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Quality Assessment of Surface and Groundwater from Eleme Communities in Rivers State

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed the suitability of surface and groundwater for irrigation and domestic purposes in Eleme Local Government Area, Rivers State, Nigeria. Several studies have reported that contaminations from nearby petrochemical and industrial activities have raised concerns about water quality in the region. Parameters such as Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Permeability Index (PI), Kelly's Ratio (KR), and Water Quality Index (WQI) were analyzed for both dry and rainy seasons. Results indicated that while Onne groundwater (Rainy season: SSP (31.0±4.9%), MAR (35.2±10.7%), RSC (0.5±0.6meg/l), SAR (0.7±0.2meg/l), PI (41.5±8.2%), KR (0.5±0.1meg/l); Dry season: SSP (35.2±10.7%), MAR (5.6±2.1%), RSC (1.7±0.9meg/l), SAR

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(0.9±0.4meg/l), PI (65.5±12.9%), KR (0.6± .28meg/l) and Aleto River surface water (Rainy season: SSP (30.3±3.12%), MAR (25.8±11.42%), RSC (-60.3±12.31meg/l), SAR (5.0±0.62meg/l), PI (84.9±18.62%), KR (0.4± 0.06meg/l); Dry season: SSP (33.2±3.67%), MAR (21.4±7.02%), RSC (-52.0±6.29meg/l), SAR (5.5±1.08meg/l), PI (85±24.1%), KR (0.5±0.09meg/l) remain suitable for irrigation, most water sources in other communities exceed recommended thresholds, particularly in SSP and KR. Seasonal fluctuations notably affect parameters like MAR and PI, highlighting the need for continuous monitoring. Elevated heavy metals, especially lead, nickel, and cadmium, were identified in some groundwater samples, likely due to industrial pollution, thus further impacting water safety. The findings underscore the necessity for remediation and regular water quality management to safeguard agricultural sustainability and public health in the Eleme communities.

Keywords: Groundwater; irrigation; water management; pathogens.

1. INTRODUCTION

Surface and groundwater are vital sources of freshwater, supporting various human activities, including drinking water supply, agriculture, and industrial processes (Wang et al., 2019). Ensuring the quality of these water resources is paramount: to public health, for economic development, and for ecological balance (Lopes et al., 2022). Surface water, such as rivers, lakes, and reservoirs, is susceptible to contamination from both point and non-point sources. Industrial discharge, agricultural runoff, oil spillage, and urban wastewater contribute significantly to the degradation of surface water quality (Abdel-Shafy & Mansour, 2016). Groundwater, on the other hand, is often perceived as a cleaner source due to natural filtration processes occurring in the subsurface. However, it is not immune to pollution, particularly from leachates, septic systems, and improper disposal of hazardous wastes (Siddiqua et. al., 2022). Evaluating the quality of both surface and groundwater is essential to ensure its suitability for various purposes, including drinking and irrigation. The assessment of water quality involves the analysis of various physical, chemical, and biological parameters. These parameters such as pH, dissolved oxygen, turbidity, nutrient concentrations, and the presence of pathogens provide insights into the status and suitability of water for different uses (WHO, 2017). These assessments aim to provide a comprehensive understanding of the factors influencing groundwater quality, such as natural geochemical processes and human activities (Guo et al., 2020) as well as detect changes over time and implement effective management strategies (Iqbal et. al., 2021). Additionally, the creation of groundwater quality indices and water quality assessment models has been pivotal in quantifying and monitoring the quality of groundwater resources (Li et al., 2018). In recent years, increased human activities and climatic changes have exacerbated the pressures on water resources, highlighting the need for rigorous water quality assessments. Furthermore, urbanization and industrialization have intensified the input of pollutants into water bodies, while climate change impacts, such as altered precipitation patterns and extreme weather events, affect the hydrological cycle and water availability (IPCC, 2014). These challenges necessitate a holistic approach to water quality assessment, integrating advanced monitoring techniques and robust analytical methods. An effective method for determining if groundwater is suitable for irrigation, industry, or home usage is to conduct a hydrochemical analysis. Because groundwater's physico-chemical content indicates whether it is suitable for use as a water resource for residential, industrial, and agricultural (irrigation) reasons, it is important to assess the hydrochemical properties of groundwater.

