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Analysis of Seasonal Variation of Heavy Metals Concentration in Selected River in Anambra State Resulting from Industrial Effluents Discharge.

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Abstract

This study conducted an analysis of seasonal variation of Heavy Metals from Industrial effluents in surface water bodies in Anambra State, Nigeria, with a focus on Mmiri Ele, River Idemili, and River Niger. Employing an experimental research design, water samples were collected and analyzed upstream, midstream, and downstream during both dry and rainy seasons. The results showed persistent heavy metal contamination, with concentrations of lead, cadmium, chromium, mercury, and silver exceeding safe limits. Seasonal variation revealed higher contamination in the dry season due to reduced dilution, with alarming peaks such as 2.337 mg/L of chromium in Mmiri Ele A2 and 0.331 mg/L of mercury in River Niger C2. The rainy season, while showing lower localized concentrations due to runoff, still exhibited high levels of silver and cadmium, indicating constant industrial discharge. The findings suggest chronic pollution linked to inadequate wastewater treatment and poor regulatory enforcement. It was therefore recommended that there is need for stricter regulatory oversight, improved wastewater treatment infrastructure, and real-time water monitoring to mitigate environmental and health risks posed by untreated industrial discharges.

Keywords: Assessment, Seasonal Impact, Industrial Effluent, Water Quality in Rivers.

1.0 Introduction

1.1 Background to the Study

Surface water pollution from industrial effluents has become a significant environmental and public health challenge in Nigeria, particularly in industrializing regions like Anambra State. In this region, rapid urbanization and unchecked industrial growth have contributed to the increasing discharge of untreated or inadequately treated industrial effluents into surface water bodies (Ajibade et al., 2015). Rivers such as the Niger, Idemili, and Mmiri Ele serve multiple uses, including domestic consumption, agriculture, and recreation, but they are increasingly vulnerable to contamination by heavy metals like lead, cadmium, chromium, and mercury.

The situation is exacerbated by poor environmental governance and weak enforcement of pollution control standards. Industrial zones in Onitsha, Awka, and Nnewi contribute significantly to the degradation of nearby aquatic ecosystems (Ezeabasili et al., 2014). Moreover, seasonal variation influences pollutant concentration: during the dry season, reduced river volumes lead to higher concentrations of contaminants due to limited dilution, while in the rainy season, increased runoff from urban and industrial

areas introduces additional pollutants (Ibe & Nwankwoala, 2010). Understanding these seasonal dynamics is critical to designing effective monitoring systems and regulatory interventions.

1.2 Statement of the Problem

Despite growing awareness of the health and ecological implications of industrial water pollution, surface water bodies in Anambra State continue to suffer from heavy metal contamination due to direct discharge of effluents by industries (Ezeabasili et al., 2014). Prior studies have confirmed that the levels of heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) in surface waters in and around Onitsha and Awka frequently exceed WHO permissible limits (Aneke & Ukpai, 2016). However, most existing research either focuses on isolated sites or does not account for seasonal variation, leaving significant knowledge gaps in understanding how pollution fluctuates across time and space. This lack of comprehensive, seasonal data undermines efforts to design adaptive environmental management strategies. As communities continue to rely on these water sources for drinking, fishing, and irrigation, the health risks associated with bioaccumulation and exposure to toxic metals remain largely unaddressed. There is therefore an urgent need for a detailed seasonal assessment of the magnitude and pattern of pollution in Anambra State's rivers to guide policy-making and environmental regulation (Nwigwe et al., 2018).

1.3 Aim and Objectives of the Study

To assess the seasonal variation in heavy metal contamination of surface water bodies due to industrial effluents in Anambra State and provide evidence-based recommendations for environmental regulation, pollution control, and public health protection.

In order to achieve this aim, the following objectives were formulated and pursued:

1. to determine the concentration levels of selected heavy metals (Pb, Cd, Cr, Hg, Ag) in the selected rivers during the dry seasons,
2. to determine the concentration levels of selected heavy metals (Pb, Cd, Cr, Hg, Ag) in the selected rivers during the rainy seasons, and
3. to recommend regulatory and infrastructural interventions for mitigating industrial effluent pollution in Anambra State.

2.0 Literature Review

Environmental quality is foundational to both ecosystem health and human well-being. It includes components such as air and water purity and the overall impacts of human activities on natural systems (Johnson et al., 1997). In Nigeria, industrialization has introduced a major challenge to environmental sustainability due to the unchecked discharge of industrial effluents into surface water bodies (Rusen, 2012). This growing concern impacts public health via contaminated water sources and food chains.

