# Association between Drinking-Water Source and Detected Microbiological Contamination in Selected Urban Communities of Akure Metropolis, Southwestern Nigeria: A Pilot Study

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**ABSTRACT**

*Access to safe drinking water remains a public-health priority in urban Nigerian communities where households depend on groundwater and packaged water. Few studies have directly compared well, borehole and sachet-water sources within the same urban setting while accounting for physicochemical covariates. This quantitative laboratory-based cross-sectional pilot study assessed the association between drinking-water source and detected microbiological contamination in 45 purposively selected samples (15 well, 15 borehole and 15 sachet) from Oba-Ile, Oke-Ijebu and Aule, Akure Metropolis, Ondo State. Physicochemical parameters were measured with calibrated meters, while microbiological assessment used culture on Nutrient and MacConkey agar followed by Gram staining and microbial-load assessment. The contamination outcome was defined operationally from culture findings and indicator-organism isolation; the primary statistical analysis used the culture-based detection classification rather than the numerical microbial-load values. Under this operational definition, detected microbiological contamination occurred in 35/45 samples (77.8%), including 14/15 wells, 14/15 boreholes and 7/15 sachet samples. Among combined groundwater samples, 28/30 (93.3%) were classified as contaminated compared with 7/15 (46.7%) sachet samples. Groundwater had higher odds of detected contamination than sachet water (crude OR = 16.00, 95% CI: 2.76–92.72; Fisher's exact p = 0.0009). Turbidity was higher among contaminated samples (4.40 vs 3.62 NTU; p = 0.043) and showed a weak positive correlation with the contamination outcome (ρ = 0.307, p = 0.040). In exploratory logistic regression adjusted for turbidity, groundwater remained associated with detected contamination (AOR = 11.42, 95% CI: 1.91–68.47; p = 0.008). Because the sample was purposive and pilot-sized, the estimates are intended to describe the sampled communities rather than city-wide prevalence or disease risk.*

***Keywords:*** *Drinking water; groundwater; sachet water; detected microbiological contamination; water quality assessment; turbidity; odds ratio; Akure; Nigeria; pilot study*

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## INTRODUCTION

Access to safe drinking water is fundamental to public health. The World Health Organization (WHO) identifies microbial contamination, particularly contamination associated with faecal pollution, as the most widespread and immediate risk to drinking-water safety (WHO, 2022). Globally, substantial inequalities in access to safely managed drinking-water services persist, especially in low- and middle-income countries and rapidly growing urban areas (WHO & UNICEF, 2023). Where public piped supplies are inadequate or unreliable, households turn to alternative sources such as hand-dug wells, boreholes and commercially packaged water.

In Nigeria, sachet water and groundwater have become important components of the urban drinking-water supply. A systematic review estimated that approximately 18% of urban households rely on packaged sachet water as a primary drinking-water source, yet the same review documented substantial microbial contamination of packaged drinking water across Nigerian studies, including total coliforms, faecal indicator bacteria and organisms such as *Escherichia coli*, *Klebsiella* and *Enterobacter* (Udoh *et al.*, 2021). More recent investigations continue to report bacterial contamination of sachet-water brands sold in Nigerian urban neighbourhoods (Tenebe *et al.*, 2023; Agbasi *et al.*, 2024; Adesemoye *et al.*, 2024).

Groundwater is equally important, particularly in communities where access to reliable public water is limited. However, groundwater quality is vulnerable to urbanization, inadequate sanitation, wastewater infiltration and poor source protection. In Ondo State, urban groundwater has been reported to be of poorer quality than corresponding rural groundwater, with surface sealing, wastewater seepage and intensive exploitation cited as contributing factors (Ojo *et al.*, 2024). Bacteriological contamination of hand-dug wells has been documented in both urban and rural areas of the state (Ojo *et al.*, 2023). Specifically, Olalemi *et al.* (2023) found sanitary risks and enteric bacterial contamination in wells and boreholes in Ilara-Mokin and Ibule-Soro, with several sanitary-risk factors significantly associated with the presence of *E. coli* and thermotolerant coliforms.

