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# Seasonal Variation in Hydrochemical Characteristics and Heavy Metal Risk Assessment Of Groundwater in Andoni-Isiokwan District, Niger Delta, Nigeria

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## Abstract

This study investigates seasonal variations in groundwater quality and heavy metal contamination in five oil-exposed rural communities—Dema, Ibotirem, Samanga, Ajakajak, and Udungama—within the Isiokwan District of Andoni Local Government Area, Niger Delta, Nigeria. Groundwater samples were collected from hand-dug wells in each community during the dry, wet, and post-rainy seasons and analysed for physicochemical parameters and toxic metals. Parameters assessed included pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), while concentrations of lead (Pb), cadmium (Cd), arsenic (As), and iron (Fe) were measured using Atomic Absorption Spectrophotometry. Results showed that pH remained acidic across all seasons, with values ranging from 5.19 to 5.42. EC and TDS were highest during the dry season, indicating concentration effects due to reduced aquifer recharge, while turbidity and organic pollution indicators increased during the wet and post-rainy seasons, respectively. Pb, Cd, and As concentrations consistently exceeded WHO safety thresholds in all samples and seasons, posing serious public health risks. Iron exceeded aesthetic limits but remained within health-based guidelines. The study concludes that the hand-dug well water in the investigated communities is unsafe for direct human consumption without treatment. The findings reveal critical groundwater vulnerability due to hydrocarbon pollution and seasonal hydrological shifts, highlighting the urgent need for integrated water safety planning, well protection, and strengthened environmental regulation in oil-producing regions of the Niger Delta.

**Keywords:** Groundwater pollution; Seasonal variability; Heavy metals; Hydrochemical analysis


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## 1.0 Introduction

Groundwater plays an indispensable role in providing domestic, agricultural, and industrial water in Nigeria, particularly in rural and oil-producing regions such as the Niger Delta. In the absence of treated municipal water supplies, many communities depend on shallow hand-dug wells for their daily water needs. However, increasing anthropogenic pressure, notably from crude oil exploration, artisanal refining, and poor environmental management practices, has raised serious concerns about groundwater quality in the region (Federal Ministry of Agriculture and Rural Development, 2008; Edwin et al., 2022).

Persistent environmental contamination from oil-related activities introduces both organic and inorganic pollutants into the subsurface. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are of particular concern due to their toxicity, long-term persistence, and bioaccumulative nature (Dan et al., 2018; Dawaki et al., 2013). These metals can infiltrate groundwater through soil leaching, pipeline corrosion, waste discharge, and acid rain—especially in areas with high rainfall and porous soil profiles, as characteristic of the Niger Delta (Estefan et al., 2013; Dandwate, 2020).

Heavy metals not only affect groundwater quality but can also pose significant health risks to local populations when present above recommended thresholds. For instance, studies by Dosumu et al. (2005) have shown high levels of metal uptake in edible vegetables irrigated with contaminated water. In a related aquatic context, Anarado et al. (2023) reported alarming concentrations of Pb, Cd, As, and Hg in blue crabs from creeks in Bayelsa State, with calculated health risk indices indicating potential carcinogenic effects from long-term exposure. These findings emphasise the broader ecological and public health implications of environmental metal contamination in the Niger Delta.

Despite growing awareness of the risks, many earlier assessments of groundwater pollution in Nigeria have focused either on broad regional patterns or single-timepoint analyses, thereby missing important temporal variations. Seasonal fluctuations—driven by rainfall, aquifer recharge, and runoff—can significantly influence the mobility and concentration of contaminants (Edwin et al., 2022). As such, seasonal hydrochemical monitoring is essential for generating accurate contamination profiles and guiding public health interventions. This study aims to assess the seasonal variation in physicochemical properties and heavy metal concentrations of hand-dug well water across five oil-impacted communities in the Isiokwan District of Andoni Local Government Area, Rivers State.

## 2.0 Materials and Methods

### 2.1 Study Area

This study was conducted in five rural communities—Dema, Ibotirem, Samanga, Ajakajak, and Udungama—within the Isiokwan District of Andoni Local Government Area in Rivers State, Nigeria. These communities, located in the oil-rich coastal region of the Niger Delta, are characterised by high annual rainfall, low elevation, and proximity to petroleum infrastructure and artisanal refining activities. Groundwater in this region is sourced predominantly from shallow hand-dug wells, with some wells powered by solar systems. These wells constitute the primary source of domestic water, especially in the absence of a municipal piped water supply as shown in Figure 1.


