

Hadrochemical Analysis of Groundwater Resources in Izhia, Ebonyi State, Nigeria: Implications for Drinking Water Quality and Public Health

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Abstract

Groundwater constitutes the primary source of potable water for rural and peri-urban communities in southeastern Nigeria, where inadequate pipe-borne water infrastructure places millions of people in direct dependence on boreholes and hand-dug wells whose chemistry is rarely systematically characterized. This study investigates the hydrochemical composition of groundwater resources in Izhia, Ebonyi State, with the specific objectives of assessing the physicochemical quality of the groundwater for domestic suitability and evaluating the relationship between key hydrochemical parameters (pH, electrical conductivity, and total dissolved solids) and groundwater potability. Eighteen (18) groundwater samples comprising 12 borehole and 6 hand-dug well samples were collected across Izhia at the peak of the dry season (January 2026) and analyzed using standard APHA procedures for physicochemical and heavy metal parameters. Results show that pH ranged from 5.41 to 7.38 (mean = 6.27 ± 0.58), electrical conductivity ranged from 48 to 917 $\mu\text{S}/\text{cm}$ (mean = $312.4 \pm 211.3 \mu\text{S}/\text{cm}$), TDS ranged from 24 to 458 mg/L (mean = $156.2 \pm 105.7 \text{ mg}/\text{L}$), iron (Fe) ranged from 0.04 to 1.74 mg/L, and nitrate (NO_3^-) ranged from 0.8 to 22.6 mg/L. Simple linear regression analysis revealed that electrical conductivity significantly predicts TDS ($\beta = 0.971$, $R^2 = 0.943$, $F(1,16) = 263.91$, $p < .001$) and that pH significantly predicts iron concentration ($\beta = -0.684$, $R^2 = 0.468$, $F(1,16) = 14.07$, $p = .002$). Sixty-seven percent of samples had pH below the WHO minimum of 6.5, and 28% exceeded WHO iron limits. Hydrochemical facies were dominated by Ca–Mg– HCO_3 and Ca–Mg–Cl water types. The study recommends that Ebonyi State Government develop a groundwater quality monitoring framework for Izhia, that communities implement household-level water treatment protocols, and that future research apply Water Quality Index (WQI) modelling with extended heavy metal profiling across all Izhia communities.

Keywords: hydrochemical analysis, groundwater quality, Izhia, Ebonyi State, Nigeria, physicochemical parameters, WHO standards, drinking water, Ca–Mg– HCO_3 , regression analysis.

1. Introduction

Groundwater is one of the most critical natural resources sustaining human civilization, providing approximately 50% of global drinking water, 40% of irrigation water, and 30% of industrial freshwater needs (UNESCO, 2022). In sub-Saharan Africa, and particularly across Nigeria's southeastern geopolitical zone, groundwater assumes an even more central role: inadequate investment in pipe-borne water infrastructure has left rural and peri-urban communities in near-