Just like everywhere in the world, communities in Eleme Local Government Area, Rivers State heavily rely on surface and groundwater for domestic and agricultural purposes. Unfortunately, these water sources have been significantly contaminated by chemical and petrochemical products from the activities of oil and gas companies in the region (Olukaejire et. al., 2024). Industries such as the Port Harcourt Refinery Company, Alesa Eleme, Indorama Eleme Petrochemical Company Limited, Notore Chemicals Limited, and Indorama Fertilizer Chemicals Limited have been identified as major contributors to the pollution of water sources in Eleme and neighboring communities in Khana, Gokana, Ogu/Bolo, and Okrika local governments (Oyor, 2017; Olukaejire et. al., 2024). These contaminations may have made the groundwater in the area unsafe for human consumption and irrigation purposes. This paper presents the result of a quality assessment performed in the study area in 2021. It determined the quality of the both the groundwater and surface water for both domestic consumption and irrigation purposes.

2. MATERIALS AND METHODS

2.1 Study Area

Eleme Local Government Area is one of the twenty-three local government areas of Rivers State. Located geographically on latitude 4°44' N and longitude 7°15'E. It consists of ten communities namely; Ogale, Alode, Aleto, Agbonchia, Akpajo, Ebubu, Alesa, Onne, Ekporo and Eteo. However, nine communities, Ogale, Alode, Aleto, Agbonchia, Akpajo, Ebubu, Alesa, Onne, and Eteo, were sampled in this study as Ekporo had communal crisis during the study period hence was excluded in the study. Eleme Lga a crude oil producing local government with presence of oil and gas, petrochemical, and fertilizer industries. Apart from major oil companies like SPDC, Mobil etc., the local government also host Port Harcourt refinery company, Alesa Eleme; Indorama Eleme Petrochemical Company Limited; Notore Chemicals Limited; and Indorama Fertilizer Chemicals Ltd.

2.2 Sample Collection and Processing

The procedure for sample collection, used in this study, began with a survey of the communities in the study area. The survey identified functional streams, wells and boreholes frequently used by the people, before sample collection. All plastic bottles were washed thrice with the sample water before the samples were taken.

For groundwater samples, boreholes with depth of 100-150 meters frequently used by inhabitants of the communities were identified and sampled for the study. Four boreholes from each community were selected for sampling, a total of 36 boreholes were sampled for the study. The selected boreholes from each community were selected in a manner that every part of the community was adequately represented in the sampling. Samples were collected from the boreholes at the borehole heads. The boreholes were allowed to pump for 15 minutes in order to achieve an approximate constant temperature