Despite a growing body of evidence on drinking-water contamination in Nigeria, important gaps remain. Studies in Ondo State have examined bacteriological contamination of hand-dug wells, sanitary risks in wells and boreholes, and broader groundwater quality, but they have not directly quantified the association between three commonly used source categories—well, borehole and sachet water—within the same urban communities while simultaneously considering a physicochemical covariate. Recent Nigerian evidence further shows the value of quantitative and context-specific assessment: a 2025 Katsina study compared wells, boreholes and sachet water using bacterial-load measurements and investigated multidrug-resistant Pseudomonas aeruginosa, while a 2026 Yenagoa study examined microbiological and physicochemical changes in packaged water under different storage conditions. These studies address important dimensions of water quality, but they do not provide the same-setting Akure comparison undertaken here, particularly the source-level association analysis adjusted for turbidity. The present pilot therefore bridges a comparative and analytical gap by examining well, borehole and sachet water concurrently within selected urban communities, while explicitly treating the microbiological endpoint as an operational culture-based classification rather than a quantitative WHO-compliance measure.

### Aim

To assess the association between drinking-water source and detected microbiological contamination among water samples collected from selected urban communities in Akure Metropolis, Ondo State, Nigeria.

### Primary Objective

To compare the occurrence of detected microbiological contamination among water samples obtained from well, borehole, and sachet-water sources across the selected urban communities.

### Secondary Objectives

To quantify the association between water-source category (well, borehole, and sachet water) and the occurrence of detected microbiological contamination.

To examine the association between turbidity and the occurrence of detected microbiological contamination.

To determine whether water-source category remains associated with detected microbiological contamination after adjustment for turbidity.

## MATERIALS AND METHODS

### Study design and setting

A quantitative laboratory-based cross-sectional pilot design was used to assess the relationship between drinking-water source and detected microbiological contamination in selected communities of Akure Metropolis, the capital of Ondo State in southwestern Nigeria. Akure lies approximately between latitude 7°15′N–7°21′N and longitude 5°05′E–5°15′E. Three residential communities Oba-Ile, Oke-Ijebu and Aule were purposively selected because residents commonly use well water, borehole water and commercially packaged

