Spatial Variability and Physicochemical Quality of Borehole Water in Anambra State, Nigeria: Assessment of Compliance with International Drinking-Water Standards and Public Health Implications

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ABSTRACT

Physicochemical monitoring is needed to distinguish chemically acceptable borehole supplies from those requiring corrective action. This study assessed geographic variation and conformity with World Health Organization (WHO) drinking-water guidance using the physicochemical component of a cross-sectional investigation in Anambra State, Nigeria. Sixty boreholes were sampled once across nine communities in Awka South and Nnewi North local government areas. Sample-level appendix records were reanalysed for descriptive statistics and benchmark exceedances. Community comparisons were reconstructed from reported group sizes, means, and standard deviations using Welch analysis of variance with Holm adjustment. Mean pH was 5.17 ± 0.73, and 57 samples (95.0%) were below the operational reference of 6.5. Reported lead exceeded the provisional 0.01 mg/L guideline in 40 samples (66.7%; 95% CI [54.1%, 77.3%]), while manganese exceeded 0.08 mg/L in 12 (20.0%; 95% CI [11.8%, 31.8%]). Neither nitrate nor nitrite individually exceeded its guideline, but one record exceeded the combined nitrate–nitrite ratio criterion. Eleven of 15 measured parameters showed exploratory community differences after adjustment; evidence was insufficient for pH, temperature, lead, and manganese. Data checks identified sulphate concentrations greater than reported total dissolved solids in 42 records The findings prioritize confirmatory lead and manganese monitoring and assessment of acidic supplies. Geographic patterns are community comparisons rather than geostatistical clusters. The study does not establish attributable disease or statewide prevalence.

Keywords: groundwater, borehole water, physicochemical quality, spatial variability, lead, manganese, Anambra State

INTRODUCTION

Boreholes are important drinking-water sources, but their chemical suitability cannot be determined from source type or visual appearance alone. Water chemistry reflects subsurface conditions and may also change during abstraction, storage, and distribution. A useful assessment therefore distinguishes constituents of direct health concern from parameters that principally affect treatment, corrosion, or consumer acceptability. It must also identify whether a geographic difference is large enough to inform management, rather than treating every statistically detectable difference as evidence of a health hazard.

Evidence from Anambra State supports location-specific investigation. Akudu et al. (2024) assessed groundwater from industrial cluster areas over rainy and dry periods and reported variation in physicochemical characteristics. Eboagu et al. (2023) examined 16 borehole sampling sites around eight industries in Nnewi over 12 months, documenting a range of physicochemical conditions. Ezeudu et al. (2024) investigated 12 boreholes in Oba and reported trace-metal contamination alongside other parameters within the comparison standards. These studies suggest that conventional indicators and trace metals can

present different patterns. Their findings do not, however, establish the quality of supplies in other communities or justify assuming that industrial activity caused contamination in every sampled borehole. Research in the western Niger Delta has assessed physicochemical and bacteriological contaminants together (Ocheli et al., 2020).

International guidance provides a framework for interpretation, but not every numerical value commonly reproduced in water-quality tables is a health-based limit. The World Health Organization (WHO, 2026) distinguishes health guidance, operational considerations, and acceptability. This matters when interpreting acidic water, iron staining, low mineral content, and trace-metal exceedances. The provisional lead value of 0.01 mg/L is based on treatment performance and analytical achievability rather than a demonstrated harmless exposure threshold. WHO's dedicated lead guidance emphasizes monitoring and control of lead-containing materials (WHO, 2022b). Manganese also requires attention because the provisional 0.08 mg/L value is intended to protect sensitive populations, particularly bottle-fed infants (WHO, 2021).

Geographic analysis can help direct limited surveillance resources, provided the scale of inference is clear. Community-level means describe differences between sampled places. They do not establish aquifer-wide contamination zones, spatial autocorrelation, or causal pathways without coordinates, hydrogeological information, and appropriate models. Similarly, a pooled mean below a guideline may conceal individual exceedances.

This manuscript reports the physicochemical component of Ogamba's (2026) doctoral investigation. The objectives were to describe measured water chemistry, compare individual records with applicable international drinking-water guidance, and examine variation among nine communities. Public health implications were evaluated as exposure concerns and management priorities rather than measured clinical effects.