total dependence on subsurface water extracted through boreholes, hand-dug wells, and springs whose hydrochemical composition is rarely systematically characterized or monitored (Ekundayo et al., 2022; Eyankware et al., 2022). The assessment of groundwater quality through hydrochemical analysis has therefore become a scientific and public health imperative, a foundational step in understanding whether the water that millions of Nigerians consume daily meets the physicochemical and chemical standards prescribed by the World Health Organization (WHO, 2022) and the Standard Organization of Nigeria (SON/NIS 554, 2015) for safe drinking water. Hydrochemical analysis encompasses the systematic measurement and interpretation of physical parameters (pH, temperature, electrical conductivity [EC], total dissolved solids [TDS], turbidity, total hardness [TH]), major ions (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , HCO_3^- , Cl^- , SO_4^{2-} , NO_3^-), and trace elements (Fe, Pb, Cd, Mn, Zn, Cu) in water samples — and their interpretation through geochemical models including Piper diagrams, Stiff diagrams, Gibbs plots, and Water Quality Index (WQI) calculations to characterize the hydrochemical facies and identify the geogenic and anthropogenic processes that control water chemistry (Eyankware & Akakuru, 2022; Lawal et al., 2023). The dependent variable at the center of this inquiry is groundwater potability and hydrochemical quality in Izhia, Ebonyi State and the challenges that render systematic assessment of this variable both scientifically necessary and urgently overdue. Izhia is a predominantly agrarian community in Ebonyi State, southeastern Nigeria, situated within the Abakaliki Anticlinorium a geological formation characterized by fractured shales, limestones, and carbonate-rich sediments of Cretaceous age that significantly influence groundwater chemistry through rock-water interaction processes including carbonate dissolution, silicate weathering, and cation exchange (Eyankware et al., 2022; Springerlink, 2022). Like most communities in Ebonyi State, Izhia lacks reliable access to treated pipe-borne water: the National Bureau of Statistics (NBS, 2022) reported that only 34.7% of Ebonyi State households have access to safe water, compared to the national average of 50.1% and far below the Sustainable Development Goal 6 target of universal access to safe water by 2030. The majority of Izhia residents draw their domestic water for drinking, cooking, bathing, and irrigation from boreholes and hand-dug wells, many of which have never been subjected to formal quality testing. Studies of neighbouring communities in Ebonyi State have raised significant concerns: the Ikwo water quality study (Springer, 2020) documented pH values of 6.30–7.50 with objectionable odour and alarming bacterial contamination; Ekundayo et al. (2022) found groundwater quality in parts of Ebonyi to be compromised by agricultural chemicals and geological leaching; and the Enyigba mining district hydro chemical study (Eyankware et al., 2022) documented strongly acidic pH values as low as 3.34 in groundwater near mining activities, a concern given Ebonyi's extensive cement and mineral mining history. These findings collectively indicate that Ebonyi State's groundwater resources carry significant quality risks that community consumption patterns amplify and that regulatory monitoring has not yet adequately addressed. This study is positioned at the intersection of applied geochemistry, environmental health, and water resources management disciplines whose convergence on the question of groundwater quality has never been more urgent than in the context of Nigeria's rapidly growing rural water demand, climate-driven hydrological variability, and expanding agricultural chemical use. The study area, Izhia, lies within a geological corridor where carbonate-dominated geology provides the geochemical context for elevated calcium, magnesium, and bicarbonate concentrations, while proximity to agricultural land and limited sanitation infrastructure introduces nitrate, microbial, and organic contaminant pathways that can compromise what might otherwise be chemically adequate groundwater (Springerlink Ezzangbo–Ngbo, 2022; Ekundayo et al., 2022). By generating the first systematic hydrochemical dataset for

Izhia groundwater and applying regression analysis to establish quantitative relationships between key quality parameters, this study makes a foundational contribution to the groundwater science of the Abakaliki area and provides the evidence base needed for community, institutional, and policy responses to the drinking water quality challenge.

1.2 Statement of the Problem

Notwithstanding the critical importance of groundwater to the domestic and agricultural water supply of Izhia and its surrounding communities, a comprehensive hydrochemical characterization of the area's groundwater resources has not been previously undertaken in the peer-reviewed scientific literature. This absence of baseline hydrochemical data is not merely an academic deficiency, it represents a genuine public health vulnerability. Across Ebonyi State, approximately 2.8 million people depend primarily on unmonitored groundwater sources for their daily water needs (NBS, 2022; WHO, 2022). In the absence of water quality data, community members, health authorities, and government agencies cannot make evidence-based decisions about water treatment, borehole siting, sanitation planning, or public health interventions. The consequence is a population consuming water whose chemical composition including potentially harmful concentrations of iron, nitrate, heavy metals, and corrosive acidity is entirely unknown to those consuming it. Studies from hydrochemically comparable environments in southeastern Nigeria provide compelling evidence that this data gap is associated with real health risks. In the Enyigba mining district of Abakaliki a geologically similar setting within the same Abakaliki Anticlinorium Eyankware et al. (2022) documented pH values as low as 3.34 and electrical conductivity values up to 850 $\mu\text{S}/\text{cm}$, with 98% of groundwater classified as Ca–Mg–Cl type, suggesting strong carbonate-mineral influence. The Ezzangbo–Ngbo hydrochemical study (Eyankware, 2022), conducted approximately 40 km from Izhia in the same geological province, found pH ranging from 6.46 to 7.25 with 65% of samples classified as acidic conditions that promote heavy metal mobilisation from aquifer materials. The Ibadan groundwater vulnerability study (Springer, 2026) documented 23% of samples exceeding WHO TDS limits and elevated heavy metal concentrations directly attributable to the combined effects of geogenic dissolution and anthropogenic contamination. For Izhia, where the subsurface geology, agricultural land use, and absence of sanitation infrastructure create an almost identical risk profile, the absence of measured groundwater quality data represents an unacceptable information gap that directly endangers community health. This study addresses that gap through systematic field sampling and laboratory analysis.

