exposure among others (Brindha et al., 2020; Tajudeen et al., 2021; Okafor et al., 2024). The data underscore urgent needs for improved effluent treatment, regular monitoring, and community-level intervention strategies in the Port Harcourt metropolis.

Conclusion

Seasonal variation significantly affects the concentration of heavy metals in groundwater around abattoir locations. Dry season values were generally higher, possibly due to reduced dilution and increased accumulation. Most metals exceeded permissible limits, highlighting the environmental and public health risks posed by abattoir effluents and the urgent need for regulatory enforcement and remediation strategies as well as remediation. Conclusively, the seasonal fluctuation in heavy metal concentrations in abattoir effluents significantly influences the quality of groundwater in Port Harcourt. Thus, understanding these patterns is essential for devising effective environmental management strategies that safeguard both human health and the natural environment.

Recommendations

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

1. Government and environmental agencies should implement seasonal effluent treatment systems with a view to integrating sustainable waste management practices like recycling and reuse, especially in abattoirs where chromium and iron concentrations exceed the NSDWQ limits, to minimize health risks from heavy metal exposure during the wet season.
2. Urgent regulatory enforcement is needed to monitor and control abattoir waste disposal during the dry season, especially in Eliozu and Iwofe, where zinc and iron show alarming increases, posing severe

ecological and public health threats. This will discourage the use of untreated wastes from abattoirs by farmers as organic manure, with its impending danger along the food chain, which is detrimental to the health of both man and the environment.

3. Owing to the persistent exceedance of permissible limits in both wet and dry seasons, the Ministries of Health, Environment, and Agriculture, in collaboration with Veterinary and environmental professionals, should establish continuous groundwater monitoring and enforce best management practices (BMPs) at all abattoir locations to mitigate the long-term accumulation of toxic metals such as lead and iron in nearby water sources.

References

1. Adamu, C. I., Mustapha, A. O., & Amadi, A. N. (2021). Assessment of heavy metal pollution in groundwater around abattoir wastes in Gombe, northeastern Nigeria. *Environmental Earth Sciences*, *8*(2), 1-12. https://doi.org/10.1007/s12665-021-09379-6.
2. Adekola, F. A., & Salami, A. T. (2020). Environmental risk assessment of trace metal pollution from abattoir effluents on groundwater resources in Ilorin, Nigeria. *African Journal of Environmental Science and Technology*, *14*(3), 87-97. https://doi.org/10.5897/AJEST2020.2786.
3. Adeleke, A. E. Adegbite, S. A. Onifade, A. P. Sangoremi, A. A. & Adegbite, A. A. (2022). Seasonal variation of heavy metals concentration of industrial effluents and receiving rivers in Iguosa and Ikopba, Benin City, Edo State, Nigeria. *Asian Journal of Applied Chemistry Research, 11*(1), 73-78.
4. Akaninwor, J. O., & Ijeoma, M. N. (2020). Heavy metal pollution in abattoir environments and its effects on water quality in Port Harcourt. *Journal of Environmental Health and Safety, 11*(2), 67-78.
5. Akinnibosun, F. I., & Ayejuyoni, T. P. (2015). Assessment of microbial population and physico-chemical properties of abattoir effluent-contaminated soils in Benin City, Nigeria. *Journal of Tropical Agriculture Food Environment Extension*, *14*, 1-6.
6. Al-Khuzaie, M. M., Abdul Maulud, K. N., Wan Mohtar, W. H., & Yaseen, M. Z. (2023). Assessment of untreated wastewater pollution and heavy metal contamination in the Euphrates River. *Environmental Pollution and Bioavailability*, *36*(1), Article 2292110. accscience.com+1accscience.com+1.
7. Amaechi-Onyerimma, C. N. (2021). *Impact of abattoir effluents on groundwater quality in Port Harcourt metropolis, Rivers State*. Unpublished PhD Thesis, Ignatius Ajuru University of Education, Rumuolumeni, Rivers State.
8. Brindha, K., Paul, R., Walter, J., Tan, M. L., & Singh, M. K. (2020). Trace metal contamination in groundwater and implications for human health: A comprehensive hydrogeochemical assessment. *Journal of Environmental Geochemistry and Health*, *42*, 3819-3839.
9. Chiadikobi, K. C., Omoboriowo, A. O., Chiaghanam, O. I., Opatola, A. O., & Oyebanji, O. (2011). Flood risk assessment of Port Harcourt, Rivers State, Nigeria. *Pelagia Research, 2*(6), 287-298.
10. Edward, A. (2020). Seasonal variability of heavy metal concentration in water and sediments from Upper River Benue, Yola-Adamawa, State. *Journal of Environmental Science, Toxicology and Food Technology, 14*(2), 01-04.
11. Edward, A., & Adamu, N. (2023). Dry and Wet Seasonal levels of Heavy Metals in Water, Fish (Brycinus leuciscus) and Sediments from Kiri Reservoir in Shelleng Local Government, Adamawa State, Nigeria. *Journal of Agriculture and Aquaculture*, 5(2), 184-198.
12. Ekpechi, D., & Okori, B. (2022). Seasonal variation of heavy metals in sediments, water, shiny nose fish, shrimp, and periwinkle in Esuk Ekpo Eyo Beach, Akpaiyo, South East, Nigeria. *Journal of Environmental Treatments Techniques, 10*(4), 264-283.