MATERIALS AND METHODS

Study design and setting

The thesis used a cross-sectional design combining water sampling, environmental observation, and questionnaires. This paper focuses on the physicochemical laboratory results from 60 boreholes in Awka South and Nnewi North local government areas, Anambra State, southeastern Nigeria. The sampled communities were Amawbia, Awka, Mbaukwu, Nibo, Nise, Nnewichi, Otolo, Umudim, and Uruagu. Each borehole was sampled on one occasion.

Sampling and unit of analysis

There was a multistage selection of senatorial districts, local government areas, villages, and households. Households without boreholes were skipped; where a household contained more than one borehole, one was selected. Thirty boreholes were sampled in each local government area. Community sample sizes ranged from three to 13 (Table 3). The unit of analysis was the borehole, not a technical replicate or questionnaire respondent.

The sample-size calculation did not constitute a separate precision calculation for the 60 boreholes. Accordingly, the estimates describe the sampled supplies and are not design-based estimates for all boreholes in Anambra State. Community membership was used as the geographic grouping variable; sample-to-community assignments were reconstructed by assuming that adjacent appendix rows belonged to the same community.

Collection and laboratory procedures

Water was collected from outlets after approximately 3–5 minutes of flushing. The thesis describes cleaned sample bottles, nitric-acid treatment of collection containers, and transport to the laboratory under cooling within six hours.

The reported pH procedure used an electrometric meter, identified as a Hanna HI991300. Turbidity was measured using an AQ4500 instrument with reference to an EPA 180 method. Chloride was determined by argentometric titration, hardness by EDTA titration, and nitrate by a phenol-disulphonic-acid spectrophotometric procedure read at 410 nm.

Sulphate was as a barium sulphate gravimetric determination. Metals were examined by atomic absorption spectrometry following nitric-acid digestion; wavelengths were reported as 283.3 nm for lead, 285.2 nm for magnesium, 279.5 nm for manganese, and 248.4 nm for iron.

Both AA220 and AA240 instrument models describe TDS using both a digital tester and an evaporation/residue procedure. Separate reproducible procedures for colour, temperature, sodium, and nitrite are specified in the supplied methods.

Extraction and consistency checks

Fifteen quantitative parameters were extracted: pH, colour, temperature, turbidity, chloride, hardness, iron, lead, magnesium, manganese, nitrate, nitrite, sodium, sulphate, and TDS. Values preceding ± in the physical and chemical appendix tables were treated as reported borehole-level estimates. The dispersion terms were not counted as independent observations. Numerical analyses were implemented in Python and checked using SciPy.

The chemical appendix contains 60 rows but repeats the identifier 58, with no row labelled 59. Its limit row also uses mg/mL where Chapter 4 presents concentrations in mg/L. The analyses retained all 60 rows in their printed order and adopted mg/L provisionally because that unit is used consistently in the main results and concentration descriptions.

International guideline comparison

The comparison used WHO guidance available at manuscript preparation in November 2026. Lead and manganese were assessed against provisional values of 0.01 and 0.08 mg/L, respectively. Nitrate and nitrite were assessed as ions against 50 and 3 mg/L. Their joint criterion was calculated as $R = C(\text{nitrate})/50 + C(\text{nitrite})/3$, with $R > 1$ classified as an exceedance

Operational and acceptability comparisons were kept separate from health-guideline exceedances. A pH below 6.5 was summarized relative to the lower end of the usual operational range, without treating this as a WHO health-based limit (WHO, 2022a).

Iron above 0.3 mg/L was counted as an acceptability concern. Parameters without an applicable WHO health-based value were described rather than declared compliant with an invented health standard. WHO guidance was used as an international benchmark, not presented as a legally enforceable Nigerian standard.

Statistical analysis

For each parameter, arithmetic means, sample standard deviations, and observed ranges were calculated across 60 records. Exceedance proportions were calculated using strict greater-than comparisons with the relevant guideline; equality was recorded separately where important. Wilson 95% confidence intervals summarize binomial uncertainty, assuming independent records. They do not incorporate selection probabilities, clustering, laboratory uncertainty, or repeated temporal measurements. The confidence interval calculation follows Wilson (1927).