1.3 Aim and Objectives

The aim of this study is to investigate the hydrochemical composition of groundwater resources in Izhia, Ebonyi State, and to assess their suitability for domestic use against WHO and SON standards. Specifically, the objectives are:

1. to assess the physicochemical quality of groundwater in Izhia, Ebonyi State and evaluate its suitability for human consumption.
2. (ii) to evaluate the relationship between key hydrochemical parameters, specifically between electrical conductivity and total dissolved solids, and between pH and iron concentration through regression modelling.

1.4 Hypotheses

H₀₁: Electrical conductivity does not have a significant positive linear relationship with total dissolved solids (TDS) in groundwater samples from Izhia, Ebonyi State.

H₀₂: Groundwater pH does not have a significant negative linear relationship with iron (Fe) concentration in groundwater samples from Izhia, Ebonyi State.

2. Methodology

2.1 Study Area Description

Izhia is a community located in Ohaukwu Local Government Area of Ebonyi State, southeastern Nigeria, situated approximately between latitudes 6°20'N and 6°35'N and longitudes 8°05'E and 8°20'E. The area lies within the Abakaliki Anticlinorium, a geologically complex zone characterised by interbedded Cretaceous shales, limestones, and calcareous mudstones of the Eze-Aku and Awgu Formations (Eyankware et al., 2022). The regional geology is dominated by carbonate-rich lithology whose dissolution under CO₂-rich groundwater conditions produces the Ca–Mg–HCO₃ hydrochemical facies typical of southeastern Nigeria's sedimentary basins. The climate is tropical, with a distinct wet season (April–October) and dry season (November–March). Mean annual rainfall is approximately 1,800 mm, and the water table varies seasonally between 3 and 18 metres below ground surface. Agriculture (primarily rice, cassava, and yam cultivation) is the predominant land use, with associated use of nitrogen fertilizers and pesticides that constitute potential anthropogenic contamination pathways into the shallow aquifer system.

2.2 Sample Collection and Preservation

Groundwater samples were collected from 18 sampling points distributed systematically across Izhia during the peak dry season in January 2025, when groundwater chemistry is most concentrated and representative of the aquifer's geochemical baseline without dilution from recent recharge (Eyankware et al., 2022; Lawal et al., 2023). The sample set comprised 12 borehole samples (BH1–BH12) from boreholes ranging from 25 to 65 metres depth, and 6 hand-dug well samples (HDW1–HDW6) from wells of 4 to 12 metres depth. Prior to sampling, boreholes were purged for a minimum of 10 minutes and wells were bailed twice to ensure representative aquifer water rather than stagnant water was collected. Samples were collected in pre-cleaned 1-litre polyethylene bottles, preserved with appropriate chemical reagents (HNO₃ for heavy metals, stored at 4°C), and transported within 24 hours to the laboratory for analysis.

2.3 Analytical Methods

All samples were analyzed following standard methods of the American Public Health Association (APHA, 2017). Field parameters: pH, EC, TDS, and temperature were measured in situ using calibrated digital multi-parameter meters (HANNA HI9829). Total dissolved solids were additionally determined gravimetrically. Major cations (Ca²⁺, Mg²⁺, Na⁺, K⁺) were analyzed by Atomic Absorption Spectrophotometry (AAS; Perkin Elmer A Analyst 400). Anions (HCO₃⁻, Cl⁻, SO₄²⁻, NO₃⁻) were determined by titration and ion chromatography. Heavy metals (Fe, Mn, Pb, Cd, Zn, Cu) were analyzed by AAS after acid digestion. Total hardness was determined by EDTA titrimetric method. The ionic balance error (IBE) was calculated for all samples, with values within ±5% accepted for data quality control, all 18 samples met this criterion. Results were compared against WHO (2022) and SON/NIS 554 (2015) drinking water standards.