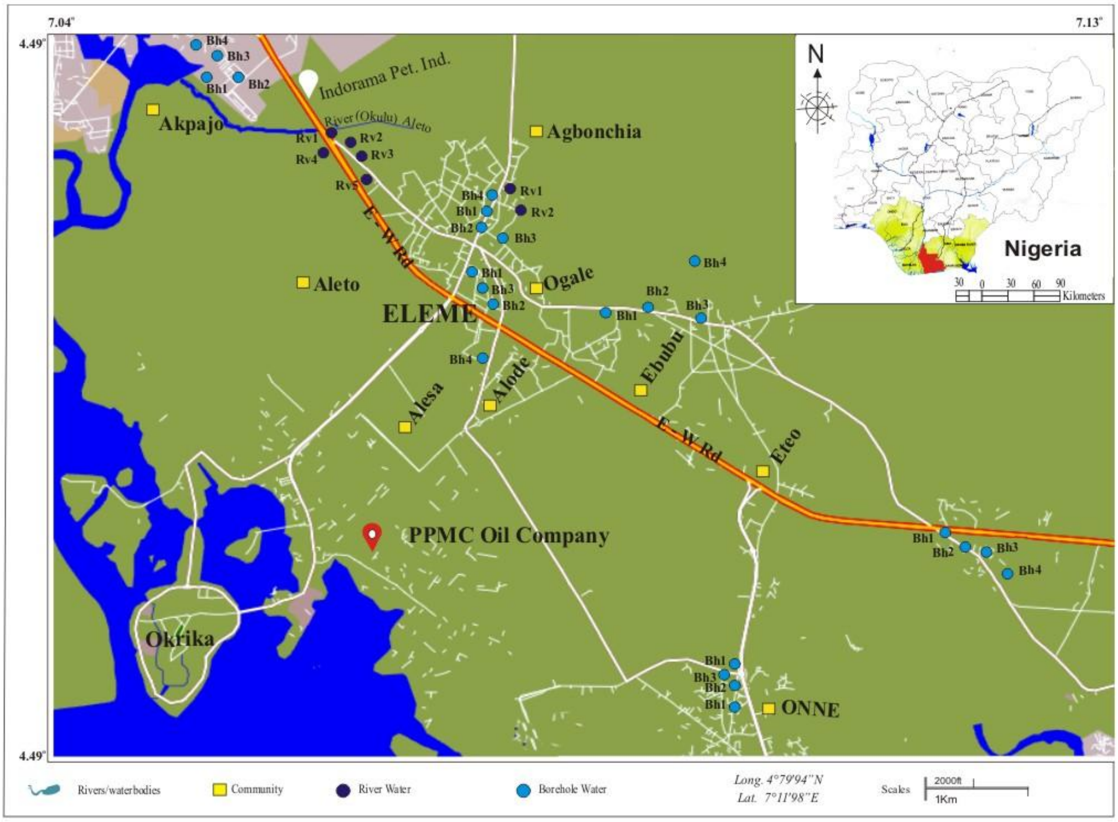

Fig. 1. Map of Eleme communities showing the sampling locations

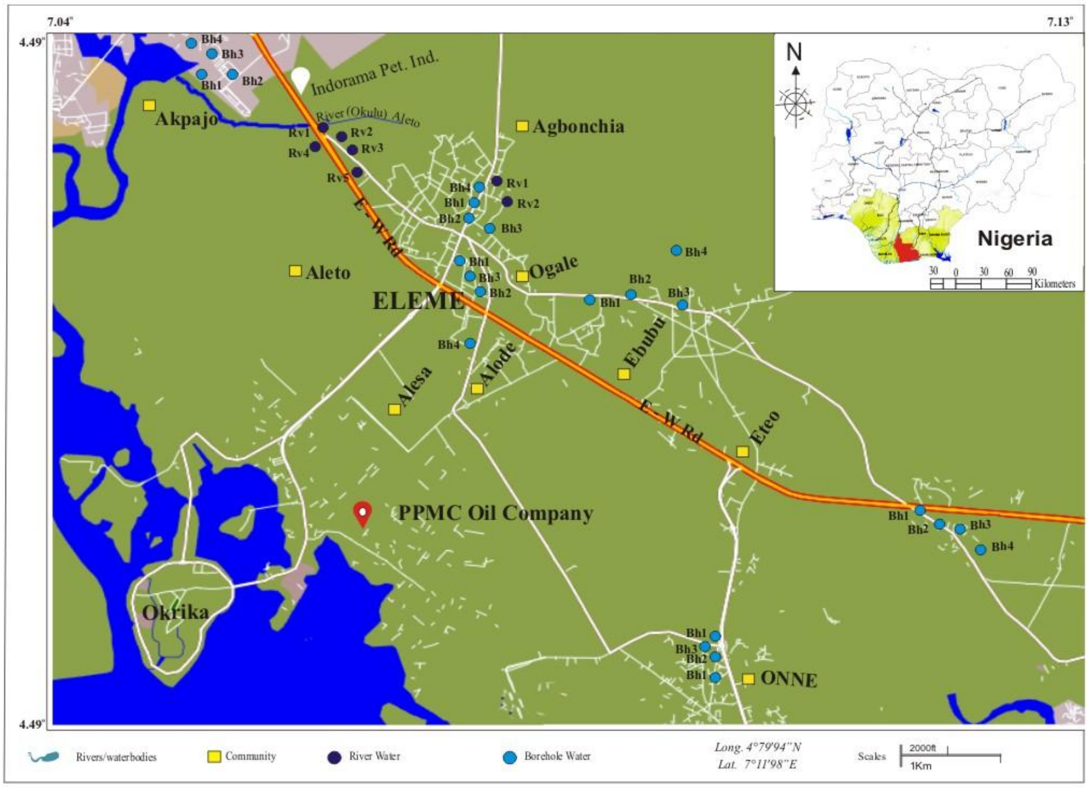

Fig. 2. Map of Eleme Communities Showing the Sampling Locations

and pH before samples were taken. Water samples were collected in 1 litre plastic bottles. For surface water samples, samples from the rivers (Aleto and Agbonchia) were collected in the morning (when minimum activity was taking place). Samples were collected from Aleto and Agbonchia at the top depth of 10metres and 20 metres respectively as Agbonchia River is deeper than Aleto River. All samples were collected in June (rainy season) and November (Dry season) of 2021. After sample collection, the containers were tightly covered and appropriately labelled and transported to the laboratory for process of analysis.