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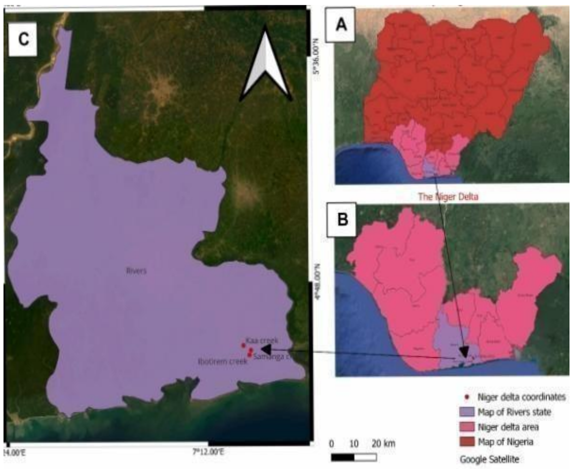


**Figure1**: Map showing the study area

### 2.2 Study Design and Sampling Schedule

To capture temporal variations in water quality and support statistically meaningful analyses, the study employed a longitudinal sampling design. Groundwater samples were collected from one hand-dug well in each of the five selected communities over **three distinct periods**—once during the **dry season (December–February)**, the **wet season (June–August)**, and the **post-rainy season (October–November)**. This seasonal approach enabled the assessment of fluctuations in physicochemical parameters and heavy metal concentrations due to climatic variation, surface runoff, aquifer recharge, and anthropogenic activity. Each well was sampled three times per season, resulting in a total of **nine samples per community** across the study period. This repeated sampling approach allowed for the calculation of mean values, standard deviation, and coefficients of variation, thereby improving the reliability of trend detection and pollutant behaviour over time.

### 2.3 Sample Collection

At each sampling event, groundwater was drawn after flushing the well for approximately five minutes to remove stagnant water. Samples were collected into pre-cleaned 1-litre high-density polyethene (HDPE) bottles, which had been rinsed with the respective well water prior to final sample collection. All samples were immediately stored in ice-packed coolers and transported to the laboratory within six hours of collection to minimise degradation and preserve sample integrity.

### 2.4 Physicochemical Analysis

Standard methods were adopted for the determination of key physicochemical parameters. In-situ measurements of pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS) were taken using a calibrated Hanna HI 9829 multiparameter water quality meter. Turbidity was measured using a HACH 2100Q turbidity meter, and dissolved oxygen (DO) was determined via the Winkler titration method. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were analysed in the laboratory according to protocols recommended by the American Public Health Association (APHA, 2022). These parameters were selected based on their environmental relevance and sensitivity to hydrocarbon and organic pollution.

### 2.5 Heavy Metal Determination

The concentrations of lead (Pb), cadmium (Cd), arsenic (As), and iron (Fe) were determined using Atomic Absorption Spectrophotometry (AAS), employing the Perkin Elmer AAnalyst 400. Before analysis, samples were acidified to pH $< 2$ with concentrated nitric acid and digested using a mixture of nitric and perchloric acids. Calibration was conducted using certified standard solutions, and results were reported in milligrams per litre (mg/L). The values obtained were compared with the World Health Organisation (WHO, 2022) and Nigerian Standard for Drinking Water


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Quality (NSDWQ, 2015) to assess compliance and potential health risks.

### 2.6 Quality Assurance and Quality Control

Stringent quality control measures were adopted throughout the field and laboratory procedures to ensure the accuracy and reproducibility of results. Acid-washed sampling bottles and glassware were used to prevent contamination. Analytical precision was monitored using duplicate samples, reagent blanks, and field blanks. Instrument calibration was verified using multi-point standard curves with correlation coefficients greater than 0.995. Spike recovery tests using certified reference materials were conducted to confirm analytical accuracy. Relative standard deviations (RSDs) were maintained within acceptable analytical limits (<10%) across repeated measurements.

### 2.7 Data Processing and Statistical Analysis

Descriptive statistics, including means, standard deviations, and ranges, were calculated for each water quality parameter across the three sampling periods. Inferential statistical tests such as one-way ANOVA were employed to detect significant seasonal differences in water quality variables. Pearson correlation analysis was performed to explore relationships among parameters, while principal component analysis (PCA) was used to identify potential sources of contamination. All statistical analyses were performed using IBM SPSS version 26.0

## 3.0 Results

The groundwater quality assessment across the five selected communities in the Isiokwan District revealed distinct seasonal variations in both physicochemical parameters and heavy metal concentrations. A total of 45 samples were analysed—three from each community per season—allowing for the calculation of mean values, standard deviations, and the identification of temporal trends in contamination levels.

