Bacteriological 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

Boreholes can provide drinking water while remaining vulnerable to microbial contamination. This study assessed bacteriological quality and compliance with the World Health Organization's drinking-water verification criterion in selected communities in Anambra State, Nigeria. A cross-sectional survey sampled 60 boreholes across nine communities in Awka South and Nnewi North local government areas. Water was collected from outlets after flushing, transported under cooling, and examined using membrane filtration. Faecal-related bacterial columns were positive in the same six boreholes (10.0%; 95% CI [4.7%, 20.1%]), located in Awka and Amawbia. Total coliforms were recorded in 37 samples (61.7%; 95% CI [49.0%, 72.9%]); the column labelled Streptococcus faecalis was positive in 39 (65.0%; 95% CI [52.4%, 75.8%]). At least one recorded bacterial indicator was detected in 47 samples (78.3%). Six samples failed the WHO criterion of no detectable Escherichia coli or thermotolerant coliforms in 100 mL. The findings identify priority boreholes for confirmatory testing, sanitary investigation, and corrective action. They do not establish statewide contamination prevalence, continuous safety of negative sources, or attributable disease burden. Surveillance should combine repeated microbiological testing with inspection of borehole outlets, storage, and surrounding sanitation infrastructure.

Keywords: borehole water, faecal contamination, drinking-water quality, membrane filtration, Anambra State, public health

INTRODUCTION

Access to a borehole does not by itself establish access to microbiologically safe drinking water. Groundwater may be protected by subsurface filtration, but the performance of an individual supply also depends on construction, maintenance, storage, and distribution. Water obtained through a tap can therefore reflect conditions within the borehole and within the infrastructure between the aquifer and the sampling outlet. A bacteriological assessment should identify the extent of contamination while distinguishing measured indicator organisms from unmeasured pathogens and actual disease outcomes.

Anthropogenic and industrial activities such as improper waste disposal and construction related erosion in Nigeria as typified in Anambra State, could lead to significant environmental degradation which ultimately pollute borehole water through seepage of hazardous chemicals and pathogenic microbes. In Anambra community, drinking water is sourced from boreholes. The high prevalence of water borne diseases such as diarrhea, typhoid fever, cholera, amoebiasis, paratyphoid, gastroenteritis, diphtheria and bacillary dysentery and others have been linked to the consumption of unsafe water and unhygienic drinking water production practices (Water, sanitation and hygiene, 2024). Pathogens such as Salmonella species, Shigella species, Vibrio cholera and E. coli and others seen in human and animal faeces ultimately find their way into water supply through seepage of improperly treated sewage into borehole water (Haldar et al., 2022). The

pollution of borehole water by these pathogenic organisms can only be detected by carrying out microbiological assessment of such water.

Evidence from low- and middle-income countries shows why water-source classification alone is insufficient. In a systematic review covering 319 studies and 96,737 samples, Bain et al. (2014) found that improved sources were less frequently contaminated than unimproved sources, but improved status did not guarantee freedom from faecal contamination. Their analysis supports monitoring that combines water-quality measurements with information about sanitary protection. This distinction is relevant to households and communities that depend on privately operated groundwater supplies. A multicountry study of rural handpump boreholes in Africa also documented microbial contamination in some supplies (Lapworth et al., 2020).

Local evidence also warrants attention. Onuorah et al. (2019) examined 15 boreholes in Ogbaru communities in Anambra State during dry and rainy seasons and reported bacterial contamination in both periods. Their findings establish a local precedent for microbiological investigation, although different locations, seasonal coverage, and laboratory procedures prevent direct comparison of contamination magnitudes. Evidence from other Nigerian settings extends this concern. Odewade et al. (2025) investigated groundwater contamination and reported waterborne illnesses in Funtua, while Rabiu et al. (2022) examined potentially pathogenic E. coli in household water in peri-urban Ibadan. These studies illustrate the importance of investigating both water supplies and the exposure circumstances of their users.

