Seasonal Variation of Groundwater Quality in Bonny Island, Rivers State Nigeria

Abstract

This study investigated the seasonal variations in physicochemical parameters, heavy metals, and petroleum hydrocarbons in groundwater samples collected in nine locations in Bonny Island, Rivers State Nigeria. A quantitative approach was employed, involving the collection ofquantitative data through field sampling and laboratory analysis. Physicochemical parameters, including pH, electrical conductivity, dissolved oxygen, and nutrient levels, were measured using standard analytical techniques. Heavy metal concentrations (Fe, Cd, etc.) were determined using atomic absorption spectrophotometry, while petroleum hydrocarbons (total hydrocarbons and polycyclic aromatic hydrocarbons) were analyzed through solvent extraction and gas chromatography techniques. The study revealed significant seasonal variations in several parameters, with notable significant decreases in phosphateduring the wet season and significant increases in chromium and cadmium levels during the dry season. Petroleum hydrocarbon concentrations also exhibited seasonal fluctuations, potentially influenced by precipitation patterns, oil and gas activities, and accidental spills or leaks which were observed during the dry season.

Keywords: Groundwater contamination, Seasonal variations, Physicochemical parameters, Heavy metals, Petroleum hydrocarbons,Oil and gas industry, Bonny Island.

1. Introduction

The oil and gas industry plays a major role in the economy of Nigeria, as it is a source of major revenue which forms the larger portion of her GDP. Bonny Island is one of the major towns in Nigeria, known for the exploration and production of oil and gas. Bonny Island hosts several local and international oil and gas companies such as the Shell Petroleum Development Company (SPDC) and Nigeria Liquefied Natural Gas (NLNG) Limited (Akintoye et al., 2016). However, the oil and gas production activities of these companies have raised several concerns such as environmental pollution and the human health impact from these activities. Some of the oil and gas-related activities by these companies can result in contamination of the environment from several hazardous contaminants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs) and other petroleum hydrocarbons

(Swartenbroux et al., 2010). These pollutants can further pollute water resources, soil and air which may in turn pose health risks to people and the whole ecosystem (Masindi &Muedi, 2018). The group of pollutants that are the most worrying and have serious health issues arecontaminants from crude oil products and heavy metals due to their toxicity and bio-accumulative properties (Häder et al., 2020; Kim et al., 2018).

Almost the entirety of activities in the exploration and production of oil and gas has serious consequences mainly for surface and groundwaters via leaks in wells, corrosion, blowouts, and ageingpipelines. Groundwater contamination is a significant concern in areas with intensive oil and gas activities are taking place. According to some researchers, contamination levels in the groundwater at Bonny Island were above safe limits (Nnaemeka, 2020; Odekanle et al., 2021). Ryan et al. (2022) found in their study that the water wells in Colorado near drilled oil wells, were contaminated. They stated that 3.9% of the 1,837 water wells that were drilled between 2001 and 2019 were contaminated with chemicals toluene, ethylbenzene, or xylenes. The contamination of groundwater poses serious health risks to residents as most people within the community consume the water without any treatment at all.

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The concentration of contaminant in the groundwater can also be affected by seasonality. Seasonal variations in rainfall, temperature, and other environmental factors can influence the transport and distribution of contaminants in groundwater (Allison & Mandler, 2018; Kurwadkar et al., 2020). However, there is limited information on the seasonal variations in groundwater contamination by physicochemical parameters, heavy metals, and petroleum hydrocarbons at Bonny Island. Several studies have reported elevated levels of heavy metals and petroleum hydrocarbons in various environmental media on Bonny Island, raising concerns about potential health risks (Frank et al., 2020; Obeka&Numbere, 2020). However, there is a need for comprehensive studies to evaluate the seasonal variations in groundwater contamination and the associated risks to human health and the ecosystem.

2. Methods

2.1 Study Area

The research wasconducted on Bonny Island, an ancient coastal attenuation and a LocalGovernment Area in Rivers State in southern Nigeria, on the Bight of Bonny (Dalby, Routledge 1971). The island is Bonny City, which is the capital of Bonny Kingdom. Much of the oil extracted onshore in Rivers State is piped to Bonny for export. The local government has an estimated population of 172,549 inhabitants who practice Christianity and traditional religion, which is characterized by high volume of oil and gas activities.