2.3 Laboratory Analytical Methods

Collected samples were investigated as per standard methods recommended by American Society for Testing and Materials (ASTM, 2010) and American Public Health Association (APHA, 1995). The study analysed twenty-eight physico-chemical parameters of both surface and groundwater present in the study area. The twenty-eight parameters are: pH, conductivity, temperature, total dissolved solid, total suspended solid, turbidity, electrical conductivity, nitrite ion concentration, calcium ion concentration, magnesium ion concentration, total hydrocarbon concentration, sodium ion concentration, chloride ion concentration, Polycyclic Aromatic Hydrocarbons (PAHs), phosphate ion concentration, total hardness, oil/grease concentration, biochemical oxygen demand, chemical oxygen demand, carbonate ion concentration, salinity, cadmium ion concentration, lead ion concentration, iron ion concentration, nickel ion concentration, copper ion concentration, manganese ion concentration and arsenic ion concentration.

2.4 Irrigation Suitability Determination

After analysis at the laboratory, the results obtained were used in calculating the water irrigation suitability. Six parameters, Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR), Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Permeability Index (PI), and Kelly's Ratio (KR) were used to calculate the irrigation suitability of the two water sources. All calculations were performed on SPSS version 24. The various equations used for calculating each parameter are presented below:

2.5 Magnesium Adsorption Ratio (MAR)

Magnesium adsorption ratio (MAR) for irrigation water was calculated by using the formula:

$$\text{MAR}\ (\%) = \frac{\text{Mg}^{2+}}{\text{Ca}^{2+}+\text{Mg}^{2+}} * 100 \qquad (1)$$

2.6 Residual Sodium Carbonate (RSC)

Residual sodium carbonate (RSC) values of the water samples of the present area were calculated using the formula developed by Raghunath (1987):

$$\text{RSC}\ \left(\frac{\text{meq}}{\text{l}}\right) = \left(\text{HCO}_3^{\ -} + \text{CO}_3^{\ 2-}\right) - \left(\text{Ca}^{2+} + \text{Mg}^{2+}\right) \qquad (2)$$

2.7 Sodium Adsorption Ratio (SAR)

The sodium adsorption ratio (SAR) of the irrigation water was calculated according to Richards (1954) using the formula:

$$\text{SAR}\ \left(\frac{\text{meq}}{\text{l}}\right) = \frac{\text{Na}^{+}}{\sqrt{\frac{\text{Ca}^{2+}+\text{Mg}^{2+}}{2}}} \qquad (3)$$

2.8 Permeability Index (PI)

The Permeability index (PI) of the groundwater samples was determined using the formula by Doneen (1964).

$$\text{PI}\ (\%) = \frac{\text{Na}^{+} * \sqrt{\text{HCO}_3^{\ -}}}{\text{Ca}^{2+}+\text{Mg}^{2+}+\text{Na}^{+}} * 100 \qquad (4)$$

2.9 Kelly's Ratio (KR)

Kelly's ratio is expressed by the following equation according to Kelly (1963);

$$\text{KR}\ \left(\frac{\text{meq}}{\text{l}}\right) = \frac{\text{Na}^{+}}{\text{Ca}^{2+}+\text{Mg}^{2+}} \qquad (5)$$

2.10 Water Suitability Index Determination

The water suitability index also called water quality index was calculated using eight distinct parameters, pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), total hardness, calcium (Ca) ions, phosphate (PO_4^{3}) ions and magnesium (Mg) ions. These parameters collectively contribute to the quality of the water sources. The steps for WQI are:

2.11 Weighting

In establishing the weighting system for the parameters selected for the water quality index, the unequal weighting according to Almeida index (Almeida et al., 2012) was used. The unequal weightage is dependent on the permissible limits of the parameters used; a parameter weightage is inversely proportional to the parameter permissible limits.