Welch's unequal-variance analysis of variance was reconstructed from the nine group sizes, means, and standard deviations (Welch, 1951). It was preferred to the thesis's pooled-variance analysis because group sizes and reported dispersions differed. Holm adjustment was applied to the family of 15 Welch tests at an overall .05 level (Holm, 1979). Conventional ANOVA was reconstructed as a sensitivity analysis. No unsupported pairwise significance, equivalence, or source attribution was inferred from an omnibus result. Small groups and unavailable distributional diagnostics make all community tests exploratory.

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Spatial variability in this paper means geographic variation among named communities. No interpolation, Moran's I, variogram, or hotspot test was performed because georeferenced source-level data were unavailable.

A community profile figure was used to display measured summaries without implying unsampled geographic coverage. Hydrochemical facies, ionic charge balance, and corrosion saturation indices were not calculated because the necessary validated analytes were incomplete.

Ethics and relationship to other reporting

The thesis contains participant-information and consent materials. Ethical permission was granted by Abia State University Research Ethical Clearance Committee (ABSU/REC/PG/PHDPH/002) of 19th November 2025.

RESULTS

Overall physicochemical characteristics

Mean pH was 5.17 ± 0.73, with values from 3.87 to 7.77. Fifty-seven of 60 records (95.0%) were below 6.5, while three were within 6.5–8.5. Mean turbidity was 2.59 ± 1.01 NTU, with values of 1.00–5.00 NTU. Colour ranged from 1.03 to 5.00 TCU, and temperature from 30.00 to 36.47 °C. These physical measurements do not establish chemical safety.

Reported TDS averaged 67.84 ± 79.84 mg/L, whereas sulphate averaged 78.83 ± 16.65 mg/L. Lead averaged 0.0262 ± 0.0234 mg/L, with a maximum of 0.110 mg/L. Manganese averaged 0.0443 ± 0.0490 mg/L and reached 0.210 mg/L. Full descriptive results are presented in Table 1.

Table 1 Overall physicochemical results.

Parameter	Unit	Mean ± SD	Observed range
pH	—	5.17 ± 0.73	3.87–7.77
Colour	TCU	2.54 ± 0.83	1.03–5.00
Temperature	°C	33.23 ± 1.64	30.00–36.47
Turbidity	NTU	2.59 ± 1.01	1.00–5.00
Chloride	mg/L	29.83 ± 22.91	2.10–126.00
Hardness	mg/L	28.35 ± 31.58	2.06–145.67
Iron	mg/L	0.1645 ± 0.1823	0.0000–0.8600
Lead	mg/L	0.0262 ± 0.0234	0.0000–0.1100
Magnesium	mg/L	1.827 ± 1.731	0.007–8.271
Manganese	mg/L	0.0443 ± 0.0490	0.0000–0.2100
Nitrate	mg/L	7.77 ± 5.58	0.10–29.21

Nitrite	mg/L	0.389 ± 0.278	0.010–1.440
Sodium	mg/L	1.16 ± 0.69	0.03–2.48
Sulphate	mg/L	78.83 ± 16.65	40.45–129.81
TDS	mg/L	67.84 ± 79.84	5.10–384.00

Note. SD = sample standard deviation. Values are reported measurements.

Conformity with international guidance

Forty records (66.7%; 95% CI [54.1%, 77.3%]) were above 0.01 mg/L lead. Thirteen were reported exactly at 0.01 mg/L and seven below it. Values printed as 0.00 were not interpreted as confirmed absence of lead because reporting and detection limits were unspecified. The overall lead mean was 2.62 times the provisional value, equivalent to 162% above it, rather than 260% above it.

Twelve records (20.0%; 95% CI [11.8%, 31.8%]) were above the provisional manganese value of 0.08 mg/L. Forty-seven records (78.3%) exceeded at least one of the lead or manganese values; five exceeded both. This is a comparison of reported concentrations with selected guidelines, not proof of a clinical outcome or a complete chemical-safety classification.

Neither nitrate nor nitrite individually exceeded 50 or 3 mg/L. Nevertheless, the third printed chemical record contained nitrate of 29.21 mg/L and nitrite of 1.44 mg/L, producing R = 1.0642.