Bonny is positioned in the Niger Delta basin estimated to have a total volume of 37.4 billion barrels of oil and 202 trillion cubic feet (TCF) of gas (Samargandi, 2019). The presence of this huge deposit of petroleum hydrocarbon is characterized by a high intensity of exploration, processing, and transportation of crude oil and its refined products. These activities have led to the contamination of the environment through the discharge of wastes, spillage through sabotage and accidental discharge, oil bunkering, and artisanal refining, (Zhang et al., 2019).

2.2 Samples

Aquantitative research design method was adopted for the study. A quasi-experimental design was employed to assess the impact of the oil and gas operations on Bonny Island. Groundwater samples were collected from 9 sampling locations in Bonny Island as shown in Figure 1. The names of the 9 sampling locations were Water well 6, Abalamabie, worker's camp, NLNG industrial area gate (IA), NLNG residential area gate (RA gate), Lighthouse, Finima Market, Shell gate and the Bonny Jetty.The sample locations were denoted with GPS coordinates, and sampling was carried out seasonally over the twelve (12) calendar months, with samples taken in July and October 2022 for the wet season, and December 2022 and January 2023 for the dry season.Triplicate samples of water were collected twice in both wet and dry seasons.

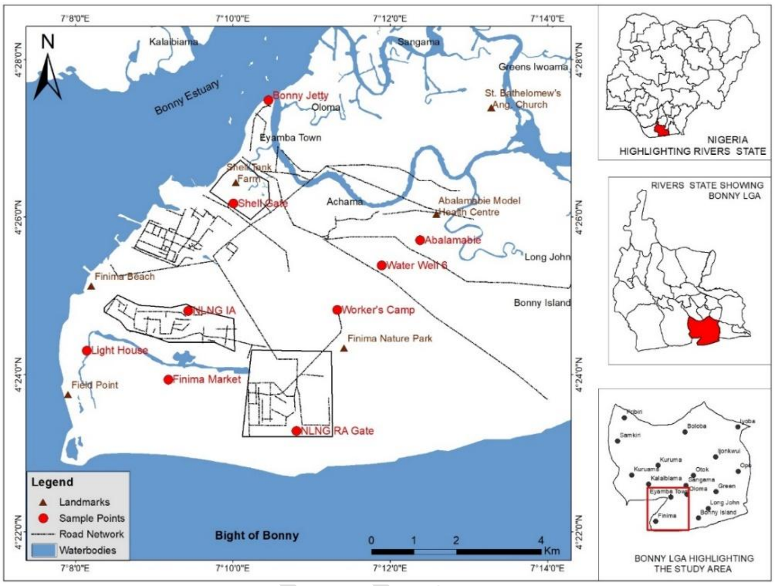

Figure 1: Map of Bonny area showing the sampling locations

2.3 Instrument Analysis

Obtaining the concentration of the physicochemical parameters, heavy metals and petroleum hydrocarbon was done using the various instruments:

2.3.1 Physico-chemical parameters

The physico-chemical parameters were determined using prescribed laboratory standard methods; the heavy metals were determined usingatomic absorption spectrophotometry (AAS); while,for determining the Total Hydrocarbon Content (THC) in water samples, a solvent extraction method was employed.

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2.3 Data analysis and procedures

The data obtained from the analysis of physicochemical parameters, heavy metals, and petroleum hydrocarbons in the groundwater samples were subjected to statistical analysis using appropriate methods.Pearson's correlation analysis was performed to establish the relationships between the different parameters studied (physicochemical, heavy metals, and petroleum hydrocarbons). This analysis helped to identify any significant correlations or associations between the various parameters, which can provide insights into potential sources, transport mechanisms, or interactions among the contaminants.The mean values of each parameter were computed for both the wet and dry seasons. The Z-testwas employed to determine if there were significant differences between the mean values of the parameters during the wet and dry seasons. This analysis helps to assess the influence of seasonal variations on the levels of contaminants in the groundwater.

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3. Results

3.1 Relationship between physiochemical, heavy metal, and petroleum hydrocarbon for groundwater

The Pearson correlation analysis was conducted to examine the relationships among physiochemical parameters, heavy metals, and petroleum hydrocarbons in the water samples. The results presented in Figure 2, revealed interesting associations, and provides insights into potential interactions within the aquatic environment.