### 3.1 Physicochemical Parameters

Across all communities and seasons, pH values consistently fell below the World Health Organisation (WHO) recommended range of 6.5 to 8.5, indicating persistent acidity in the groundwater. The mean pH ranged from 5.19 ± 0.08 in the dry season to 5.42 ± 0.06 in the post-rainy season. Although a slight seasonal increase in pH was observed, likely due to dilution during the wet season and aquifer recharge, the water remained acidic throughout the study period.

Electrical conductivity (EC) values were generally highest in the dry season, with a mean of 868.3 ± 45.1 µS/cm, declining marginally during the wet season to 795.2 ± 39.7 µS/cm. This pattern suggests a concentration of dissolved salts during the dry months and dilution during periods of higher rainfall. Similar trends were observed for total dissolved solids (TDS), which ranged from 521.6 ± 21.3 mg/L in the dry season to 456.4 ± 24.1 mg/L in the wet season, with post-rainy values stabilising around 475.8 ± 19.7 mg/L. In some communities, dry season TDS values exceeded the WHO threshold of 500 mg/L, indicating anthropogenic influence, possibly from nearby waste or hydrocarbon residues. Turbidity levels were also highest during the wet season, reaching up to 6.4 ± 1.1 NTU in some wells, likely due to surface runoff and sediment disturbance during heavy rainfall. In contrast, turbidity values remained closer to the WHO limit of 5.0 NTU during the dry and post-rainy seasons. Dissolved oxygen (DO) levels were consistently below the recommended minimum of 6.0 mg/L, with seasonal averages ranging between 3.0 ± 0.4 and 3.6 ± 0.3 mg/L. These low values


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suggest ongoing microbial activity or the presence of organic matter and may point to underlying redox processes. Biochemical oxygen demand (BOD) values were highest during the post-rainy season, averaging 8.1 ± 0.6 mg/L, compared to 7.5 ± 0.4 mg/L in the dry season and 6.7 ± 0.5 mg/L during the wet season. This may reflect the accumulation of organic waste during the rainy months, followed by microbial degradation. Chemical oxygen demand (COD) values followed a similar trend, with the highest mean values recorded in the post-rainy season, suggesting an increased load of oxidisable organic compounds from

| Parameter | Dry Season | Wet Season | Post-Rainy Season | WHO Standard |
|---|---|---|---|---|
| pH (units) | 5.19 ± 0.08 | 5.31 ± 0.07 | 5.42 ± 0.06 | 6.5 – 8.5 |
| Temperature (°C) | 27.3 ± 0.2 | 26.8 ± 0.3 | 27.1 ± 0.2 | 25 – 30 |
| Electrical Conductivity (µS/cm) | 868.3 ± 45.1 | 795.2 ± 39.7 | 812.7 ± 33.5 | ≤ 750 |
| Total Dissolved Solids (mg/L) | 521.6 ± 21.3 | 456.4 ± 24.1 | 475.8 ± 19.7 | ≤ 500 |
| Turbidity (NTU) | 4.9 ± 0.7 | 6.4 ± 1.1 | 5.2 ± 0.8 | ≤ 5.0 |
| Dissolved Oxygen (mg/L) | 3.2 ± 0.3 | 3.6 ± 0.3 | 3.0 ± 0.4 | ≥ 6.0 |
| Biochemical Oxygen Demand (mg/L) | 7.5 ± 0.4 | 6.7 ± 0.5 | 8.1 ± 0.6 | ≤ 6.0 |
| Chemical Oxygen Demand (mg/L) | 19.3 ± 2.1 | 16.7 ± 2.4 | 21.5 ± 2.6 | — |

both natural and anthropogenic sources, as shown in Table 1.