It was the only record above the joint criterion. Ten records exceeded the iron acceptability reference of 0.3 mg/L. Counts and their interpretation are summarized in Table 2.

Table 2 Guideline comparisons and operational observations

Parameter	**Reference**	**Outside reference, n (%)**	**95% CI, %**	**Interpretation**
Lead	0.01 mg/L	40 (66.7)	54.1–77.3	Provisional value
Manganese	0.08 mg/L	12 (20.0)	11.8–31.8	Provisional value
Nitrate	50 mg/L	0 (0.0)	0.0–6.0	As nitrate ion
Nitrite	3 mg/L	0 (0.0)	0.0–6.0	As nitrite ion
Combined nitrogen species	$R \leq 1$	1 (1.7)	0.3–8.9	Ion basis assumed
pH	6.5–8.5	57 (95.0)	86.3–98.3	Below 6.5; operational
Iron	0.3 mg/L	10 (16.7)	9.3–28.0	Acceptability reference

Note. N = 60. Proportions use printed values and unadjusted Wilson intervals. Strict > defines chemical exceedance; pH entries count values below 6.5. R = nitrate/50 + nitrite/3, with ion concentrations in mg/L. The upper Wilson bound for zero of 60 is 6.0%. Sources: WHO (2016, 2021, 2022a, 2026). These rows are not interchangeable measures of health risk.

Geographic variation among communities

All nine community mean lead concentrations were above 0.01 mg/L, ranging from 0.0144 mg/L in Otolo to

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0.0443 mg/L in Nibo. This does not mean every borehole exceeded the value. Community mean manganese was highest in Mbaukwu (0.1310 mg/L) and Nibo (0.1180 mg/L); the other seven means were below 0.08 mg/L.

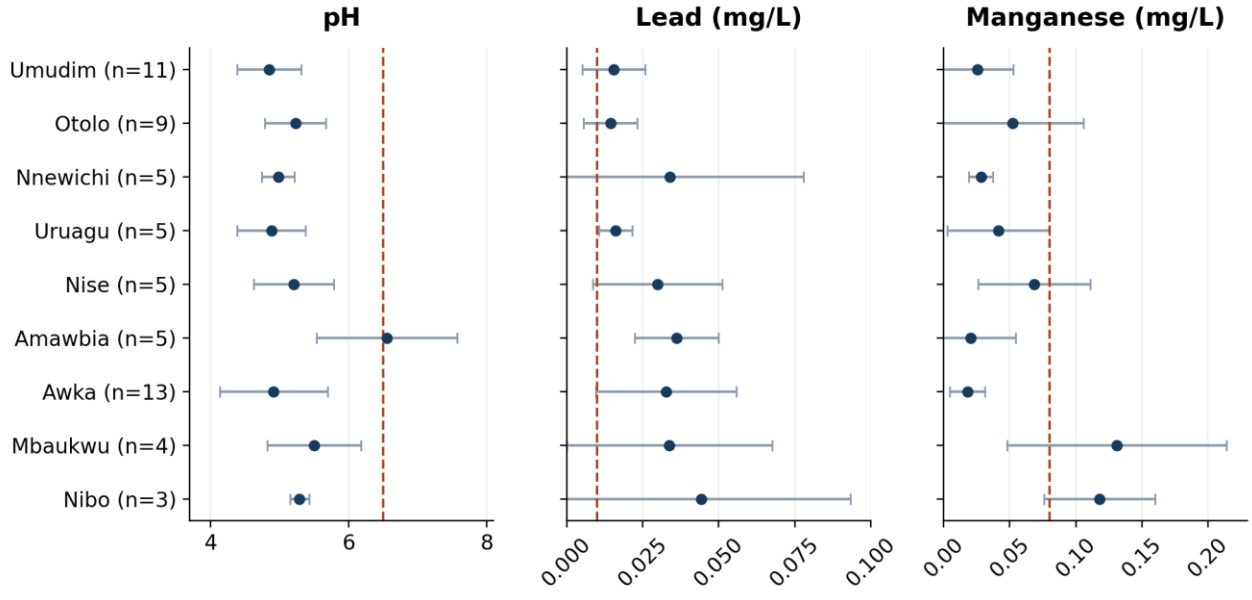
Amawbia had the highest reported mean pH (6.55), whereas the other community means ranged from 4.85 to 5.50. Reported mean iron was highest in Amawbia (0.458 mg/L) and Awka (0.317 mg/L). Mean TDS was highest in Awka (175.31 mg/L), followed by Amawbia (117.60 mg/L), with appreciable within-community dispersion. Table 3 and Figure 1 present these descriptive profiles; they are not pairwise significance rankings.