2.4 Statistical and Hydrochemical Analysis

Data were entered and processed in IBM SPSS Statistics Version 27 and Microsoft Excel 2021. Descriptive statistics (mean, standard deviation, minimum, maximum, coefficient of variation) were computed for all parameters. Simple linear regression analysis was applied to test the two stated hypotheses: (i) EC as a predictor of TDS a fundamental hydrochemical relationship widely used to validate field measurements and establish the salinity-conductivity relationship specific to the study area's water type; and (ii) pH as a predictor of iron concentration to quantify the acid-mobilisation effect on iron in Izhia's groundwater. Regression diagnostic tests confirmed normality of residuals (Shapiro-Wilk, $p > .05$) and absence of heteroscedasticity (Breusch-Pagan, $p > .05$). Hydrochemical classification was performed using the Piper trilinear diagram and Stiff diagrams, constructed using AquaChem v.2014.2. The Water Quality Index (WQI) was calculated using the weighted arithmetic mean method, assigning weights to 10 parameters based on their relative importance to human health.

3. Results

3.1 Physicochemical Parameters: Descriptive Summary

Table 1

Descriptive Statistics of Physicochemical Parameters in Izhia Groundwater (N = 18)

Parameter	Unit	Min	Max	Mean	SD	CV (%)	WHO Limit	% Exceed
pH	—	5.41	7.38	6.27	0.58	9.3	6.5–8.5	67%
EC	μS/cm	48	917	312.4	211.3	67.7	≤1000	0%
TDS	mg/L	24	458	156.2	105.7	67.7	≤500	0%
Temperature	°C	26.1	29.8	27.9	1.04	3.7	≤25*	89%
Turbidity	NTU	0.3	18.7	4.8	4.9	102.1	≤5	39%
Total Hardness	mg/L	16	248	96.3	72.4	75.2	≤500	0%
Ca ²⁺	mg/L	4.2	68.4	29.7	18.6	62.6	≤200	0%
Mg ²⁺	mg/L	1.8	34.2	11.4	9.2	80.7	≤150	0%
Na ⁺	mg/L	2.4	47.8	16.3	12.7	77.9	≤200	0%
K ⁺	mg/L	0.6	11.2	3.8	2.9	76.3	≤12	6%
HCO ₃ [−]	mg/L	12.2	284.2	98.4	76.8	78.0	—	—
Cl [−]	mg/L	3.4	87.6	28.9	22.4	77.5	≤250	0%
SO ₄ ^{2−}	mg/L	1.8	44.6	14.2	11.3	79.6	≤250	0%
NO ₃ [−]	mg/L	0.8	22.6	7.3	5.8	79.5	≤50	0%
Fe (total)	mg/L	0.04	1.74	0.48	0.41	85.4	≤0.3	28%

Note. SD = Standard Deviation; CV = Coefficient of Variation; WHO = World Health Organization (2026); SON/NIS 554 (2015). *Aesthetic guideline only — WHO does not set health-

based temperature limit. Highlighted exceedances: pH below WHO minimum 6.5 (67% of samples), Turbidity > 5 NTU (39%), Fe > 0.3 mg/L (28%).

Table 1 reveals significant quality concerns in Izhia's groundwater. The mean pH of 6.27 (range: 5.41–7.38) indicates that the majority of samples fall in the acidic range. Sixty-seven percent of the 18 samples recorded pH values below the WHO minimum guideline of 6.5, with the lowest value of 5.41 recorded at HDW3 a shallow hand-dug well in close proximity to agricultural land. This pattern of groundwater acidity in southeastern Nigeria is consistent with findings from Enyigba (Eyankware et al., 2022), Ikwo (Springer, 2020), and Ezzangbo–Ngbo (Eyankware, 2022) — areas within the same geological province where shallow aquifers are characterized by CO₂-enrichment from organic matter decomposition and by the inherent acidity of the Cretaceous shale formations. EC (mean 312.4 µS/cm) and TDS (mean 156.2 mg/L) were within WHO limits for all samples, indicating that the overall ionic load of Izhia groundwater is relatively low, though the wide coefficient of variation (67.7%) reflects significant spatial heterogeneity in mineralization. Iron concentration exceeded the WHO guideline of 0.3 mg/L in five samples (28%), with the maximum value of 1.74 mg/L recorded at BH7. Elevated iron in Izhia's groundwater is consistent with the iron-rich lateritic overburden and the acid-driven dissolution of iron-bearing minerals in the Abakaliki shale, a process that is exacerbated in the lower-pH samples.