**Table 1. Seasonal Variations in Physicochemical Parameters of Hand-Dug Well Water (Mean ± SD)**

**Note**: WHO standards from WHO Guidelines for Drinking Water Quality (2022).

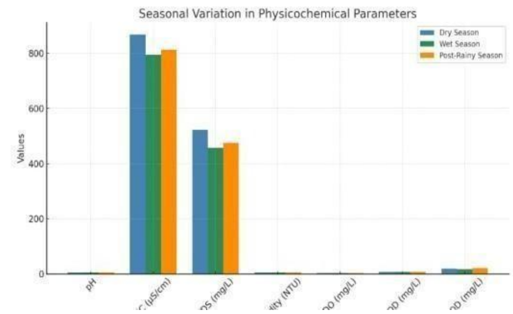


**Figure 1: Seasonal Variations in Physicochemical Parameters of Hand-Dug Well Water**

### 3.2 Heavy Metal Concentrations

Heavy metal analysis showed seasonal fluctuations in concentrations, with notable exceedances of WHO limits for several metals. Lead (Pb) concentrations were consistently elevated in all communities and across all seasons. Mean Pb levels ranged from 0.036 ± 0.005 mg/L in the wet season to 0.042 ± 0.006 mg/L in the dry season, significantly surpassing the WHO limit of 0.01 mg/L. The highest values were observed in Ibotirem and Dema during the dry season, likely linked to leaching from corroded infrastructure or historic petroleum contamination intensified by low water table conditions. Cadmium (Cd) concentrations also exceeded the safety threshold of 0.003 mg/L, with values highest during the post-rainy season (0.012 ± 0.002 mg/L), possibly due to delayed leaching and infiltration of surface contaminants. Wet season levels were comparatively lower, averaging 0.008 ± 0.001 mg/L, though still above the permissible limit.

Arsenic (As) was detected in all samples and showed less seasonal fluctuation, with mean values ranging from 0.027 ± 0.003 mg/L in the wet season to 0.031 ± 0.004 mg/L in the dry season. These concentrations, which are two to three times higher than the WHO guideline of 0.01 mg/L, indicate chronic contamination potentially linked to both geogenic sources and oil-related industrial discharge. Iron (Fe) concentrations varied moderately across seasons but remained


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above the WHO aesthetic limit of 0.3 mg/L in all samples. The highest mean value (0.66 ± 0.05 mg/L) was recorded in the post-rainy season, potentially due to increased aquifer mobilisation under reducing conditions. Although iron does not pose a direct health risk at these levels, its elevated concentration may affect water taste, appearance, and infrastructure. Zinc (Zn) and chromium (Cr) were also detected but remained within permissible limits across all seasons. However, slight seasonal increases in Cr during the post-rainy period may require further monitoring given its toxicity at elevated concentrations, as shown in Table 2.

**Table 2. Seasonal Variations in Heavy Metal Concentrations (mg/L) in Groundwater (Mean ± SD)**

| Metal | Dry Season | Wet Season | Post-Rainy Season | WHO Limit |
|---|---|---|---|---|
| Lead (Pb) | 0.042 ± 0.006 | 0.036 ± 0.005 | 0.039 ± 0.004 | 0.01 |
| Cadmium (Cd) | 0.010 ± 0.002 | 0.008 ± 0.001 | 0.012 ± 0.002 | 0.003 |
| Arsenic (As) | 0.031 ± 0.004 | 0.027 ± 0.003 | 0.030 ± 0.004 | 0.01 |
| Iron (Fe) | 0.60 ± 0.06 | 0.58 ± 0.05 | 0.66 ± 0.05 | 0.3 (aesthetic) |
| Zinc (Zn) | 2.52 ± 0.15 | 2.47 ± 0.18 | 2.56 ± 0.13 | 3.0 |
| Chromium (Cr) | 0.046 ± 0.004 | 0.043 ± 0.003 | 0.049 ± 0.005 | 0.05 |

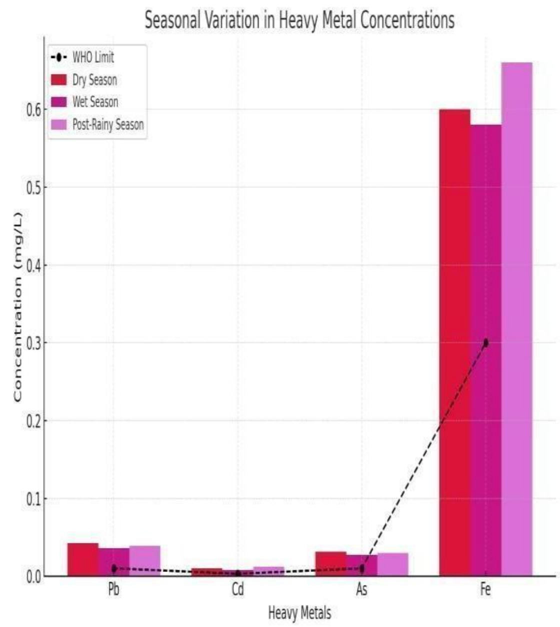


**Figure 2: Seasonal Variations in Heavy Metal Concentrations**

## 4.0 Discussion

The seasonal assessment of groundwater quality in the five oil-impacted communities of Isiokwan District revealed distinct patterns of contamination, with physicochemical parameters and heavy metal concentrations frequently exceeding recommended safety limits. The persistent acidity of groundwater across all seasons, as reflected in substandard pH values, suggests strong influence from acid-generating processes, possibly due to hydrocarbon oxidation, organic matter decomposition, or the infiltration of industrial waste (Dan et al., 2018; Dawaki et al., 2013). Acidic conditions are particularly hazardous, as they enhance the solubility and mobility of toxic metals such as lead (Pb), cadmium (Cd), and arsenic (As), thereby exacerbating contamination in shallow aquifers (Estefan et al., 2013).