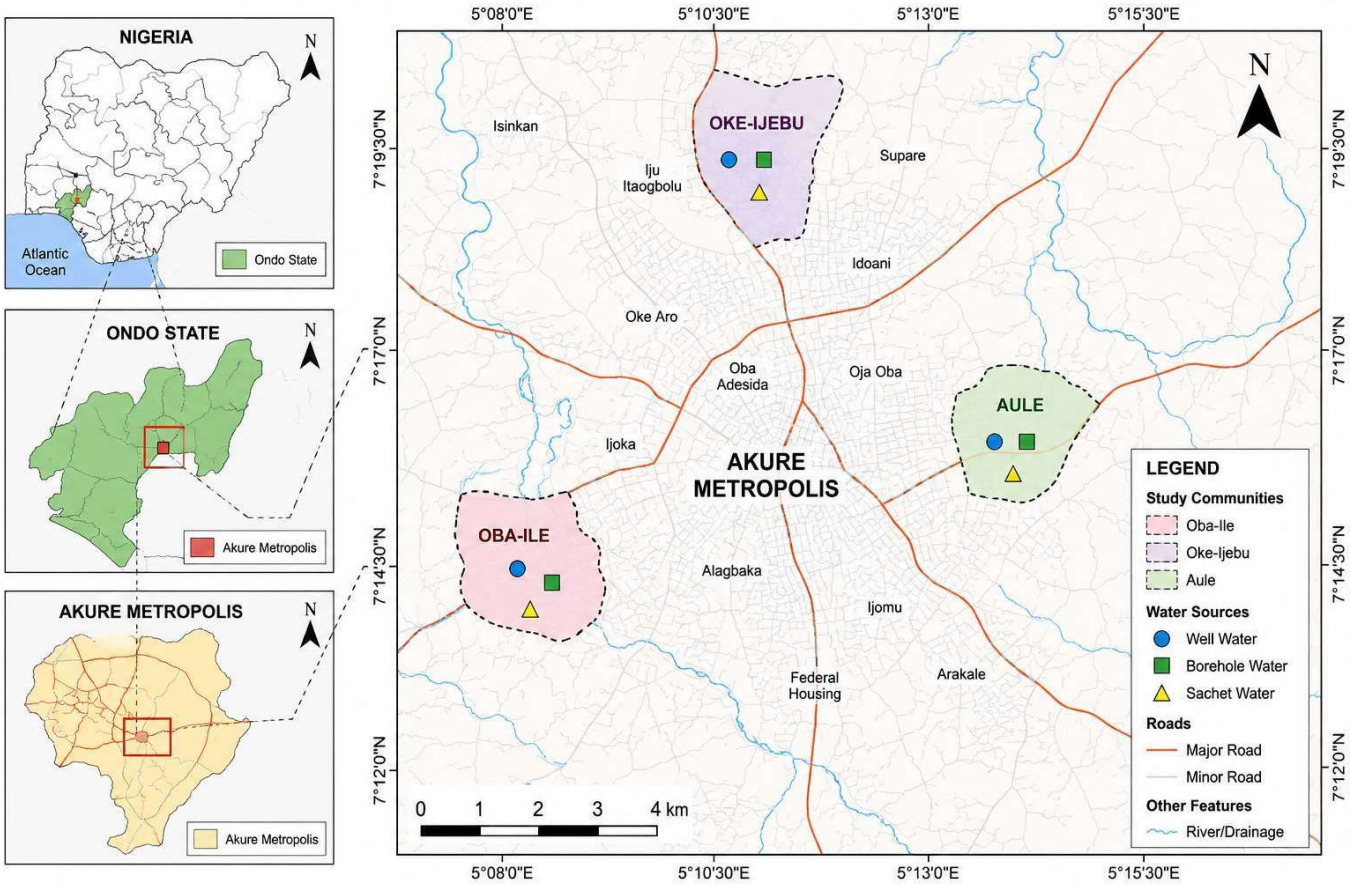


**Figure 1:** Map of the study area showing Akure Metropolis, Ondo State, Nigeria, and the selected study communities (Oba-Ile, Oke-Ijebu and Aule). Source: Author's construction based on Obiora-Okeke et al. (2022), with study locations based on the present study.

sachet water for domestic and drinking purposes. The purposive design and equal allocation were selected to test the feasibility of source-level comparison and laboratory procedures; they do not constitute a probability sample of Akure Metropolis. The investigation was designed as a pilot to assess sampling procedures, laboratory protocols and analytical methods before a larger study (Figure 1).

## Sample size and sampling

The initial sample size was estimated using the Cochran formula for prevalence studies: $n = Z^2pq/d^2$, where $Z = 1.96$ (95% confidence), $p = 0.50$, $q = 0.50$ and $d = 0.15$. The calculated minimum was 42.68 and was rounded to 45 as an operational pilot target to permit equal representation of the three communities and three source categories. The calculation was not used to justify city-wide prevalence estimation because the communities and individual sources were selected purposively rather than through probability sampling. Within each community, five functioning well sources, five borehole sources and five sachet-water samples available from retail outlets were selected. Well and borehole sources were selected purposively as sources used for domestic/drinking purposes. Sachet samples were purchased as intact, properly sealed units within their stated shelf-life. The available study records did not contain a standardized sampling frame, source-owner characteristics, sachet brand identities, NAFDAC registration numbers, batch/production numbers or retail exposure times; these omissions are treated as limitations rather than being inferred retrospectively.

Well and borehole samples were collected directly from the respective sources after allowing water to flow continuously for approximately two minutes. Sterile bottles were used and samples were handled aseptically. Sachet-water samples were purchased from retail outlets within the selected communities; only intact, properly sealed sachets within their stated shelf-life were included. The available records did not systematically document brand, NAFDAC registration status, batch/production information, exact storage temperature or duration of retail exposure. Samples were placed in insulated ice-packed containers

and transported to the Biology Research Laboratory, Federal University of Technology, Akure. Laboratory analyses commenced within 24 hours of collection.