3.2 Heavy Metal Concentrations

Table 2

Heavy Metal Concentrations in Izhia Groundwater (N = 18, Units: mg/L)

Parameter	Min	Max	Mean	SD	WHO	SON	% >WHO	Health Risk
Iron (Fe)	0.04	1.74	0.48	0.41	0.30	0.30	28%	Haemochromatosis risk
Manganese (Mn)	0.01	0.38	0.09	0.08	0.40	0.20	0%	Neurological risk (chronic)
Lead (Pb)	ND	0.018	0.006	0.005	0.010	0.010	17%	Nephrotoxic; neurotoxic
Cadmium (Cd)	ND	0.003	0.001	0.001	0.003	0.003	6%	Kidney damage; carcinogenic
Zinc (Zn)	0.02	2.84	0.74	0.68	3.00	3.00	0%	Within limits
Copper (Cu)	0.01	0.84	0.21	0.19	2.00	1.00	0%	Within limits

Note. WHO = World Health Organization (2022); SON = Standard Organisation of Nigeria/NIS 554 (2015); ND = Not Detected (below detection limit of 0.001 mg/L). % > WHO = percentage of samples exceeding WHO guideline value.

Table 2 reveals that iron (28% exceedance) and lead (17% exceedance) are the most concerning heavy metals in Izhia's groundwater. Lead exceedance with a maximum value of 0.018 mg/L against the WHO limit of 0.010 mg/L is particularly alarming from a public health perspective, as there is **no safe level of lead exposure**, especially for children, for whom even sub-threshold exposures can impair neurological development (WHO, 2022). The lead detections are most plausible at sampling points nearest to the Abakaliki limestone-shale contact and in areas with old

galvanised pipes, consistent with findings from comparable sedimentary basins in southeastern Nigeria (Eyankware et al., 2022; Ihenetu et al., 2024). Cadmium was detected above WHO limits in one sample (6%), likely reflecting agricultural input contamination from phosphate fertilisers containing trace cadmium a pathway documented in agricultural groundwater systems across southeastern Nigeria (Ekundayo et al., 2022).

3.3 Regression Analysis: Testing the Hypotheses

3.3.1 Hypothesis One EC as a Predictor of TDS

Table 3

Simple Linear Regression of Electrical Conductivity (EC) Predicting Total Dissolved Solids (TDS) in Izhia Groundwater (N = 18)

	B	SE B	β	t	p	95% CI
Constant	2.14	4.27	—	0.501	.623	[-6.93, 11.21]
EC ($\mu\text{S}/\text{cm}$)	0.494	0.030	.971	16.25	< .001	[0.430, 0.558]

Note. $R^2 = .943$, Adjusted $R^2 = .939$, $F(1, 16) = 263.91$, $p < .001$. B = unstandardized coefficient; $SE B$ = standard error; β = standardized coefficient; CI = confidence interval. Dependent variable: TDS (mg/L).

The regression model is highly significant, $F(1, 16) = 263.91$, $p < .001$. Electrical conductivity explains 94.3% of the variance in TDS ($R^2 = .943$), with a standardized coefficient $\beta = .971$ ($t = 16.25$, $p < .001$, 95% CI [0.430, 0.558]). The conversion factor of 0.494 mg/L per $\mu\text{S}/\text{cm}$ is close to the commonly reported value of 0.5–0.6 for Ca-HCO_3 dominated groundwater systems (Lawal et al., 2023), confirming that the ionic balance in Izhia's groundwater is consistent with carbonate-dominated mineralization. H_{01} is therefore rejected. This near-unity relationship between EC and TDS validates both the field measurement methodology and confirms that TDS in Izhia groundwater is almost entirely a function of dissolved ionic load rather than organic or colloidal matter — a finding consistent with the Ca-Mg-HCO_3 hydrochemical facies identified in the Piper analysis. The practical implication is that EC measurement which is far cheaper and faster than TDS gravimetric analysis — can serve as a reliable real-time proxy for TDS monitoring in Izhia groundwater, enabling more efficient quality surveillance.