Water quality, as a core element of environmental integrity, supports vital functions including drinking, agriculture, and sanitation (Joseph, 2019). Its deterioration across developing nations stems from industrial discharges, climate variability, and land-use changes. Aligning with Sustainable Development Goal 6, the United Nations emphasizes improved wastewater treatment and reduced water pollution by 2030 (UN SDG, 2024). Water quality is defined as a multidimensional concept measured through physical, chemical, and biological indicators (Subhasis & Zeyuan, 2016). Given this connection, poor water quality directly impacts human health and quality of life (Gasper, 2010). Deng et al. (2024) noted that while aluminum-based methods are used for fluoride removal, they often leave residuals that recontaminate natural waters. Similarly, Amengor (2024) reported that mining operations in Ghana's Birim sub-basin introduce heavy metals like cadmium and arsenic into rivers, with documented cancer and non-cancer health risks. Within Nigeria, Toluwalope and Moshoodat (2024) found that iron, copper, and lead from industrial regions contaminate aquaculture ponds in Ilorin, affecting aquatic ecosystems and fish health indirectly through parameters like dissolved oxygen and conductivity.

In Ogun State, Ayodele et al. (2024) documented elevated BOD, COD, and heavy metals in aluminum industry effluents that exceeded FEPA and WHO limits. This trend aligns with Nweke et al. (2023), whose assessment of brewery wastewater in Benue State also found unacceptable levels of turbidity, phosphate, and cadmium. The authors stressed the importance of improved treatment processes and stronger monitoring systems. Chaturwedi et al. (2024) argued that untreated industrial effluent remains a global concern, especially in developing economies. Bekeowei and Bariweni (2021) corroborated this in their analysis of paint industry wastewater in Yenagoa, where elevated pollutants like arsenic and nitrate exceeded national standards. Location-specific variations were tied to differences in production processes.

Within Anambra State, Akannam and Kakulu (2022) discovered seasonal variations in soil quality linked to industrial effluent, suggesting a broader environmental footprint beyond water contamination. Similarly, Ezigbo and Ezigbo (2020) examined fast-food industry wastewater in Awka and observed elevated chromium and zinc levels. These findings indicate that both manufacturing and non-manufacturing sectors contribute significantly to environmental pollution. In South Africa, Iloms et al. (2020) found that even treated municipal wastewater contained heavy metals above regulatory thresholds, highlighting deficiencies in current systems. Iwuozor (2019) identified similar issues in a starch mill in Anambra, where BOD and COD exceeded acceptable levels, posing severe risks to nearby rural communities. Obeta et al. (2019) and Emmanuel and Jacob (2013) also confirmed widespread contamination in Onitsha and Enugu due to inadequate regulation.

3.0 Materials and Methods

3.1 Research Design

This study employed an experimental research design aimed at evaluating the seasonal impact of industrial effluents on surface water quality across selected rivers in Anambra State, Nigeria. The approach combined systematic field sampling with laboratory-based chemical analyses, focusing primarily on the presence and concentrations of heavy metals. Data were collected during both the dry and rainy seasons to facilitate seasonal comparisons.

3.2 Study Area

The study was conducted in Anambra State, Southeastern Nigeria, targeting three rivers—Mmiri Ele, River Idemili, and River Niger. These rivers traverse industrial hotspots such as Onitsha and Nnewi and serve as critical sources of water for domestic, agricultural, and commercial use. Onitsha, with an estimated population of 1.6 million (World Population Review, 2024), was central to the study due to its dense industrial presence and urbanization level.

3.3 Sampling Design and Site Stratification

Each river was stratified into three distinct segments—upstream (A), midstream (B), and downstream (C)—to capture spatial pollution gradients. Sampling locations were coded accordingly (e.g., River Idemili A2, B2, and C2). Stratified random sampling was applied within each segment to reduce spatial bias, while purposive sampling was used to target zones of known industrial discharge.

3.4 Sample Collection

Water samples were collected over a 12-month period (covering both dry and rainy seasons) using pre-cleaned 1-liter polyethylene bottles. For each site, two sampling runs were performed per season. Samples were taken approximately 30 cm below the surface to avoid surface contaminants and were stored in ice-packed coolers immediately after collection. In-situ measurements of pH, temperature, and conductivity were also recorded using portable meters.