13. Elemile, O. O., Raphael, D. O., Omole, D. O., Oloruntoba, E. O., Ajayi, E. O., & Ohwavborua, N. A. (2019). Assessment of the impact of abattoir effluent on the quality of groundwater in a residential area of Omu-Aran, Nigeria. *Environmental Science Europe*, *31*, 1-10.

14. Ihenyen, A. E., & Otaru, A. J. (2022). Impact of seasonal variations on heavy metal concentrations in abattoir-impacted groundwater in Benin City, Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, *6*(1), 110-120.

15. Nduka, J. C., Okafor, I. P., & Ekweozor, C. (2022). Seasonal dynamics of heavy metal contamination in abattoir effluents and the implications for groundwater quality in Port Harcourt, Nigeria. *Nigerian Journal of Environmental Sciences, 16*(1), 45-59.

16. Ndukwe, M. K. Igara, C. E., Nkama, O. J., Ibe, C. O., Okoro, O. E., Nnnachi, E. O., & Atiaetuk, I. E. (2023). Effect of abattoir waste on surface water quality parameters of Iwofe River, Port-Harcourt, Rivers State, Nigeria. *Journal of Geography, Environment and Earth Science International, 27*(9), 93-101. journaljgeesi.com.

17. Nwankwo, O. C. (2016). *A practical guide to research writing for students in education and social sciences* (6th Edition). M & J Grand Orbit and Communication Ltd.

18. Okafor, I. E., & Omokpariola, O. (2024). Groundwater heavy metal contamination in Southeast Nigeria: Implications for public health. *African Journal of Environmental Science*, *12*(3), 112-125.

19. Okerulu, O., & Offor, C. (2019). Seasonal variation of heavy metal concentrations in water and fish (*Malapterurus electricus*) from the Obii stream, Ufuma, Anambra state, Nigeria. *Journal of Basic Physics Research*, *9*(1), 34-44.

20. Okon, S. U., Atakpa, E. O., & Ewa-Oboho, I. T. A. (2019). Spatial and seasonal characteristics of heavy metals in Ikpa River, Niger Delta, Nigeria. *International Journal of Fisheries and Aquatic Studies, 7*(2), 193-199.

21. Okoye, T. A., & Amadi, A. N. (2021). Assessment of groundwater vulnerability to heavy metal pollution from slaughterhouses in the Niger Delta region. *Journal of Water and Health Research, 9*(3), 112-124.

22. Oyeku, O. M., & Eludoyin, A. O. (2019). Heavy metals in groundwater from a solid waste landfill in Lagos, Nigeria. *Journal of Environmental Science and Water Resources*, *8*(2), 25-33.

23. Standards Organization of Nigeria. (2008). *Nigerian Standard for Drinking Water Quality (NSDWQ)*. Nigerian Industrial Standards (NIS 554:2008).

24. Tajudeen, Y., Abdulganiyu, Y., Gulumbe, B. H., Oladele, E. O., Anyebe, D., & Shemishere, U. (2022). Heavy metals and microorganisms in borehole water around Olusosun dumpsite, Lagos, Nigeria. *Avicenna Journal of Environmental Health Engineering*, *9*(2), 69-74. ajehe.umsha.ac.ir.

25. Umeuduji, J. E., & Okezie, C. C. (2022). Hydrogeochemical assessment of shallow groundwater quality near slaughterhouses in urban centers of southern Nigeria. *African Journal of Water Resources and Environmental Engineering, 14*(4), 132-145. https://doi.org/10.5897/AJWREE2022.0956.

26. Uwalaka, T. (2014). *Port Harcourt city survey*. Academia.edu. from the original on 8 December 2016. Retrieved 23 August 2014.

27. Wokoma, O. A. F., Edoghotu, A. J., Gboeloh, L. B., Alikor, E. O., & Owoh, A. A. (2022). Heavy metal load of creeks receiving abattoir effluent in Port Harcourt metropolis. *Irish Journal of Environment and Earth Sciences, 6*(5), 116-123. aspjournals.org.

28. Wokoma, O. A. F., Onugha, A. C., & Amaechi-Onyerimma, C. N. (2023). Assessment of heavy metal composition of abattoir effluents on groundwater quality in Port Harcourt Metropolis, Rivers State.

IAU Journal of Applied and Environmental Biology, *1*(1), 88-97. sciety.org+12researchgate.net+12researchgate.net+12.

29. World Health Organization (WHO) (2022). *Guidelines for drinking water quality*: *World incorporating the first and second Addenda* (3^{rd} Edition). WHO Publication.

30. World Health Organization. (2023). *Guidelines for drinking-water quality* (4th Edition). WHO Press. https://www.who.int/publications/i/item/9789241549950.

31. Yahaya, M. I., Mohammad, S., & Abdullahi, B. K. (2009). Seasonal variation of heavy metal concentration in abattoir dumping site soil in Nigeria. *Journal of Applied Sciences and Environmental Management, 13*(4), 112-119. ajol.info+4ajol.info+4journalajacr.com+4.