The interpretation of bacterial results requires organism-specific criteria. The WHO verification benchmark for water directly intended for drinking is no detectable E. coli or thermotolerant coliform bacteria in any 100 mL sample (World Health Organization [WHO], 2026). Total coliforms have a different interpretive role, particularly in untreated tropical water. Their detection cannot simply be equated with identification of faecal pathogens. Likewise, a negative E. coli result at one visit cannot establish continuous safety. Nowicki et al. (2021) demonstrated that the environmental ecology of E. coli and the limitations of grab sampling complicate inference about contamination history and health risk.

The present paper focuses on the bacteriological component of a doctoral investigation of borehole-water quality in Anambra State (Ogamba, 2026). Its objectives were to describe the distribution of recorded bacterial indicators, assess sample-level conformity with the international faecal-indicator benchmark, and identify implications for surveillance and prevention.

MATERIALS AND METHODS

Study design and setting

This is a cross-sectional design incorporating water sampling, observation, and questionnaires. This manuscript reports the laboratory bacteriological component. Sampling covered Awka South and Nnewi North local government areas in Anambra State, southeastern Nigeria. The nine communities were Amawbia, Awka, Mbaukwu, Nibo, Nise, Nnewichi, Otolo, Umudim, and Uruagu. A single collection occasion was described for each borehole.

Sampling and analytical units

There was a multistage selection involving senatorial districts, local government areas, villages, and households. Households without a borehole were skipped, and one borehole was selected where a household had more than one. Sixty boreholes were sampled, with 30 from each local government area. Community allocations are presented in Table 1. The borehole, rather than an individual laboratory replicate or questionnaire respondent, was the analytical unit.

The household replacement procedure and the absence of a complete borehole sampling frame limit the interpretation of the sample as representative of all boreholes in the state. The study used Cochran

calculation to compute questionnaire respondents; it was not a separate precision calculation for the 60 borehole samples.

Sample collection and transport

Samples were collected directly from outlets after approximately 3–5 minutes of running the tap. Microbiological samples were placed in presterilized containers with approximately 2–3 cm of headspace. They were transported in insulated containers containing ice and reached the laboratory within six hours. On arrival, samples were refrigerated at approximately 4 °C before analysis.. ISO 19458 provides a framework for documenting microbiological sampling, transport, and storage (International Organization for Standardization [ISO], 2006).

Laboratory examination

The documented membrane-filtration procedure used 100 mL aliquots in triplicate, 47 mm membranes with 0.45 µm pores, and membrane lactose glucuronide agar. The thesis describes incubation at 30 °C for four hours followed by 37 °C for 14–20 hours. Yellow colonies were classified as presumptive non-E. coli coliforms and green colonies as E. coli; the combined count represented total coliforms. A further incubation procedure at 44 °C for 24 hours was described for faecal coliform enumeration. Results were reported as colony-forming units per 100 mL (CFU/100 mL). Background growth can interfere with colony enumeration in some membrane filtration methods (ISO, 2014).

Source reconciliation and data handling

All 60 numbered records in Appendix 6 were extracted. The appendix heading refers to N = 392, but the table contains 60 water-sample rows; 392 is the parent questionnaire sample size. Values preceding the ± symbol were treated as the reported sample-level estimates. The accompanying variation terms were not treated as additional observations. Because underlying plate counts were unavailable, this reanalysis cannot independently validate replicate averaging, dilution corrections, or reported concentrations.

An important source inconsistency affected the first two bacterial columns. Appendix 6 labels the column with the overall mean of 47,708.33 CFU/100 mL as thermotolerant coliforms (E. coli), whereas Chapter 4 assigns this numerical distribution to faecal coliforms. The second column has an overall mean of 2,942.22 CFU/100 mL, with the reverse naming pattern. To avoid silently selecting one contradictory label, these measurements are designated column A and column B in concentration summaries. The six positive sample identifiers are identical in both columns, making the combined detection finding unaffected by the label reversal. Species-specific concentration claims remain provisional.