Table 3 Reported community means for selected physicochemical parameters

Community	n	pH	Lead	Manganese	Iron	TDS
Umudim	11	4.85	0.0155	0.0256	0.024	46.56
Otolo	9	5.23	0.0144	0.0522	0.098	12.62
Nnewichi	5	4.98	0.0340	0.0282	0.042	17.66
Uruagu	5	4.88	0.0160	0.0414	0.122	27.83
Nise	5	5.21	0.0298	0.0686	0.126	25.60
Amawbia	5	6.55	0.0362	0.0204	0.458	117.60
Awka	13	4.91	0.0326	0.0180	0.317	175.31
Mbaukwu	4	5.50	0.0338	0.1310	0.092	34.75
Nibo	3	5.29	0.0443	0.1180	0.167	27.67

Note. All concentrations except pH are in mg/L. Means and group sizes are reproduced from the community summaries. Awka South includes Amawbia, Awka, Mbaukwu, Nibo, and Nise; Nnewi North includes Nnewichi, Otolo, Umudim, and Uruagu.

Figure 1 Community profiles of pH lead and manganese



Note. Points show reported community means; bars show ±1 SD, not confidence intervals. Dashed lines mark pH 6.5 (operational reference), lead 0.01 mg/L, and manganese 0.08 mg/L. Community order is categorical and does not represent geographic distance. Negative lower SD bounds for metals are clipped at zero for display.

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After Holm adjustment, exploratory Welch tests identified community differences in colour, turbidity, chloride, hardness, iron, magnesium, nitrate, nitrite, sodium, sulphate, and TDS. Adjusted evidence was insufficient for pH ($p = .143$), temperature ($p = .054$), lead ($p = .143$), and manganese ($p = .079$). The conventional pooled-variance analysis produced nominal $p < .05$ for 14 parameters, with lead the exception. The change in conclusions, especially for pH, illustrates sensitivity to variance assumptions and multiple testing. Non-significance does not demonstrate equal concentrations or equivalent exposure across communities.

Table 4 Exploratory community comparisons using Welch analysis of variance

Parameter	Welch F	Denominator df	Unadjusted p	Holm-adjusted p
pH	2.312	16.47	.071	.143
Colour	3.868	16.55	.010	.048
Temperature	3.795	14.48	.013	.054
Turbidity	4.948	14.47	.004	.025
Chloride	4.884	16.94	.003	.021
Hardness	17.414	15.31	< .001	< .001
Iron	6.019	14.18	.002	.014
Lead	1.952	14.52	.128	.143
Magnesium	26.076	15.77	< .001	< .001
Manganese	3.214	14.28	.026	.079
Nitrate	17.188	15.88	< .001	< .001
Nitrite	16.615	15.88	< .001	< .001
Sodium	27.748	15.82	< .001	< .001
Sulphate	5.567	16.87	.001	.013
TDS	7.273	15.85	< .001	.004

Note. Numerator df = 8 for all tests. Tests were reconstructed from nine reported group means, standard deviations, and sample sizes. Holm adjustment covers all 15 parameters; adjusted $p < .05$ identifies an exploratory difference. Summary rounding and unavailable diagnostics limit precision and interpretation. No pairwise significance is implied.

DISCUSSION

This assessment identifies three management-relevant findings. Recorded lead and manganese values exceeded applicable provisional guidance in substantial subsets of the sample. Acidity was widespread relative to an operational reference. Community profiles varied, but the strength of statistical evidence depended on variance assumptions and multiplicity adjustment.

The lead findings deserve particular attention because a reassuring pooled mineral profile would not negate an individual trace-metal exceedance. Ezeudu et al. (2024) reported trace-metal contamination in Oba even where several other physicochemical indicators met their comparison standards. The present results reinforce the need to examine metals directly rather than infer suitability from general water appearance or a small group of conventional parameters. The two studies cannot establish a common contamination source or a statewide prevalence because their locations, samples, and analytical frameworks differ.