The correlation analysis showed a significant positive correlation between DO and pH ($r = 0.18$), ~~indicating that an increase in the pH level result to an increase in the DO level and vice versa~~. A significant positive correlation was observed between DO and TDS ($r = 0.21$), suggesting that increase in the DO would result to an increase in the TDS and vice versa. The relationship between DO and EC was positive ($r = 0.21$, $p > 0.05$). The relationship between DO and EC was also significant. These findings suggests a potential influence of certain physiochemical parameters on the availability of dissolved oxygen in the water.The pH exhibited a significant positive correlation with various parameters, including TDS ($r = 0.37$,

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An increase in pH levels is associated with an increase in dissolved oxygen (DO) levels, and a decrease in pH levels is similarly associated with a decrease in DO levels

$p > 0.05$), EC ($r = 0.37$, $p > 0.05$). These associations indicate that changes in pH may be influenced by multiple factors within the aquatic system.TDS and EC demonstrated significant positive correlations with each other ($r = 1.00$, $p > 0.05$), indicating a strong relationship between these two parameters. This association suggests that the concentration of dissolved solids is closely linked to the electrical conductivity of the water.Temperature exhibited weak positive correlations with several parameters, including TDS and EC. These findings suggest a potential relationship between temperature and the concentration of dissolved substances in the water.TSS showed significant positive correlations with pH, indicating potential interactions between suspended solids and the pH of water.Chloride exhibited positive correlations with various parameters, including TDS, EC, Temperature, and sulphate. These associations suggest potential sources of chloride in the water, influenced by other physiochemical factors. Chloride and nitrate showed positive correlations with each other ($r = 0.40$), indicating a potential relationship between nutrient concentrations in the water.

Sulphate displayed positive correlations with multiple heavy metals, highlighting potential interactions between sulphate levels and the presence of these contaminants.TPH and PAH exhibited positive correlations with each other ($r = 0.51$, $p > 0.05$), suggesting a potential common source or similar transport mechanisms for these hydrocarbons in the water.

3.2 Seasonal variation in physiochemical, heavy metal, and petroleum hydrocarbon

The variations in physiochemical parameters, heavy metals and petroleum hydrocarbon between dry and wet conditions are presented from Figures3 to 5. The analysis revealed interesting trends in the environmental factors.

Dissolved Oxygen (DO) exhibited a slight increase during the dry season, with a mean of 5.42 mg/l compared to 5.34 mg/l in the wet season. The result from the Z-test revealed that there was no difference in the DO concentration between the wet and dry seasons. The result from theZ-Testprovides sufficient evidence to state that seasonality might not be a factor in the distribution of DO.