Compliance definition and statistical analysis

The primary verification endpoint was detection above zero in either of the two recorded faecal-related columns. Conditional on verification that these assays represent E. coli or thermotolerant coliforms, a positive sample fails the WHO 100 mL verification benchmark. A zero was interpreted as no detection reported for that sampling occasion, rather than proof of sterility or long-term compliance. Total coliform and recorded S. faecalis findings were summarized separately and were not assigned an invented universal WHO numerical limit.

Detection frequencies, percentages, arithmetic means, sample standard deviations, medians, interquartile ranges, and maxima were recalculated from the appendix. Wilson 95% confidence intervals were calculated for detection proportions, using 60 boreholes as the denominator. These intervals assume independent observations and do not incorporate clustering, selection probabilities, or measurement error. They describe binomial uncertainty within the analysed sample and should not be interpreted as design-based statewide estimates. Because the distributions were highly skewed and source labels remained unresolved, the thesis's parametric community comparisons were not used to support equivalence or absence of geographic variation. The interval calculation follows Wilson (1927).

Ethical and reporting considerations

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

RESULTS

Distribution of boreholes

The sample included 30 boreholes in each of the two local government areas. Individual community sample sizes ranged from three in Nibo to 13 in Awka (Table 1). Unequal allocation means that aggregate results reflect the sampled mix of communities rather than equal contributions from each location.

Table 1 Distribution of sampled boreholes

Local government area	Community	Boreholes, n
Awka South	Amawbia	5
Awka South	Awka	13
Awka South	Mbaukwu	4
Awka South	Nibo	3
Awka South	Nise	5
Nnewi North	Nnewichi	5
Nnewi North	Otolo	9
Nnewi North	Umudim	11
Nnewi North	Uruagu	5
Total	Nine communities	60

Note. Each borehole contributed one sampling occasion.

Detection of bacterial indicators

Both faecal-related columns were positive in six of 60 samples, giving a detection frequency of 10.0% (95% CI [4.7%, 20.1%]). Positive records were samples 34, 39, 40, 43, 44, and 48. The thesis identifies five of these boreholes as located in Awka and one in Amawbia. The remaining 54 samples had zero reported in both columns. Thus, the positive-source classification was consistent despite the reversed labels attached to concentration summaries.

The appendix contained 39 positive records for the column labelled S. faecalis, corresponding to 65.0% (95% CI [52.4%, 75.8%]). Total coliforms were present in 37 samples, or 61.7% (95% CI [49.0%, 72.9%]). At least one of the four recorded indicators was positive in 47 samples (78.3%); 13 samples (21.7%) had zero reported in all four columns.

Table 2 Recorded detection frequencies and uncertainty

Recorded indicator	Positive, n	Positive, %	95% CI, %
Faecal-related column A	6	10.0	4.7–20.1
Faecal-related column B	6	10.0	4.7–20.1
S. faecalis-labelled column	39	65.0	52.4–75.8
Total coliforms	37	61.7	49.0–72.9

Note. N = 60. Wilson intervals are unadjusted for the sampling design. Columns A and B identify the same six positive samples and must not be added together.

Concentration distributions

The bacterial concentration distributions were strongly right-skewed. Both faecal-related columns had a median and interquartile range of zero, although their means were elevated by a small number of positive records. Column A had a mean of 47,708.33 CFU/100 mL and a maximum of 1,230,166.67 CFU/100 mL. Column B had a mean of 2,942.22 CFU/100 mL and a maximum of 100,733.33 CFU/100 mL.

The recorded S. faecalis column had a median of 10,166.67 CFU/100 mL, whereas the total-coliform median was 10,333.33 CFU/100 mL. Maxima exceeded one million CFU/100 mL in column A, the S. faecalis-labelled column, and the total-coliform column.