The mean lead concentration in the current records exceeds the provisional benchmark, and all nine community means lie above it. However, the 40 individual exceedances provide a more informative management endpoint than the community means alone. The 13 records reported exactly at the guideline also require attention to laboratory precision and the absence of a demonstrated harmless lead threshold. A rounded concentration at the benchmark should not be treated as proof of zero concern.

WHO's lead technical brief emphasizes investigation of the water supply and materials in contact with water (WHO, 2022b). Here, the flushed-outlet protocol does not distinguish aquifer contamination from release through pumps, tanks, fittings, or pipes, and it does not estimate first-draw exposure after stagnation. Paired source and outlet samples, together with inspection of materials and a defined lead-sampling protocol, would better locate the point of entry. The present evidence does not justify attributing the lead solely to geological formations, industrial discharge, or plumbing. A study in Washington, DC, linked periods of elevated lead in drinking water with elevated blood lead levels in young children (Edwards et al., 2009). A pooled analysis also found an association between lead exposure and lower intellectual test scores among children with maximum measured blood lead concentrations below 7.5 μg/dL (Lanphear et al., 2005).

Manganese interpretation changes when the correct provisional value is used. The thesis's 0.2 mg/L comparison misses exceedances captured at 0.08 mg/L. Although the pooled manganese mean is below the latter value, 12 individual records exceed it. The higher reported means in Mbaukwu and Nibo are useful for prioritizing confirmation, but the adjusted omnibus test did not establish geographic differences at .05. A potential public health concern can therefore exist without statistically conclusive differentiation among communities.

The WHO manganese assessment identifies neurological effects and particular concern for bottle-fed infants as reasons for protective guidance (WHO, 2021). The present study measured neither infant intake nor neurological outcomes, so it cannot establish toxicity among consumers. Its contribution is to identify reported concentrations warranting verification and exposure prevention. Higher manganese exposure from drinking water was associated with lower intellectual test scores in a study of school-age children (Bouchard et al., 2011). A survey of rural handpump boreholes in Ethiopia, Malawi, and Uganda also documented manganese exceedances under the WHO benchmark used at the time (Lapworth et al., 2020).

The low pH findings are operationally important but should not be translated into a diagnosis. WHO provides no health-based guideline value for pH (WHO, 2022a). Thus, a pH below 6.5 does not by itself establish systemic acidosis, chronic poisoning, or an attributable disease burden. In this dataset, the appropriate concern is the potential effect of acidic water on supply management and material compatibility. Co-occurrence of low pH and lead warrants investigation, but corrosion was not established by a measured corrosion rate, saturation index, or material-release test.

The regional literature also cautions against reducing water quality to a single mean. Akudu et al. (2024) examined seasonal physicochemical variation across industrial cluster areas, while Eboagu et al. (2023) used 12 months of observations around Nnewi industries. Both designs capture temporal information absent from the present single-visit survey. Their results provide context for heterogeneity, not a basis for claiming that concentrations here are higher, lower, or worsening over time. Comparable repeated sampling and harmonized laboratory methods would be needed for those conclusions. Dry- and rainy-season sampling in Ogbaru provides a local precedent for repeating measurements across seasons (Onuorah et al., 2019).

Nitrogen-species interpretation differs from the thesis narrative. No printed nitrate or nitrite value individually exceeds current ion-based guidance, but the combined calculation flags one record. WHO's nitrate–nitrite background assessment explains the importance of simultaneous exposure and the distinction

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between ion and nitrogen units (WHO, 2016). Accordingly, both the joint criterion and laboratory reporting basis must be retained in the final analysis. The near-proportional nitrate and nitrite pattern makes verification especially important; it cannot be used as independent confirmation of a nitrogen-pollution pathway. Ion chromatography provides a method for separately measuring nitrate, nitrite, chloride, and sulphate in confirmatory samples (Pfaff, 1993).