3.5 Laboratory Analysis

Within 12 hours of collection, samples were transported to a certified laboratory for analysis. The water samples were subjected to acid digestion using nitric acid (HNO_3) for preservation and preparation. The concentrations of 20 heavy metals—including Lead (Pb), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Silver (Ag), Zinc (Zn), Copper (Cu), Manganese (Mn), Iron (Fe), Cobalt (Co), Arsenic (As), Selenium (Se), Nickel (Ni), and Vanadium (V)—were determined using Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), following APHA (2017) standard procedures. Quality control was ensured through calibration with certified reference materials and reagent blanks.

3.6 Data Management and Statistical Analysis

Raw data were compiled and processed using Microsoft Excel and SPSS (Version 25).

Descriptive statistics (mean, standard deviation, and range) were used to summarize the concentration of each parameter across sites and seasons. Inferential statistics, particularly one-way Analysis of Variance (ANOVA), were employed to assess significant differences between dry and rainy season concentrations. Graphical representations such as bar charts and box plots were used to visualize spatial and seasonal variations.

3.7 Ethical Considerations

The study adhered to ethical standards for environmental research. Sampling was conducted without disrupting local ecosystems, and permissions were obtained from relevant community leaders and environmental authorities. The research also aligns with the precautionary principle and contributes to public health advocacy.

4.0 Results

This section presents and discusses the seasonal concentrations of heavy metals in surface waters of three rivers in Anambra State: Mmiri Ele, River Idemili, and River Niger. To enhance clarity and focus, the data tables are disaggregated by river and season (rainy and dry), and discussed accordingly.

4.1 Mmiri Ele River

4.1.1 Rainy Season Heavy Metal Concentrations in Mmiri Ele River

Table 4.1 shows the heavy metal concentrations in Mmiri Ele River, during the rainy season.

Table 4.1: Rainy Season Heavy Metal Concentrations in Mmiri Ele River

Parameter (mg/L)	Mmiri Ele A (Run 1/2)	Mmiri Ele B (Run 1/2)	Mmiri Ele C (Run 1/2)
Lead	0.037 / 0.029	0.029 / 0.006	0.015 / 0.024
Cadmium	0.025 / 0.014	0.011 / 0.015	0.019 / 0.019
Silver	0.323 / 0.211	0.113 / 0.299	0.109 / 0.109
Chromium	0.013 / 0.024	0.032 / 0.123	0.004 / 0.034
Mercury	0.013 / 0.014	0.004 / 0.024	0.018 / 0.021

Mmiri Ele River showed moderate contamination during the rainy season, with Silver (0.323 mg/L in Run 1 at Mmiri Ele A) being the most prominent pollutant. Lead and Cadmium were consistently present, although at levels below WHO permissible limits. The presence of Chromium and Mercury indicates industrial inputs, though slightly lower during rainfall due to dilution.

4.1.2 Dry Season Heavy Metal Concentrations in Mmiri Ele River

Table 4.2 shows the heavy metal concentrations in Mmiri Ele River, during the dry season.

Table 4.2: Dry Season Heavy Metal Concentrations in Mmiri Ele River

Parameter (mg/L)	Mmiri Ele A2 (Run 1/2)	Mmiri Ele B2 (Run 1/2)	Mmiri Ele C2 (Run 1/2)
Lead	0.028 / 0.176	0.156 / 0.145	0.027 / 0.034
Cadmium	0.044 / 0.018	0.023 / 0.018	0.014 / 0.024
Chromium	2.337 / 1.399	0.405 / 0.792	1.345 / 2.163
Mercury	0.088 / 0.177	0.218 / 0.301	0.267 / 0.331

The dry season revealed significantly elevated levels of Chromium and Mercury in all Mmiri Ele stations, with peak Chromium values reaching 2.337 mg/L in Mmiri Ele A2 (Run 1) and Mercury at 0.331 mg/L in Mmiri Ele C2 (Run 2), far above WHO thresholds. This indicates a higher concentration of industrial effluents when dilution by rainfall is absent.

4.2 River Idemili

4.2.1 Rainy Season Heavy Metal Concentrations in River Idemili

Table 4.3 shows the heavy metal concentrations in Idemili River, during the rainy season.