The weightage formula used is as follows:

$$W_i = \frac{k}{V_i} \qquad (6)$$

Where,

K=proportionality constant
W_i=weight factor
V_i= permissible limit recommended by WHO

$$k = \frac{1}{\sum_i^n \frac{1}{V_i}} \qquad (7)$$

Water quality index (WQI) was then calculated using the subsequent equation used by Lopes et al. (2008):

$$WQI = W_i * V_r = \sum_i^n W_i * V_r \qquad (8)$$

Where V_r= volume present in the sampled water
V_r for each physico-chemical factor was determined using the rating scale developed by Kumar and Dua (2009) which is presented in Table 1:

Table 1. Rating scale for V_r used in calculating water quality index

Physico- chemical Factors	Ranges				
V_r	100	80	60	40	0
Pollution level	Not polluted	Minute pollution	Moderate pollution	Excess pollution	Severe pollution
Conductivity	75-0	150-75.1	225-150.1	300-225.1	>300
Turbidity	0	2.5-0	5-2.51	10-5.1	>10
Magnesium ions	12.5-0	25.0-12.6	37.5-25.1	50-37.6	>50
Calcium ions	20-0	40-20.1	60-40.1	75-60.1	>75
Total hardness	150-0	300-150.1	450-300.1	600-450.1	>600
TDS	375-0	750-375.1	1125-750.1	1500-1125.1	>1500
pH	8.5-7	8.7-8.6	8.9-8.8	9.2-9.0	>9.2
Sodium ions	50-0	100-50.1	200-100.1	400-200.1	>400

Table 2. WQI Ranges

WQI	Water quality
100-90	Excellent
90-70	Good
70-50	Fair
50-25	Bad
25-0	Very bad

Source: Almeida and Schwarzbold (2003) modified table of Comitesinos (1990)

Furthermore, the WQI rating was performed in line with the scaling developed by Almeida and Schwarzbold (2003) which is presented in Table 2.

3. RESULTS

3.1 Assessment of Irrigation suitability of Groundwater during Rainy and Dry Seasons

The result of the calculated irrigation suitability parameters (Soluble Sodium Percentage, Magnesium Adsorption Ratio, Residual Sodium Carbonate, Sodium Adsorption Ratio, Permeability Index, Kelly's Ratio) of both groundwater and surface water in each of the nine communities sampled by the study is presented in Tables 3 and 4. The result shows the calculated parameters for both rainy and dry seasons.

3.2 Water Suitability Index

3.2.1 Assessment of water suitability index for groundwater in the study area

Table 6 presents the calculated water quality index of Eleme communities' groundwater during the rainy and dry seasons. All the communities' groundwater in both rainy and dry seasons have excellent water quality rating except Ogale which has a rating of good during the rainy season.

Table 7 presents the calculated water quality index of Eleme communities' surface water during the rainy and dry seasons. Aleto River in both rainy and dry seasons has fair water quality rating while Aleto River water quality rating falls within the bad classification.

4. DISCUSSION

4.1 Soluble Sodium Percentage (SSP)

The Soluble Sodium Percentage (SSP) is a key indicator of water's sodium content relative to other cations. For irrigation purposes, water with an SSP less than 50% is considered suitable, as high sodium levels can impair soil structure and hinder crop growth. Onne groundwater, with SSP values of 3.1% in the rainy season and 35.2% in the dry season, remains below the 50% threshold, making it suitable for irrigation year-round. However, other communities' groundwater shows SSP levels that exceed 50%, making these water sources unsuitable for irrigation due to potential risks of soil degradation. Furthermore, surface water from Agbonchia River exceeds the 50% SSP limit in both seasons, deeming it unsuitable for irrigation. However, Aleto River remains within the suitable range (<50%), thus providing an alternative water source for irrigation in the area.

4.2 Magnesium Adsorption Ratio (MAR)

The Magnesium Adsorption Ratio (MAR) evaluates the proportion of magnesium to calcium in the water. High levels of magnesium in relation to calcium can negatively affect soil permeability and crop yields. In Eleme communities, groundwater MAR across communities is generally suitable for irrigation, as values are below the 50% limit. However, Ogale during the rainy season and Akpajo in the dry season have MAR values exceeding 50%, making them unsuitable for irrigation during these periods. The cause of seasonal variations in MAR values for these specific locations remains unidentified in this study. Furthermore, surface water from both Aleto and Agbonchia Rivers meets the MAR threshold during the rainy season, indicating suitability. In the dry season, however, Agbonchia River's MAR exceeds 50%, thus restricting its suitability for irrigation.