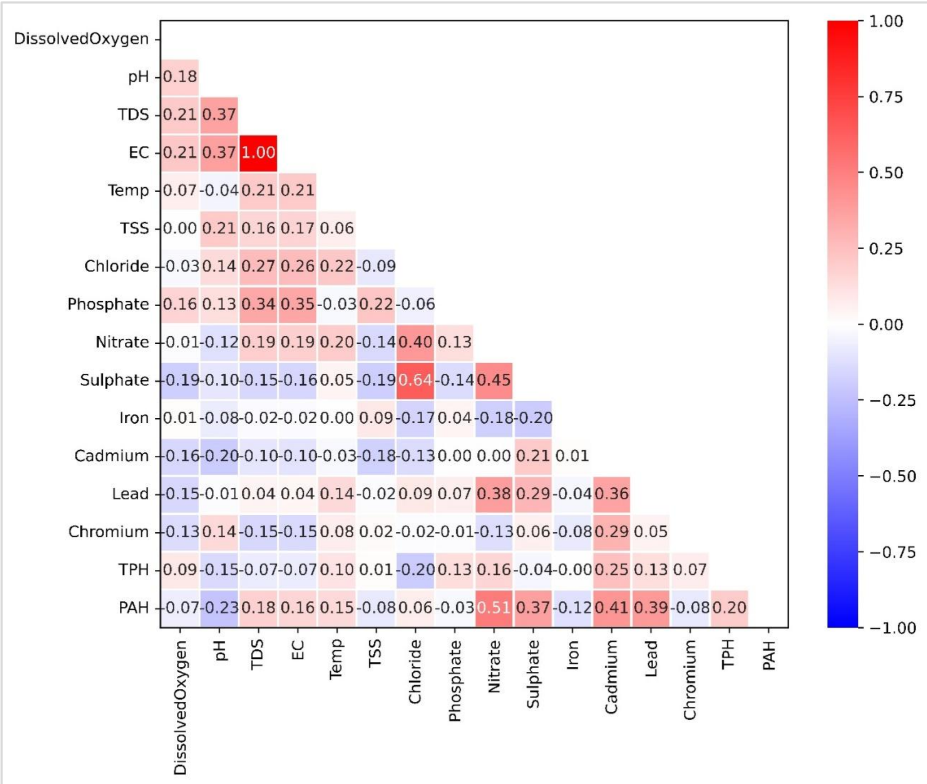

Figure 2: Heat map showing the relationship between physiochemicalparameters, heavy metal, and petroleum hydrocarbon.

Total Suspended Solids (TSS) showed a decrease from 4.46 mg/l in the dry season to 3.45 mg/l in the wet season, suggesting potential sedimentation during higher precipitation.The Z-Test result showed no significant difference in the TSS in the water found on Bonny Island for the wet and dry seasons. Phosphate levels decreased from 0.54 mg/l in the dry season to 0.38 mg/l in the wet season, indicating potential nutrient dynamics influenced by precipitation. The Z-Test result showeda significant difference in the phosphate concentration in the water sample between the wet and dry seasons p-value=0.035. The result from the Z-Testprovides sufficient evidence to state that precipitation might be an influencing factor affecting the accumulation of phosphate in the water source in the wet season. Nitrate concentrations remained relatively stable, with a slight decrease from 1.78 mg/l in the dry season to 1.60 mg/l in the wet season. The result ofthe Z-Testshowed that there was no significant difference in the nitrate concentration in the water source between the wet and dry seasons. Total Dissolved Solids (TDS) displayed a notable decrease from 413.02 mg/l in the dry season to 340.23 mg/l in the wet season. This reduction may be attributed to dilution effects associated with increased water flow but the result from the Z-Testshowed that there was no significant difference due to seasonality. Sulphate levels exhibited a substantial increase from 318.24 mg/l in the dry season to 492.04 mg/l in the wet season, possibly influenced by runoff and geological factors. The result from the Z-Testshowed no significant difference in the sulphate concentration in the water source due to seasonality. Electrical Conductivity (EC) exhibited a similar pattern, declining from 826.05 µS/cm in the dry season to 674.19 µS/cm in the wet season. The pH levels showed a decrease from 6.78 in the dry season to 6.50 in the wet season, indicating a shift towards more acidic conditions during the latter period. The result from the Z-test provided sufficient evidence to state that the water in the wet season tends to become acidic. Temperature (Temp) experienced a marginal increase from 30.20°C in the dry season to 31.05°C in the wet season, indicating a subtle warming effect. Chloride levels significantly decreased from 3248.45 mg/l in the dry season to 2372.13 mg/l in the wet season, reflecting dilution and runoff effects.

For the heavy metal seasonality effect, the result is displayed in Figure 5. The iron concentrations showed a slight decrease from 3.68 mg/l in the dry season to 3.17 mg/l in the wet season. No significant difference in the iron concentration in the water for the wet and dry seasons. Cadmium levels showed a notable increase from 0.28 mg/l in the dry season to 0.86 mg/l in the wet season, suggesting potential contamination sources. The Z-test result showeda significant difference in the cadmium concentration in the water for wet and dry seasons p-value <0.0001.