### Laboratory analyses

Physicochemical parameters (temperature, pH, electrical conductivity and total dissolved solids) were measured using a calibrated HI98136 Hanna multiparameter meter; turbidity was determined with a turbidity meter. Meters were calibrated according to the manufacturers' specifications before use. For microbiological examination, Nutrient Agar and MacConkey Agar were prepared according to the laboratory's standard procedures. Culture media and laboratory equipment were appropriately sterilized. One millilitre of each water sample was aseptically inoculated in duplicate into sterile Petri dishes, after which molten Nutrient Agar and MacConkey Agar were added separately. Plates were incubated at 37 °C for 24 hours under controlled conditions. Distinct colonies were sub-cultured onto fresh Nutrient Agar to obtain pure cultures and were examined by Gram staining (crystal violet, iodine, alcohol decolorizer and safranin) under a ×100 oil-immersion objective. Organism-level identifications were based on colonial morphology, cultural characteristics and Gram reaction. The isolates were reported at the organism/group level, while species-level confirmation by biochemical or molecular methods was not part of the laboratory protocol. Microbial-load assessment was also conducted during the laboratory analysis; however, the primary statistical outcome reported in this pilot was the binary culture-based detection classification. Operational definition of detected microbiological contamination.

A water sample was classified as having detected microbiological contamination under the study operational definition when either (a) clear colonial growth was observed on MacConkey agar, or (b) indicator organisms—E. coli, Klebsiella spp., Enterobacter spp. or other coliform bacteria were isolated on the basis of cultural characteristics and Gram reaction. Samples recorded as "no significant isolate," "nil" or "scanty/very low growth only on Nutrient Agar without MacConkey growth or identifiable indicator organisms" were classified as not contaminated. This operational definition is broader and less specific than the WHO criterion requiring absence of E. coli or thermotolerant coliforms in a 100-mL drinking-water sample. Accordingly, the present classification should not be interpreted as direct evidence of WHO microbiological compliance or non-compliance.

### Quality control

Quality-control procedures included calibration of the multiparameter and turbidity meters before use, maintenance of aseptic technique throughout sampling and inoculation, sterilization of media and equipment, duplicate inoculation of each sample, controlled incubation, and completion of laboratory analyses within 24 hours of collection. Pure cultures were examined after Gram staining under oil immersion. The available laboratory records did not document the use of named positive-control organisms, negative-control organisms, reference strains or separate media-sterility control plates. These controls therefore cannot be claimed as having been used and are acknowledged as a reproducibility limitation. The absence of documented quantitative enumeration and confirmatory organism identification is likewise considered in interpretation.

### Statistical analysis

Data were entered into Microsoft Excel and analyzed with IBM SPSS Statistics version 25.0. Descriptive statistics summarized contamination proportions and physicochemical values. The primary analysis compared the three source categories (well, borehole and sachet) using a 3 × 2 Pearson chi-square test; because of small cell counts, an exact fixed-margin test for the 3 × 2 table was also calculated. Pairwise source comparisons were then examined using odds ratios and two-sided Fisher's exact tests, with sachet water as the reference category. For the prespecified primary binary contrast, well and borehole water were combined as groundwater because both represented untreated environmental groundwater sources in this study, whereas sachet water represented commercially packaged water; this grouping was intended to test the broader contrast between untreated groundwater and packaged water, not to imply identical contamination pathways. Separate well-versus-sachet and borehole-versus-sachet estimates were also reported as a sensitivity analysis. Spearman's rank correlation examined relationships between physicochemical parameters and the binary contamination outcome. Mean turbidity was compared between contaminated and non-contaminated samples. One-way ANOVA compared physicochemical parameters among the three source types within each community. Exploratory binary logistic regression estimated the association of groundwater versus sachet water after controlling for turbidity. Because only three communities were sampled, reliable multilevel modelling of community clustering was not considered feasible; this limitation is acknowledged explicitly. Statistical significance was set at $p < 0.05$, with emphasis placed on effect estimates and confidence intervals rather than on multiple hypothesis tests as independent confirmatory evidence.

### Ethical considerations

Permission to conduct the laboratory analyses was obtained from the appropriate authorities of the Biology Research Laboratory, Federal University of Technology,

Akure. Standard laboratory safety procedures were observed. Because the investigation involved only environmental water samples and no human participants or personally identifiable information, informed consent was not applicable.