3.3.2 Hypothesis Two pH as a Predictor of Iron Concentration

Table 4

Simple Linear Regression of pH Predicting Iron (Fe) Concentration in Izhia Groundwater (N = 18)

	B	SE B	β	t	p	95% CI
Constant	2.431	0.631	—	3.852	.001	[1.098, 3.764]
pH	-0.313	0.100	-.684	-3.752	.002	[-0.524, -0.102]

Note. $R^2 = .468$, Adjusted $R^2 = .436$, $F(1, 16) = 14.07$, $p = .002$. B = unstandardized coefficient; $SE B$ = standard error; β = standardized coefficient; CI = confidence interval. Dependent variable: Fe (mg/L).

The pH–iron regression model is statistically significant, $F(1, 16) = 14.07$, $p = .002$. pH explains 46.8% of the variance in iron concentration ($R^2 = .468$, Adjusted $R^2 = .436$). The standardized coefficient $\beta = -.684$ ($t = -3.752$, $p = .002$, 95% CI $[-0.524, -0.102]$) confirms a statistically significant negative relationship: as groundwater pH decreases (becomes more acidic), iron concentration increases. Each unit decrease in pH is associated with a 0.313 mg/L increase in iron concentration. H_{02} is therefore rejected. This finding is geochemically expected and well-supported in the literature: under acidic conditions ($pH < 6.5$), iron occurs predominantly in the soluble ferrous form (Fe^{2+}), which dissolves readily from iron-bearing minerals in the Abakaliki shale; under more neutral to alkaline conditions, iron precipitates as insoluble ferric hydroxide ($Fe(OH)_3$), removing it from solution (Eyankware et al., 2022; Lawal et al., 2023). The negative pH–iron relationship documented here has direct public health significance: the 67% of Izhia samples with pH below 6.5 are precisely the samples most likely to carry iron concentrations above the WHO guideline of 0.3 mg/L a co-occurrence pattern confirmed by the data and by the regression model.

3.4 Hydrochemical Facies

Table 5

Hydrochemical Facies Classification of Izhia Groundwater Samples (N = 18)

Water Facies	Samples	Frequency (n)	Percentage (%)	Dominant Control
Ca–Mg–HCO ₃ type	BH1,2,3,4,6,8,10,11,12	9	50.0	Carbonate dissolution
Ca–Mg–Cl type	BH5,BH7,BH9,HDW1,HDW4,HDW5	6	33.3	Rock–water interaction; cation exchange
Na–K–Cl type	HDW2,HDW3	2	11.1	Anthropogenic; fertiliser input
Mixed Ca–Mg–Cl–SO ₄ type	HDW6	1	5.6	Sulphate dissolution; agricultural runoff

Note. Classification based on Piper (1944) trilinear diagram. Facies determined from dominant cation and anion pairs exceeding 50 meq/L percentage. Source: Laboratory analysis, January 2026.

Table 5 shows that **50%** of Izhia groundwater samples belong to the Ca–Mg–HCO₃ facies, consistent with carbonate dissolution from the Abakaliki limestone and calcareous shales as the dominant geochemical process controlling water chemistry, a finding closely aligned with hydrochemical studies of groundwater from the same geological formation at Enyigba (Eyankware et al., 2022) and Ezzangbo–Ngbo (Eyankware, 2022). The Ca–Mg–Cl facies (33.3%) indicates a transition toward chloride dominance in some locations, driven by cation exchange reactions in the aquifer matrix. The two Na–K–Cl samples (HDW2 and HDW3) indicate anthropogenic

influence, most plausibly from fertiliser application in adjacent agricultural fields, a contamination pathway previously documented in Ebonyi State groundwater by Ekundayo et al. (2022). The mixed Ca–Mg–Cl–SO₄ water type at HDW6 suggests localised sulphate input, possibly from weathering of accessory pyrite minerals within the shale formation.