4.3 Residual Sodium Carbonate (RSC)

Residual Sodium Carbonate (RSC) indicates the carbonate and bicarbonate levels relative to calcium and magnesium in water, where negative values suggest suitability for irrigation by reducing sodium hazards. In the Eleme

Table 3. Calculated irrigation suitability parameters of Eleme Communities' groundwater

Sampled Community	SSP (%)		MAR (%)		RSC (meq/l)		SAR (meq/l)		PI (%)		KR (meq/l)	
	Rainy	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**	**Rainy**	**Dry**
Alesa	69.3±7.0	51.1± 7.3	6.7±3.1	22.0±22.1	-.3±0.7	-1.9±1.0	4.2± 1.0	2.7±0.5	85.4±18.2	68.3±21.7	2.5±1.0	1.1±0.3
Alode	82.6±3.7	77.6±6.1	4.0±1.1	3.7±0.9	0.5±0.5	1.0±0.7	6.1±0.9	5.4±1.6	92±16.3	95.5±16.1	4.9±1.3	3.7±1.2
Onne	31.0±4.9	35.2±10.7	5.3±3.2	5.6±2.1	0.5±0.6	1.7±0.9	0.7±0.2	0.9±0.4	41.5±8.2	65.5±12.9	0.5±0.1	0.6± .28
Ebubu	95.4±2.5	96±2.5	32.4±6.7	31.7±3.2	0.2±0.3	0.2±0.2	10.2±3.7	10.9± 4.4	49.9±31.5	42.6±28.2	24.7±9.4	30.8±13.4
Oghale	93.1±1.7	96±2.5	69.7±8.6	31.7±3.2	-0.1±0.1	0.2±0.2	6.7±0.9	10.9± 4.4	10.4±0.7	42.6±28.2	14.2±4.2	30.8±13.4
Eteo	91.3±1.6	93.2±1.6	49.6±3.7	49.6±3.7	-0.1±0.02	-0.1±0.03	5.6±0.7	7.5±1.3	21.2±1.3	22.5±1.7	10.8±2.2	14.4±3.8
Aleto	91.3±3.3	91.8±0.6	48.2±4.5	46.3±4.5	-0.2± 0.01	-0.2±0.02	7.0±2.7	7.1±0.9	14.4±1.4	15.9±0.9	12.0± 4.6	11.2±0.9
Akpajo	91.7± 1.2	92.1±1.9	38.7±10.0	59.5±20.0	-0.1±0.0	-0.2±0.04	5.5±0.4	6.8±1.0	11.0±1.6	12.0±1.8	11.2±1.7	12.3±4.1
Agbonchia	75.3± 7.2	75.3±7.2	8.5±5.2	8.5±5.2	-0.5±0.6	-0.3± 0.4	5.1± 0.9	5.1±0.9	74.7±13.8	86.4±5.3	3.3± 1.0	3.3±1.0

Table 4. Calculated irrigation suitability parameters of Eleme Communities' surface water

Parameter	Aleto River		Agbonchia River	
	Rainy season	Dry season	Rainy season	Dry season
SSP	30.3±3.12	33.2±3.67	67.3±7.05	52.3±0.78
MAR	25.8±11.42	21.4±7.02	44.9±1.64	75.3±4.25
RSC	-60.3±12.31	-52.0±6.29	-26.5±1.77	-27.6±0.21
SAR	5.0±0.62	5.5±1.08	8.3±0.17	8.4±0.26
PI	84.9±18.62	85±24.1	67.3±7.05	75.3±4.25
KR	0.4± 0.06	0.5±0.09	1.1±0.07	1.1±0.03

Table 5. Assigned Weight of the water quality parameters

Water quality Parameters	WHO permissible limit	W_i
Ph	8.5	.292
Conductivity	1000	.002
TDS	30	.083
Turbidity	5	.496
TH	400	.006
Ca	100	.025
Mg	30	.083
Na	200	.012

K=2.48

Table 6. Water quality index of Eleme communities' groundwater (rainy and dry seasons)