## RESULTS

### Microbiological contamination by water source

Under the study's operational culture-based definition, detected microbiological contamination occurred in 35 of the 45 samples (77.8%). The distribution by source is summarized in Table 1. Verification against the sample-level records in Appendix A confirmed 14/15 well samples, 14/15 borehole samples and 7/15 sachet-water samples as classified contaminated under this operational definition. Note. "Detected contamination" denotes microbiological contamination under the study's operational culture-based definition: clear MacConkey growth and/or isolation of indicator organisms. It represents the binary outcome used for the primary statistical analysis and should not be interpreted as a direct determination of WHO microbiological compliance. Table 1 shows that detected microbiological contamination was common among well and borehole samples and less frequent among sachet-water samples.

**Table 1:** Distribution of microbiological contamination according to water source

| Water source | Contaminated, (%) | Not contaminated, (%) | Total |
|---|---|---|---|
| Well | 14 (93.3) | 1 (6.7) | 15 |
| Borehole | 14 (93.3) | 1 (6.7) | 15 |
| Sachet | 7 (46.7) | 8 (53.3) | 15 |
| Total | 35 (77.8) | 10 (22.2) | 45 |

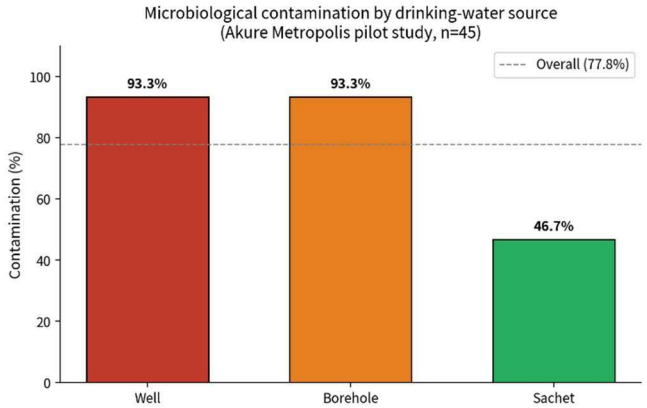


**Figure 2:** Percentage distribution of microbiological contamination according to drinking-water source.

The classification reflects the study's culture-based operational definition and is not equivalent to quantitative WHO compliance testing. The comparative distribution of contamination proportions is illustrated in (Figure 2). Figure 2 highlights the difference in the observed operational classification between untreated groundwater (well and borehole) and sachet water in the sampled communities. When well and borehole samples were combined as groundwater, 28 of 30 samples (93.3%) were classified as contaminated, compared with 7 of 15 sachet-water samples (46.7%).

### Association between water source and contamination

The primary three-source comparison showed a statistically significant association between water-source category and the operational microbiological outcome. The source-by-contamination distribution and statistical test are presented in (Table 2). The 3 × 2 Pearson chi-square test was $\chi^2(2) = 12.60$, $p = 0.0018$; an exact fixed-margin test for the same 3 × 2 table gave $p = 0.0028$. Because the primary question concerned the broader contrast between untreated groundwater and sachet water, the prespecified binary analysis was then performed. For groundwater versus sachet water, the crude OR was 16.00 (95% CI: 2.76–92.72), with Fisher's exact $p = 0.0009$. The pairwise well-versus-sachet and borehole-versus-sachet estimates are reported as sensitivity analyses in (Table 3). Figure 3 shows the crude odds ratios for well, borehole and combined groundwater relative to sachet water. The point estimates are above the null value of 1.0; the combined groundwater estimate has the narrower confidence interval because it uses 30 groundwater observations.

**Table 2:** Three-source comparison of detected microbiological contamination by water source.

| Water source | Detected contamination, n (%) | Not detected, n (%) | Total |
|---|---|---|---|
| Well | 14 (93.3) | 1 (6.7) | 15 |
| Borehole | 14 (93.3) | 1 (6.7) | 15 |
| Sachet | 7 (46.7) | 8 (53.3) | 15 |
| Total | 35 (77.8) | 10 (22.2) | 45 |

**Table 3:** Pairwise source comparisons for detected microbiological contamination.

| Comparison | OR | 95% CI | Fisher's exact p | Interpretation |
|---|---|---|---|---|
| Well vs sachet | 16.00 | 1.66–154.60 | 0.0142 | Higher odds in well samples |
| Borehole vs sachet | 16.00 | 1.66–154.60 | 0.0142 | Higher odds in borehole samples |
| Groundwater (well + borehole) vs sachet | 16.00 | 2.76–92.72 | 0.0009 | Primary binary contrast |