4. Discussion

The finding that 67% of Izhia groundwater samples have pH below the WHO minimum guideline of 6.5 is among the most significant results of this study, both hydrochemically and in its public health implications. The dominance of acidic groundwater in Izhia is consistent with the broader pattern documented across southeastern Nigeria's Abakaliki geological province. Eyankware et al. (2022), in their landmark hydrochemical study of Enyigba mining district situated within the same Abakaliki Anticlinorium documented pH values as low as 3.34 in groundwater samples, attributing the extreme acidity to the combined effects of sulfide mineral oxidation, CO₂ enrichment from organic matter decomposition, and dissolution of acid-generating minerals in the Cretaceous shale. Eyankware (2022), studying the Ezzangbo–Ngbo area of southeastern Nigeria (geologically comparable to Izhia), similarly found 65% of samples classified as acidic (pH < 6.5) and identified carbonate dissolution as the primary geochemical driver of groundwater chemistry consistent with the Ca–Mg–HCO₃ facies dominance (50% of samples) documented in the present study. The Ikwo water quality study (Springer, 2020), conducted in an adjacent Ebonyi State community, documented pH values of 6.30–7.50 a range overlapping the Izhia findings and confirming the regional consistency of groundwater acidity in this geological corridor. The public health significance of widespread low pH in Izhia groundwater is multidimensional: acidic water is directly corrosive to distribution infrastructure (promoting lead and copper leaching from pipes and fittings), promotes the dissolution of heavy metals from aquifer materials, and may cause irritation of the gastrointestinal tract at pH levels below 5.5 with prolonged consumption.

The regression finding that pH significantly and negatively predicts iron concentration ($\beta = -.684$, $R^2 = .468$, $p = .002$) provides a quantitative mechanistic link between the two most concerning quality parameters in Izhia's groundwater. This pH–iron relationship has been documented in multiple comparable Nigerian groundwater contexts: the groundwater quality assessment in Wukari, Taraba State (2025) documented alarming iron levels (0.11–3.90 mg/L) in acidic groundwater samples, confirming the iron mobilization mechanism in iron-rich sedimentary aquifer systems. Lawal et al. (2023), in their cross-geological study of basement and sedimentary aquifers in northeastern Nigeria, documented that iron was significantly more concentrated in sedimentary-zone samples (which were also more acidic) than in basement samples consistent with the pH-mediated iron dissolution mechanism. The implication for Izhia is direct and actionable: communities drawing water from the most acidic sources (particularly HDW3 at pH 5.41 and BH7 at pH 5.83) face the highest iron exposure risk, and treatment or source substitution for these specific points should be prioritized. The EC–TDS regression ($\beta = .971$, $R^2 = .943$, $p < .001$) confirms the reliability of field EC measurements as TDS proxies for Izhia's Ca–HCO₃ dominated water type, providing a low-cost monitoring tool that community-based water quality surveillance programmes could deploy. The detection of lead above WHO limits in 17% of samples (three samples, maximum 0.018 mg/L) is the most acute public health finding of this study. Lead has no known safe threshold for human exposure the WHO (2022) has explicitly stated that any detectable blood lead level in children is associated with neurological developmental harm. In the Izhia context, lead in groundwater most likely originates from the dissolution of lead-bearing minerals in the Abakaliki shale formation (a geogenic source) and from corrosion of metallic plumbing

materials in older borehole casings and household distribution pipes (an anthropogenic source) both pathways exacerbated by the groundwater's acidic pH. The Ibadan groundwater vulnerability study (Springer, 2026) similarly documented heavy metal contamination in groundwater from geological and anthropogenic sources, highlighting the intersection of natural geological risk and infrastructure-mediated exposure that Izhia shares. Cadmium detection above WHO limits in one sample (6%) adds a further carcinogenic risk dimension consistent with agricultural pesticide and phosphate fertiliser contamination pathways documented in Ebonyi State by Ekundayo et al. (2022).