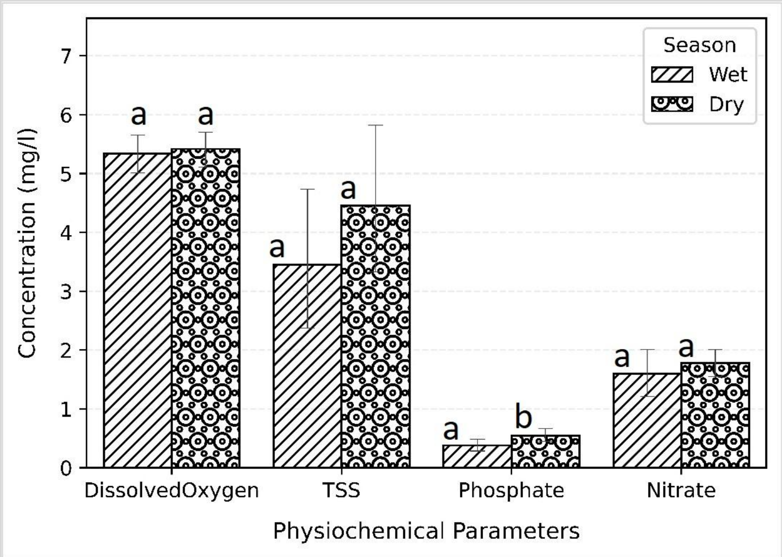

Figure 3: Concentration of physiochemical parameters (DO, TSS, Phosphate, Nitrate) for dry and wet seasons.

Lead concentrations remained relatively stable, with a slight increase from 0.73 mg/l in the dry season to 0.82 mg/l in the wet season. No significant difference in the lead concentration in the water was noticed based on the result from the Z-test. Chromium levels exhibited a significant increase from 0.44 mg/l in the dry season to 1.29 mg/l in the wet season, indicating a potential influence of runoff and industrial activities. The result from the Z-test showed that there was a significant difference in the chromium concentration in the water for dry and wet seasons p-value = 0.001.

Total Petroleum Hydrocarbons (TPH) displayed a substantial increase from 0.11 mg/l in the dry season to 0.59 mg/l in the wet season, suggesting potential contamination sources. The Z-test result showeda significant difference in the TPH concentration in the water in the dry and wet seasons p-value <0.0001. Polycyclic Aromatic Hydrocarbons (PAH) concentrations showed a notable increase from 0.09 mg/l in the dry season to 0.95 mg/l in the wet season, indicating a potential influence of runoff and anthropogenic activities. The Z-test result showeda significant difference in the PAH concentration in the water in the dry and wet seasons p-value <0.0001.

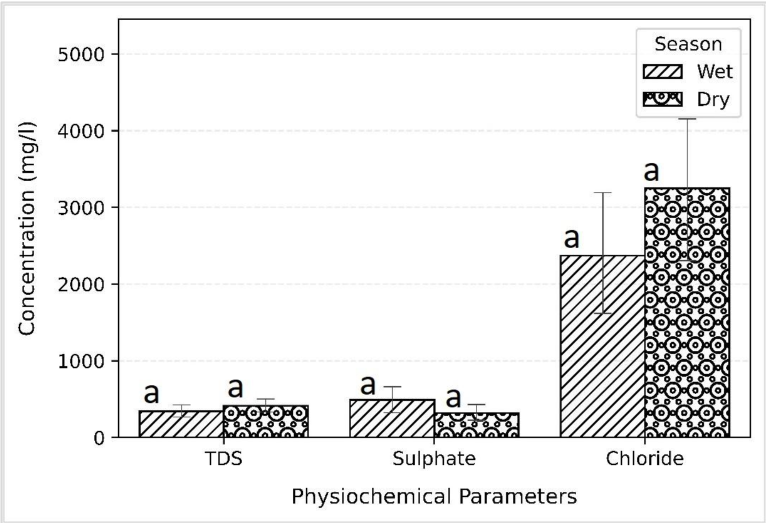

Figure 4: Concentration of physiochemical parameters (TDS, Sulphate, Chloride) for dry and wet season