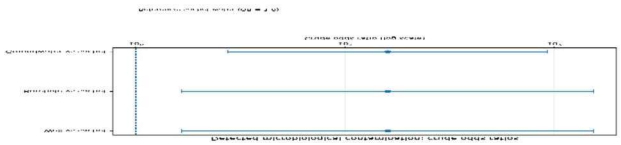

**Figure 3:** Forest plot of crude odds ratios for detected microbiological contamination, with sachet water as the reference category (OR = 1.0).

## Turbidity and microbiological contamination

Samples classified as having detected microbiological contamination had a mean turbidity of 4.40 NTU compared with 3.62 NTU among samples without detected contamination; the difference was statistically significant ($p = 0.043$). This comparison is shown in (Figure 4). Spearman's rank correlation showed a weak positive association between turbidity and the binary outcome ($\rho = 0.307$, $p = 0.040$). No statistically significant correlations were observed for temperature, pH, electrical conductivity or total dissolved solids.

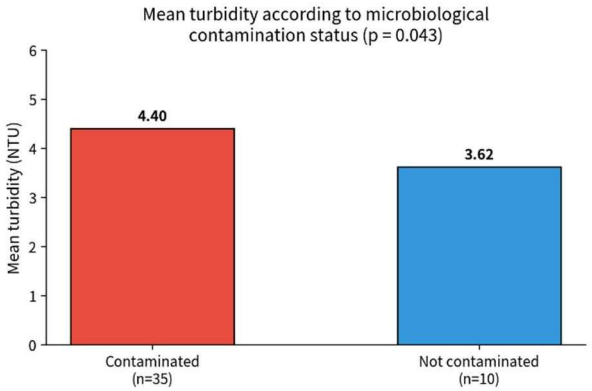


Figure 4: Mean turbidity according to microbiological contamination status ($p = 0.043$).

## Multivariable logistic regression

Exploratory binary logistic regression assessed whether water source remained associated with the operational contamination outcome after adjustment for turbidity. The adjusted estimates are reported in (Table 4) and illustrated in (Figure 5).

Table 4: Exploratory multivariable logistic regression results for factors associated with detected microbiological contamination.

| Variable | AOR | 95% CI | p-value |
|---|---|---|---|
| Groundwater vs sachet water | 11.42 | 1.91–68.47 | 0.008 |
| Turbidity (per 1-NTU increase) | 2.49 | 0.45–13.89 | 0.298 |

Note. AOR estimates are exploratory and imprecise because the pilot sample contained only 10 non-contaminated observations and the model did not account for clustering across the three communities.

The model is presented as exploratory because only 10 samples were classified as non-contaminated and the analysis did not account for community clustering. Table 4 shows that groundwater remained associated with detected microbiological contamination after adjustment for turbidity, whereas turbidity itself was not independently significant.

The wide confidence interval around the groundwater AOR (1.91–68.47) indicates substantial imprecision and should not be interpreted as a precise population estimate. Figure 5 presents the exploratory adjusted estimates; the groundwater interval lies above 1.0, whereas the turbidity interval crosses the null value. Given the pilot sample and only three community clusters, the model should be interpreted as supportive rather than definitive evidence.

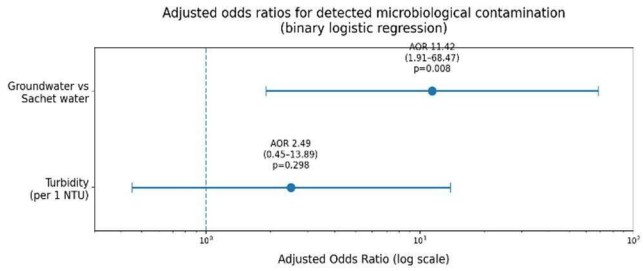


**Figure 5:** Adjusted odds ratios for factors associated with microbiological contamination.

## Bacterial isolates

Bacterial isolates varied according to water source. Well and borehole samples showed more frequent recovery of indicator organisms than sachet-water samples. The organisms reported on the basis of colonial morphology, cultural characteristics and Gram reaction included Escherichia coli, Klebsiella spp., Enterobacter spp. and other coliform bacteria. Klebsiella spp. was reported most frequently in the laboratory records. Species-level confirmation by biochemical or molecular methods was not part of the laboratory protocol; therefore, the organism-level results are reported according to the laboratory identification criteria used in this study. Detection of an organism reported as E. coli is potentially important because E. coli is a recognised indicator of faecal contamination, but the present testing does not by itself establish WHO microbiological compliance or non-compliance.