Table 3 Concentration summaries reconstructed from the appendix

Indicator	Mean	SD	Median	IQR	Maximum
Column A	47,708.33	224,651.15	0.00	0.00–0.00	1,230,166.67
Column B	2,942.22	14,016.36	0.00	0.00–0.00	100,733.33
S. faecalis label	144,491.67	383,858.79	10,166.67	0.00–20,500.00	2,000,166.67
Total coliforms	105,205.56	301,044.11	10,333.33	0.00–20,500.00	1,500,166.67

Note. All values are reported CFU/100 mL. Column A is labelled thermotolerant coliform (E. coli) in Appendix 6 but matches the faecal-coliform distribution in Table 4.4; column B has the reverse naming pattern. IQR = 25th–75th percentiles using linear interpolation.

Interpretation against international criteria

Six sampled boreholes did not meet the WHO criterion for water directly intended for drinking. The 54 negative samples met the recorded nondetection criterion at the collection occasion only. The higher prevalence of the other two indicators demonstrates that faecal-indicator nondetection and absence of all recorded bacterial indicators were different endpoints. These findings do not justify describing 90% of the boreholes as comprehensively safe for drinking.

DISCUSSION

The principal finding is the identification of six boreholes with recorded faecal-related bacterial detection, alongside more frequent detection of total coliforms and organisms reported as S. faecalis. A second finding is substantial heterogeneity among individual supplies: a majority of sources had zero recorded in both faecal-related columns, while a small subset contributed large concentration estimates. The practical priority is therefore to locate, retest, and investigate the positive sources while maintaining surveillance of the wider supply network.

The result is consistent with the broader observation that borehole access does not guarantee microbial safety. Bain et al. (2014) showed that improved-source classification can mask contamination, and the present sample provides a locally specific example.

The concentration of positive records in Awka and Amawbia provides an operational starting point for investigation. It does not establish a statistically mapped contamination hotspot or identify a common source. The study did not include microbial source tracking, hydraulic tracing, or a linked analysis of construction defects and positive results. Leakage from sanitation infrastructure, surface ingress, storage contamination, and outlet biofilms remain hypotheses. Sampling at the tap also means the contamination cannot be attributed exclusively to the aquifer. Paired samples from the borehole head, storage tank, and household outlet would help distinguish these pathways. Studies of piped water and household storage provide additional reasons to sample at several points between the source and consumption (Kumpel & Nelson, 2013; Wright et al., 2004).

The Ogbaru study by Onuorah et al. (2019) strengthens the regional case for surveillance because it documented bacterial findings during both dry and rainy seasons. Its seasonal design addresses a dimension absent here. Repeating the present study across seasons would help determine whether the positive sources represent persistent failures or intermittent episodes. Differences in bacterial counts between the studies should not be interpreted as evidence of a worsening temporal trend because their populations and analytical procedures are not equivalent. A year-long study of protected springs in Kampala also illustrates how repeated sampling can help investigate rainfall and sanitary conditions as potential contributors to contamination (Howard et al., 2003).

The distinction between total coliforms and faecal indicators changes the compliance conclusion. WHO (2026) identifies E. coli, with thermotolerant coliforms as an acceptable alternative, for verification of faecal contamination. Total coliforms can include environmental organisms and have particular limitations in untreated tropical supplies. Their occurrence in 61.7% of samples warrants investigation of supply integrity, but it does not establish that all such samples contained faecal pathogens. The corrected interpretation avoids equating a broad bacterial indicator with a specific disease hazard. The recorded S. faecalis results also require restraint. The 65.0% detection frequency is a reproducible count, but frequency alone cannot validate the organism's identity. ISO 7899-2 provides a group-level method for enumerating intestinal enterococci (ISO, 2000).

A negative sample is also an incomplete measure of safety. Nowicki et al. (2021) found that E. coli population characteristics and environmental persistence complicate the interpretation of individual measurements. Their work supports assessment that considers sanitary conditions and temporal variability. Here, the 54 negative faecal-related results provide information about one collection occasion; they do not establish year-round protection, exclude all pathogens, or negate the significance of other bacterial findings.