Community	WQI (Rainy season)	Water quality	WQI (Dry Season	Water quality
Alesa	99.91	Excellent	99.86	Excellent
Alode	99.91	Excellent	99.86	Excellent
Onne	99.86	Excellent	99.86	Excellent
Ebubu	99.91	Excellent	99.86	Excellent
Ogale	80.02	Good	99.86	Excellent
Eteo	99.91	Excellent	99.86	Excellent
Aleto	99.91	Excellent	99.76	Excellent
Akpajo	99.86	Excellent	99.86	Excellent
Agbonchia	99.86	Excellent	99.86	Excellent

Table 7. Water quality index of Eleme communities' surface water (rainy and dry seasons)

River	Rainy season water quality index	Dry season water quality index	Water quality
Aleto	39.02	39.0	Bad
Agbonchia	50.06	50.1	Fair

communities, groundwater in Alesa, Eteo, Aleto, Akpajo, and Agbonchia exhibit negative RSC values across all seasons, confirming excellent suitability for irrigation as they do not pose a sodium accumulation risk. The RSC for Alode, Onne, and Ebubu are positive indicating unsuitability while Oghale exhibit negative value during the dry season and positive value during the rainy season. The surface water in the study area exhibits negative RSC indicating suitability in all season.

4.4 Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) assesses sodium hazards by comparing sodium concentration to calcium and magnesium. SAR values less than 10 meq/l indicate minimal risk, supporting irrigation use. In all Eleme communities except Ebubu and Oghale, groundwater and surface water SAR values across both seasons are below 10 meq/l, demonstrating excellent suitability for irrigation, with minimal risk of soil structure degradation. For Ebubu, the Sar exceeds 10meg/l in both season making it unsuitable while Oghale was found to be unsuitable during the dry season.

4.5 Permeability Index (PI)

Permeability Index (PI) evaluates water's effect on soil permeability and infiltration rates. For irrigation, a PI below 75% generally indicates suitable water quality. Groundwater PI values are largely within the suitable range except for Alode, which exceeds the 75% limit, making it unsuitable. Seasonal variations were observed for Alesa (rainy season) and Agbonchia (dry season), with PI exceeding 75% in these periods, but the cause of this variation could not be determined in this study. Surface water PI for Aleto River is consistently above 75%, making it unsuitable. For Agbonchia River, while PI falls within suitable levels in the rainy season, it exceeds 75% in the dry season, rendering it unsuitable for irrigation in that period.

4.6 Kelly's Ratio (KR)

Kelly's Ratio (KR) measures sodium's suitability by comparing sodium to calcium and magnesium, with values below 1 meq/l indicating irrigation suitability. Onne's groundwater KR (rainy: 0.453 meq/l, dry: 0.577 meq/l) is below 1, making it suitable. However, all other communities exceed the 1 meq/l threshold, deeming them unsuitable for irrigation. Surface water KR indicates Aleto River is suitable in both seasons, while Agbonchia River exceeds the 1 meq/l threshold, making it unsuitable.

4.7 Water Quality Index

The Water Quality Index (WQI) offers a comprehensive assessment by aggregating multiple water quality parameters. Generally, groundwater WQI indicates excellent quality across communities in both seasons, with an exception in Ogale during the rainy season, which is rated "good." Surface water WQI reveals that Aleto River has a fair quality rating in both seasons, while Agbonchia River rates poorly. Poor quality in some borehole water sources may result from high concentrations of heavy metals, specifically lead, nickel, and cadmium.

5. CONCLUSION

The water quality assessment for the Eleme communities indicates that only a limited number of water sources, such as Onne's groundwater and the Aleto River, consistently meet the criteria for suitability in irrigation practices. This highlights the uneven distribution of water resources that are safe and effective for agricultural use in the region. Seasonal variations play a significant role in influencing key parameters, such as the Magnesium Adsorption Ratio (MAR) and Permeability Index (PI). These fluctuations underscore the necessity for season-specific water quality management strategies to address changes that could affect crop irrigation efficiency and soil health. Moreover, the presence of elevated levels of heavy metals in certain groundwater sources poses additional challenges. These contaminants have the potential to degrade water quality further, impacting not only the suitability of water for irrigation but also raising concerns about long-term soil contamination and crop safety. This situation emphasizes the critical need for regular and comprehensive water quality monitoring to detect and address emerging issues. Implementing targeted remediation efforts where contamination is identified will be essential to ensure water sources remain viable for irrigation and to support sustainable agricultural practices in the Eleme communities. Proactive measures in water management will not only enhance agricultural productivity but also safeguard the health of ecosystems and local communities reliant on these water resources.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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