Elevated electrical conductivity (EC) and total dissolved solids (TDS), especially during the dry season, suggest increased ionic concentration resulting from


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evaporative concentration, reduced aquifer recharge, and saline intrusion. Similar findings have been reported in agricultural and peri-urban settings, where waste infiltration and seasonal variations influenced water chemistry (Dandwate, 2020; Edwin et al., 2022). Turbidity levels peaked during the wet season, likely due to increased surface runoff and sediment transport, which introduces suspended particles, pathogens, and dissolved contaminants into poorly protected wells.

The concentrations of heavy metals—particularly Pb, Cd, and As—were consistently above World Health Organization (WHO) and national safety limits across all seasons. These findings align with previous research that linked heavy metal contamination in Nigerian soils and waters to anthropogenic inputs such as oil spills, industrial effluents, and abattoir waste (Dan et al., 2018; FMARD, 2008). The elevated levels of these metals raise public health concerns, as long-term exposure to Pb and Cd is associated with neurotoxicity, kidney damage, and increased cancer risk. Similar health implications were noted in aquatic studies by Anarado et al. (2023), where blue crabs from creeks in Bayelsa State accumulated high levels of Pb, Cd, As, and Hg, with estimated daily intake and carcinogenic risk values exceeding acceptable thresholds for human consumption.

The high concentrations of iron (Fe) recorded during the post-rainy season may reflect reducing conditions in the aquifer, as well as corrosion of metal well linings and plumbing systems. While Fe does not pose immediate health risks at moderate levels, it can compromise water palatability, stain plumbing fixtures, and promote microbial growth in storage systems. The general trend of elevated metal concentrations during the post-rainy season suggests delayed infiltration of contaminants, possibly due to the percolation of previously accumulated surface pollutants.

The spatial uniformity and seasonal recurrence of contamination indicate that groundwater in these oil-impacted communities is influenced by both point and non-point sources of pollution. The widespread reliance on shallow, unlined, and uncovered hand-dug wells further increases vulnerability to infiltration from surface activities. Moreover, poor land management, lack of sanitation infrastructure, and absence of regulatory oversight exacerbate the risks posed to groundwater safety (FMARD, 2008; Edwin et al., 2022).

## 5.0 Conclusion

This study assessed the seasonal variations in physicochemical properties and heavy metal concentrations of hand-dug well water across five oil-impacted communities in the Isiokwan District of the Niger Delta, Nigeria. Through repeated sampling over three distinct seasons—dry, wet, and post-rainy—the research provides robust evidence of consistent groundwater contamination influenced by both anthropogenic and geogenic factors. The findings revealed that pH values remained acidic throughout all seasons, while electrical conductivity and total dissolved solids frequently exceeded WHO permissible limits, especially during the dry season. Dissolved oxygen levels were consistently low, and elevated biochemical and chemical oxygen demand during the post-rainy period indicated increased organic pollution likely from runoff and decaying matter. Turbidity levels peaked during the wet season, reflecting surface contamination of unprotected wells. Of particular concern was the persistent exceedance of WHO thresholds for lead, cadmium, and arsenic in all communities across all seasons. These toxic metals pose


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serious public health risks, including neurological, renal, and carcinogenic effects. Iron concentrations, although not exceeding health-based limits, surpassed aesthetic guidelines and may indicate reducing conditions or corrosion within the wells.

The temporal monitoring approach adopted in this study revealed important seasonal dynamics that a single-time sampling design would have overlooked. The recurrence and magnitude of contamination underscore the urgent need for intervention. Provision of safe alternative water sources, protection and maintenance of existing wells, and continuous monitoring are imperative. Furthermore, stronger regulatory oversight of oil exploration activities and improved environmental sanitation at the community level are necessary to mitigate ongoing groundwater degradation. The study concludes that the hand-dug well water in the investigated communities is unsafe for direct human consumption without treatment. It calls for an integrated and multidisciplinary approach involving public health, environmental management, and community participation to ensure access to clean and safe drinking water, in alignment with Sustainable Development Goal 6.

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