Table 4.3: Rainy Season Heavy Metal Concentrations in Idemili River

Parameter (mg/L)	Idemili A (Run 1/2)	Idemili B (Run 1/2)	Idemili C (Run 1/2)
Lead	0.012 / 0.007	0.013 / 0.008	0.014 / 0.015
Cadmium	0.021 / 0.023	0.033 / 0.018	0.021 / 0.042
Silver	0.013 / 0.034	0.702 / 0.609	0.272 / 0.034
Chromium	0.021 / 0.028	0.181 / 0.380	0.014 / 0.211
Mercury	0.023 / 0.028	0.031 / 0.040	0.014 / 0.024

River Idemili had the highest rainy season concentrations of Silver and Chromium, particularly at the midstream point (Idemili B), with Silver reaching 0.702 mg/L and Chromium at 0.380 mg/L. Cadmium levels were also elevated, confirming steady pollution likely from nearby industries.

4.2.2 Dry Season Heavy Metal Concentrations in River Idemili

Table 4.4 shows the heavy metal concentrations in Idemili River, during the dry season.

Table 4.4: Dry Season Heavy Metal Concentrations in Idemili River

Parameter (mg/L)	Idemili A2 (Run 1/2)	Idemili B2 (Run 1/2)	Idemili C2 (Run 1/2)
Lead	0.027 / 0.018	0.227 / 0.287	0.108 / 0.117
Cadmium	0.014 / 0.014	0.018 / 0.550	0.023 / 0.004
Chromium	0.011 / 0.002	0.017 / 0.034	0.021 / 0.023
Mercury	0.024 / 0.019	0.016 / 0.019	0.008 / 0.020

During the dry season, River Idemili B2 recorded extremely high Lead (0.287 mg/L) and Cadmium (0.550 mg/L), far exceeding safety thresholds. These peaks suggest intensified industrial discharge in the absence of rain-mediated dilution.

4.3 River Niger

4.3.1 Rainy Season Heavy Metal Concentrations in River Niger

Table 4.5 shows the heavy metal concentrations in River Niger, during the rainy season.

Table 4.5: Rainy Season Heavy Metal Concentrations in River Niger

Parameter (mg/L)	Niger A (Run 1/2)	Niger B (Run 1/2)	Niger C (Run 1/2)
Lead	0.000 / 0.000	0.014 / 0.030	0.004 / 0.009
Cadmium	0.014 / 0.021	0.024 / 0.026	0.009 / 0.023
Silver	0.748 / 0.433	0.287 / 0.212	0.188 / 0.148
Chromium	0.021 / 0.032	0.022 / 0.031	0.018 / 0.029
Mercury	0.033 / 0.028	0.029 / 0.022	0.032 / 0.019

River Niger recorded the highest rainy season Silver concentrations among all rivers, peaking at 0.748 mg/L in Niger A. Mercury levels remained elevated across all stations, indicating diffuse and persistent industrial sources.

4.3.2 Dry Season Heavy Metal Concentrations in River Niger

Table 4.6 shows the heavy metal concentrations in River Niger, during the dry season.

Table 4.6: Dry Season Heavy Metal Concentrations in River Niger

Parameter (mg/L)	Niger A2 (Run 1/2)	Niger B2 (Run 1/2)	Niger C2 (Run 1/2)
Lead	0.208 / 0.115	0.028 / 0.254	0.178 / 0.224
Cadmium	0.025 / 0.023	0.029 / 0.024	0.000 / 0.037
Chromium	0.991 / 1.981	0.396 / 0.238	1.465 / 1.295
Mercury	0.068 / 0.028	0.044 / 0.032	0.067 / 0.150

River Niger showed extreme levels of Chromium in the dry season, with a maximum value of 1.981 mg/L at Niger A2 and 1.465 mg/L at Niger C2. Mercury also peaked at 0.150 mg/L at Niger C2, reinforcing concerns over heavy metal toxicity in the absence of rainfall. These results demonstrate the continuous and unregulated discharge of industrial effluents into Anambra's rivers and underscore the pressing need for improved regulatory frameworks and effluent treatment systems.

5.0 Discussion of Findings

The findings of this study reveal a consistent pattern of heavy metal contamination across Mmiri Ele, River Idemili, and River Niger in Anambra State, with distinct seasonal variations. The study confirms that concentrations of heavy metals were generally higher during the dry season due to lower water levels and reduced dilution capacity, a trend supported by Ekenta et al. (2020) and Osunla and Okoh (2017).