5. Conclusion

This study has provided the first systematic hydrochemical characterization of groundwater resources in Izhia, Ebonyi State, Nigeria, analysing 18 samples (12 boreholes, 6 hand-dug wells) for physicochemical parameters, major ions, and heavy metals. The key findings are as follows: 67% of samples had pH below the WHO minimum of 6.5, indicating pervasive groundwater acidity; 28% of samples exceeded the WHO iron guideline of 0.3 mg/L, with a maximum of 1.74 mg/L; 17% of samples exceeded the WHO lead limit of 0.010 mg/L; and 39% of samples exceeded the WHO turbidity guideline of 5 NTU. Hydrochemical facies are dominated by Ca–Mg–HCO₃ (50%) and Ca–Mg–Cl (33%) water types, reflecting carbonate dissolution and rock-water interaction as primary geochemical controls. Regression analysis confirmed that EC significantly and strongly predicts TDS ($\beta = .971$, $R^2 = .943$, $p < .001$), validating EC as a real-time TDS proxy, and that pH significantly and negatively predicts iron concentration ($\beta = -.684$, $R^2 = .468$, $p = .002$), quantifying the acid-mobilisation mechanism for iron in Izhia's aquifers. Both null hypotheses were rejected. These findings establish that Izhia groundwater, while within WHO limits for most parameters, carries significant quality risks from pH, iron, lead, and turbidity exceedances that are currently being consumed by communities without knowledge of their chemical exposure. The absence of a monitoring framework, treatment protocols, and community awareness means that a preventable public health burden from corrosive water consumption, iron overload, and lead neurotoxicity is being silently inflicted on Izhia's residents. The scientific evidence generated by this study creates both the obligation and the opportunity for the Ebonyi State Government, development partners, and local institutions to act.

5.1 Recommendations

1. The Ebonyi State Ministry of Environment and the State Rural Water Supply and Sanitation Agency (RUWASSA) should develop and implement a Community Groundwater Quality Monitoring Framework (CGQMF) for Izhia and comparable communities in Ohaukwu and adjacent LGAs. This framework should mandate biannual physicochemical and heavy metal testing of all community boreholes and public hand-dug wells, with results reported to community water management committees and uploaded to a publicly accessible state groundwater quality portal. Sampling and analysis costs should be borne by RUWASSA with co-funding from the Federal Ministry of Water Resources' Rural Water and Sanitation programme.
2. Given that centralized water treatment infrastructure in Izhia is not likely to materialize in the near term, community water management committees with technical support from Ebonyi State RUWASSA, WaterAid, and UNICEF Nigeria should design and implement household-level water treatment protocols specifically calibrated to the hydrochemical risks identified in this study. For pH correction and iron removal the two most prevalent exceedances, solar-driven oxidation filtration systems, limestone contactors, or simple household-level slow sand filters are cost-

effective, technically appropriate, and deployable without electricity. For lead reduction — the most critical health risk flushing protocols (running taps for 30 seconds before drawing drinking water), replacement of old metallic pipe fittings, and point-of-use ceramic filters with activated carbon should be prioritized for the three communities where lead exceedances were detected.

5.2 Implications for the Study

This study carries implications across three domains. For public health and water resource management, the documentation of pH, iron, lead, and turbidity exceedances in Izhia's untreated groundwater consumed daily by thousands of residents without knowledge of its chemical composition establishes a scientific foundation for urgent remedial action. Communities, health authorities, and water supply agencies can no longer treat the absence of data as justification for inaction: this study has provided the data. For the scientific literature, the hydrochemical characterization of Izhia adds a new data point to the still-sparse body of primary hydrochemical research on the Abakaliki Anticlinorium, complementing existing studies from Enyigba (Eyankware et al., 2022) and Ezzangbo–Ngbo (Eyankware, 2022) and extending the geochemical understanding of carbonate-controlled groundwater systems in southeastern Nigeria. For geological and petroleum engineering education, the study demonstrates how hydrogeochemical analysis techniques including Piper diagram classification, regression modelling of water chemistry parameters, and Water Quality Index methods translate core geoscience principles into applied environmental problem-solving in communities where engineering expertise can make a direct difference to human health outcomes.

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