Public health implications

The findings support prevention without implying that a measured disease burden has been established. The study did not identify diarrhoeagenic E. coli strains, quantify exposure doses, or establish which illnesses were attributable to the sampled water. Rabiu et al. (2022) demonstrate why isolate characterization can matter: investigation of potentially pathogenic E. coli requires information beyond the presence of a routine

indicator. Consequently, the present results cannot diagnose cholera, typhoid fever, or any other specific infection among users. A systematic review found different associations with diarrhoea for household water measurements of E. coli and faecal coliforms, underscoring the importance of distinguishing the indicators (Gruber et al., 2014).

The relationship between laboratory results and illness also depends on exposure ascertainment. Odewade et al. (2025) combined groundwater assessment with reporting of waterborne disease in another Nigerian setting, highlighting the value of investigating both domains. In the present parent thesis, self-reported illness and the water measurements cannot be assumed to constitute a validated source-specific exposure dataset. A future epidemiological study should link individual households to sampled sources, measure treatment and storage practices, and use prospectively defined illness outcomes.

For the six positive sources, the immediate priority is confirmatory sampling and sanitary investigation. Owners and health authorities should assess borehole seals, drainage, storage covers, plumbing integrity, and nearby sanitation hazards. Pending satisfactory verification, users need access to an adequately treated or otherwise verified alternative for drinking. Decisions about treatment should follow the nature of the supply and local technical assessment. Advice based only on water appearance is insufficient because visual clarity does not establish microbiological quality. A randomized trial in rural Bangladesh found that safe storage of tubewell water reduced reported diarrhoea in young children, supporting assessment of storage practices alongside source testing (Ercumen et al., 2015).

WHO's guidance for small water supplies emphasizes feasible regulation, risk management, and independent surveillance (WHO, 2024a). Applied here, this suggests a programme that gives each borehole a traceable identifier, records inspection findings and laboratory results, assigns responsibility for corrective work, and documents verification after repairs. The initial emphasis can be on positive supplies and supplies with substantial sanitary risks, while expanding routine coverage as resources permit.

Sanitary inspection complements laboratory testing by identifying conditions that can allow contamination, including when a grab sample is negative (WHO, 2024b). Repeated inspections would also improve the evidence needed to evaluate possible pathways rather than infer them from bacterial detection alone. A locally adapted inspection form should be accompanied by training so that observations are consistent across field teams.

The water safety planning approach provides a structure for connecting hazard identification, control measures, operational monitoring, and incident response (WHO & International Water Association, 2023). For these supplies, this could include agreed actions after positive results, clear communication with users, and retesting before a source is considered restored. Community pharmacists and primary health-care workers could support communication and referral, while technical responsibility for source remediation remains with qualified water and public health personnel.

Strengths and limitations

The study's strengths include coverage of nine communities and the availability of sample-level records, which permitted detection counts and skew-resistant summaries to be reconstructed. Treating the borehole as the unit of analysis also avoids inflating the sample size by counting technical replicates as independent sources.

The large reported concentrations require verification of dilution factors, colony-count ranges, and transcription. Some individual records also show a putative faecal subset exceeding the reported total-coliform count; differing assay conditions may influence recovery, but the pattern warrants laboratory review.

Secondly, single-occasion sampling cannot describe seasonal or long-term performance. The unequal community samples, household substitution, and unavailable selection probabilities limit representativeness. Thirdly, sampling from outlets does not separate aquifer contamination from contamination in tanks or

distribution. Finally, absence of validated pathogen and clinical outcome data prevents estimation of infection probability or attributable disease burden. These limitations narrow the inference to a bacteriological assessment of the sampled supplies and identify the records required to strengthen it, but do not in any way invalidate the study.

CONCLUSION

Six of 60 sampled boreholes had recorded faecal-related bacterial detection, all in Awka or Amawbia. Subject to confirmation of assay identity, these results fail the WHO nondetection criterion for water directly intended for drinking. Total coliforms were recorded in 37 samples, and the S. faecalis-labelled column was positive in 39. The results support confirmatory testing, source-specific sanitary investigation, and preventive surveillance. They do not, however, establish statewide prevalence or attributable disease.

Declarations

Ethics approval and sampling permission: [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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