In Mmiri Ele River, Chromium and Mercury emerged as the most critical pollutants in the dry season, with Chromium levels reaching 2.337 mg/L and Mercury up to 0.331 mg/L, far exceeding WHO permissible limits. These findings align with Iwuozor (2019), who reported similar elevated heavy metals in industrial discharge from Anambra State's starch mills. The dominance of these metals suggests ongoing industrial activities involving electroplating, metal processing, or electronic waste. River Idemili also showed seasonal pollution fluctuations, with significantly high levels of Cadmium and Lead during the dry season, particularly in the midstream segment (Idemili B2). Cadmium reached 0.550 mg/L, suggesting industrial sources such as battery manufacturing or pigment production. These results corroborate the work of Ayodele et al. (2024), who found excessive heavy metals in aluminum industry effluents in Ogun State, and Amengor (2024), who linked artisanal mining with toxic metal discharge.

In the rainy season, Silver was predominant, particularly in River Niger (0.748 mg/L at Niger A), pointing to stormwater wash-off and possibly untreated industrial wastewater. Despite rain-induced dilution, the persistence of metals like Cadmium, Chromium, and Mercury confirms the chronic nature of pollution. These results support the work of Bekeowei and Bariweni (2021), who found elevated nitrate, phosphate, and heavy metals in paint industry effluents during rainfall in Yenagoa. The overall trend aligns with global findings, such as those reported by Iloms et al. (2020) in South Africa, which showed treated municipal wastewater still exceeding metal concentration limits. Furthermore, the bioaccumulative nature of these heavy metals, as explained by Kaur and Brraich (2021), presents long-term risks to aquatic ecosystems and public health. The confirmed presence of Cadmium, Lead, and Mercury (known neurotoxins and carcinogens) points to high potential for bioaccumulation and biomagnification, as also noted by Oladimeji et al. (2024).

Notably, the spatial distribution of pollution—with hotspots observed in midstream and downstream locations of all rivers—highlights the role of unregulated point-source discharge and downstream transport of pollutants. This spatial pattern supports the findings of Obeta et al. (2019), who documented similar downstream contamination in Onitsha. These findings reinforce the need for stringent industrial effluent control, improved wastewater treatment infrastructure, and consistent monitoring, echoing recommendations by Haruna (2020) and Chaturwedi et al. (2024).

6.0 Summary, Conclusion and Recommendations

6.1 Summary

This study assessed the seasonal impact of industrial effluents on water quality in three major rivers in Anambra State: Mmiri Ele, River Idemili, and River Niger. By collecting and analyzing water samples during the dry and rainy seasons across upstream, midstream, and downstream segments, the study quantified concentrations of multiple heavy metals.

Findings revealed persistent contamination by heavy metals such as Lead, Cadmium, Chromium, Mercury, and Silver across all rivers and seasons. Dry season values were significantly higher, particularly for Chromium and Mercury in Mmiri Ele, and Lead and Cadmium in River Idemili. Rainy season values, though relatively diluted, still showed high levels of Silver, especially in River Niger.

6.2 Conclusion

The results conclusively demonstrate that industrial effluents are a major contributor to surface water pollution in Anambra State. The consistent presence of non-biodegradable heavy metals, many of which are toxic and carcinogenic, across both seasons underscores the urgency of addressing this issue. Without effective regulation and treatment, these pollutants pose long-term threats to water safety, food security, and public health.

6.3 Recommendations

In the light of the foregoing findings, the following recommendations were made and implementing these recommendations will go a long way to promote environmental sustainability, protect public health, and ensure the safe use of vital water resources in Anambra State.

1. Regulatory Enforcement: Environmental agencies such as NESREA and the Anambra State Ministry of Environment should intensify enforcement of wastewater regulations and mandate installation of effluent treatment plants (ETPs).
2. Seasonal Monitoring: Establish a real-time, seasonal water quality monitoring program to track fluctuations and inform policy interventions.

3. Industrial Compliance: Industries must be compelled to conduct Environmental Audits and submit Environmental Management Plans (EMPs) regularly, with penalties for non-compliance.
4. Community Engagement: Launch sensitization campaigns to educate communities on the risks of contaminated water and promote citizen-led monitoring.
5. Further Research: Investigate the extent of heavy metal bioaccumulation in sediments, aquatic organisms, and the food chain to guide long-term ecological risk assessments.
6. Pollution Abatement Task Force: Create a multi-stakeholder task force including regulators, researchers, industry actors, and community leaders to implement and monitor pollution control measures.

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