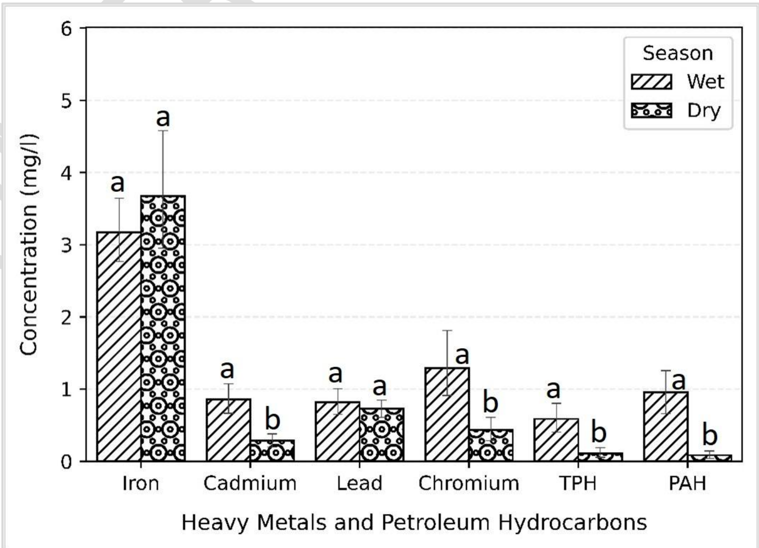

Figure 5: Concentration of heavy metals and petroleum hydrocarbons for the dry and wet season

4. Discussion

The study revealed significant seasonal variations in several physicochemical parameters, heavy metals, and petroleum hydrocarbons in the groundwater samples in Bonny Island. These variations can be attributed to various factors, including precipitation patterns, anthropogenic activities, and geochemical processes.Physicochemical parameters exhibited distinct seasonal trends. The observed increase in dissolved oxygen (DO) levels during the dry season aligns with the findings of Okpokwasili et al. (2013), likely due to the dilution effect caused by increased precipitation during the wet season, which can lower the concentration of dissolved gases. Conversely, the decrease in total suspended solids (TSS) during the wet season is consistent with the findings of Lin et al. (2009), suggesting potential sedimentation during higher precipitation, although the lack of significant differences contradicts the observations of Efe et al. (2005) in the Western Niger Delta.The significant decrease in phosphate levels during the wet season can be attributed to the dilution effect and potential uptake byorganisms (Parihar et al., 2012; Amadi et al., 2012). However, the stable nitrate concentrations in the present study contradict the findings of Okpokwasili et al. (2013), who reported higher levels during the rainy season, potentially influenced by agricultural activities and land-based runoff.The decreases in total dissolved solids (TDS) and electrical conductivity (EC) during the wet season align with the findings of Chikere and Okpokwasili (2002) and Gupta and Roy (2012), attributable to the dilution effect caused by increased precipitation. Similarly, the observed decrease in pH levels during the wet season, indicating a shift towards more acidic conditions, is consistent with the findings of Nwankwoala and Udom (2011), potentially influenced by organic matter and gas flaring activities in the Niger Delta region.

However, the increase in sulphate levels during the wet season contradicts the findings of Okpokwasili et al. (2013), suggesting the influence of geological factors, runoff from industrial or agricultural sources, or other local environmental conditions specific to the study area.Regarding heavy metals, the slight decrease in iron concentrations during the wet season aligns with the findings of Nwankwoala (2011), who attributed lower levels to the dilution effect of precipitation. Conversely, the significant increase in cadmium levels during the wet season is a concerning finding, as cadmium is a toxic heavy metal with potential adverse health effects. This increase may be attributed to runoff from industrial or agricultural sources, or the leaching of cadmium from contaminated soils or sediments (Häder et al., 2020; Asia et al., 2007; Frank et al., 2020), highlighting the need for further investigation and mitigation strategies.

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The seasonal variations in petroleum hydrocarbon concentrations can be attributed to factors such as precipitation patterns, oil and gas activities, and accidental spills or leaks (Elmobarak et al., 2021; Kurwadkar et al., 2020). These findings from this study underscore the complex interplay between natural processes, anthropogenic activities, and environmental factors in Bonny Island ecosystem, necessitating continuous monitoring and appropriate mitigation measures to ensure the protection of groundwater resources and overall environmental health.

5. Conclusion

The study on groundwater in Bonny Island, Nigeria, investigated seasonal changes in physicochemical parameters, heavy metals, and petroleum hydrocarbons. Results showed significant fluctuations, with decreases in certain parameters during the wet season and increases in others. Petroleum hydrocarbon levels also varied seasonally due to factors like precipitation and industrial activities. Collaboration between stakeholders is crucial for ongoing monitoring and mitigation efforts to protect groundwater quality and environmental health. Future research should focus on health implications and tailored remediation strategies for sustainable management.

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