Meaning of the spatial findings

The geographic results support different monitoring priorities across communities, but they remain exploratory. The nine groups contain only three to 13 boreholes, with unequal dispersions. Welch testing and Holm adjustment reduce reliance on equal variances and uncorrected multiple comparisons, but cannot compensate for an incomplete sampling frame, outliers, or unknown source clustering. Colour's adjusted result is close to .05 and should receive less emphasis than the magnitude and practical relevance of the measurements.

Descriptive rankings are not inferential statements about particular pairs of communities. Nor does the absence of adjusted significance for lead indicate equal exposure. Large within-community variation, imprecision, and limited sample size can coexist with community means above a guideline. No contamination map or hotspot surface can be justified from named communities alone. Assigning community centroids to boreholes would create false positional precision. A subsequent study should collect verified coordinates, depth, construction details, land-use information, and repeated measurements. Only then could spatial dependence, interpolation performance, or hydrogeological pathways be evaluated. For the current data, an accurately labelled community profile is the appropriate visual representation. A published groundwater arsenic model illustrates how georeferenced measurements and environmental predictors can be combined to estimate contaminant occurrence beyond sampled locations (Podgorski & Berg, 2020).

Public health and water-management implications

The findings warrant targeted confirmation rather than a blanket declaration that all sampled water is safe or all is unsafe. Priority should be given to supplies with reported lead or manganese exceedances, records near the lead benchmark, and locations with acidic water and vulnerable users. Verified alternative water should be available for drinking and infant feeding where chemical quality cannot be assured. Treatment must be selected for the confirmed contaminant; ordinary boiling is not a remedy for dissolved metal contamination.

The WHO framework for small supplies supports progressive improvement, practical risk management, and independent surveillance (WHO, 2024). Applied locally, this would involve traceable borehole identifiers, records of construction and maintenance, clear responsibilities for retesting, and verification after corrective work. Routine surveillance should include chemical parameters selected for local risks, alongside microbiological assessment, rather than assume that acceptable taste or a negative bacterial result resolves chemical concerns.

A practical programme should distinguish source remediation from distribution remediation. If metals enter through fittings or pumps, replacement and material control may be needed. If confirmed at the source, a technically validated removal process or a different source may be required. Neutralizing acidity alone should not be assumed to remove pre-existing dissolved metals. Communication should explain which result triggered action, what users should do, and how restoration will be verified, without claiming that disease has already occurred.

Data reliability and limitations

The most consequential limitation is the mismatch between reported dissolved constituents and TDS. If the concentrations share the stated units and refer to comparable fractions of the same samples, a dissolved component substantially exceeding the reported total is a strong analytical warning. The study cannot presently support an ionic balance, hydrochemical facies classification, or a reliable composite water-quality index.

Additional limitations include the duplicated sample identifier, uncertain preservation procedures, unspecified methods for some analytes, absent quality-control documentation, and near-proportional nitrate and nitrite values. Printed lead precision is particularly relevant to threshold classification. No uncertainty adjustment or substituted concentration was introduced to conceal these problems. Confirmatory metals testing should specify the fraction measured because preparation differs for dissolved and total recoverable elements (Creed et al., 1994).

The cross-sectional design limits temporal interpretation; the household selection procedure limits representativeness; and outlet collection limits attribution to the aquifer. Community tests were reconstructed from rounded summaries, with no residual diagnostics or verified source-level grouping file. The comparison of standards identifies possible exposure concerns rather than quantifying individual intake, clinical risk, or attributable disease. These limitations do not remove the value of the screening findings.

CONCLUSION

The supplied records indicate widespread acidity and lead and manganese exceedances in subsets of 60 sampled boreholes. Correct application of WHO guidance identifies 40 lead exceedances, 12 manganese exceedances, and one combined nitrate–nitrite exceedance, subject to confirmation of analytical units and methods. Exploratory community comparisons support geographic heterogeneity for several parameters, without establishing geostatistical hotspots or equivalent lead exposure.

Declarations

Ethics and permissions: [Ethical permission was granted by Abia State University Research Ethical Clearance Committee (ABSU/REC/PG/PHDPH/002) of 19th November 2025.]

Author contributions and affiliations: [Stella Ekene Ogamba – conducted the the PhD research; Professor Ezinne Enwereji – supervised the research; Professor Okechukwu Kalu Iro – co-supervised the research; and Pricillia Ngozi Ezeonuegbu – did the data collection]

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