## DISCUSSION

This pilot study found that detected microbiological contamination under the study operational definition occurred in 35/45 samples (77.8%) from the three sampled communities. The observed proportion was particularly high in groundwater: 14/15 well samples and 14/15 borehole samples were classified as contaminated, compared with 7/15 sachet-water samples. In the primary binary comparison, 28/30 groundwater samples (93.3%) versus 7/15 sachet samples (46.7%) were classified as contaminated, corresponding to a crude OR of 16.00 (95% CI: 2.76–92.72; Fisher's exact $p = 0.0009$).

**Table 5:** Comparison with recent Nigerian evidence (2024–2026).

| Study | Design/context | Key finding | Relevance to the present pilot |
|---|---|---|---|
| Ojo et al. (2024) | Ondo State; urban/rural groundwater; 13 physicochemical parameters and Water Quality Index. | Urban groundwater was generally poorer than rural groundwater; urbanisation-related factors were implicated. | Provides local environmental context; the present study adds a microbiological source comparison within selected Akure urban communities. |
| Agbasi et al. (2024) | Nigeria; state-of-the-art review of sachet-water contamination pathways. | Contamination risks were identified across manufacturing, transportation, storage, sale and environmental hygiene. | Supports cautious interpretation of the lower sachet-water contamination observed here and highlights unmeasured distribution/storage factors. |
| Abdullahi et al. (2025) | Katsina Metropolis; 45 samples from wells, boreholes and sachet water; quantitative bacterial load and MDR P. aeruginosa testing. | P. aeruginosa occurred in 71.1% of samples; wells had the highest prevalence and sachet water the lowest; resistance genes were detected. | Closely parallels the three-source design but used quantitative and resistance-focused microbiology. The present pilot uses an operational presence/absence endpoint and does not assess antimicrobial resistance. |
| Charles et al. (2026) | Yenagoa; packaged water studied under refrigerated, room-temperature and outdoor storage with repeated microbiological/physicochemical testing. | Storage conditions affected microbial and physicochemical quality; confirmatory E. coli, Salmonella, Vibrio cholerae and Shigella were not detected. | Shows the importance of storage conditions, which were not systematically recorded in the present sachet-water dataset. |

After adjustment for turbidity, the exploratory AOR remained 11.42 (95% CI: 1.91–68.47; p = 0.008). These estimates indicate an association within the sampled communities, but their wide confidence intervals and the purposive pilot design limit precision and generalisability.

These findings are consistent with recent evidence showing that untreated groundwater can present microbiological risks and that packaged water is not uniformly free of contamination. In Ondo State, Olalemi et al. (2023) reported enteric bacterial contamination and sanitary risks in groundwater sources, while Ojo et al. (2023, 2024) documented bacteriological contamination of hand-dug wells and poorer groundwater quality in urban relative to rural settings. Agbasi et al. (2024) identified contamination pathways for sachet water across production, transportation, storage and sale. The present study adds a same-setting comparison of well, borehole and sachet sources in selected Akure communities and quantifies the source-level association while considering turbidity. The high contamination rate in well water is biologically and environmentally plausible. Shallow hand-dug wells are often exposed to surface runoff, poorly protected surroundings, nearby waste disposal and wastewater infiltration. Although boreholes may provide greater physical protection against some forms of surface contamination, the present finding that borehole contamination equalled that of wells (93.3%) emphasises that boreholes are not inherently safe. Contamination can still occur through inadequate construction, poor sanitary seals, contaminated recharge zones or other environmental pathways.

The comparatively lower contamination observed in sachet water should be interpreted cautiously. The 2024 review by Agbasi et al. identified multiple points at which packaged water may become contaminated, including manufacturing, transport, storage and final sale. A 2026 Nigerian study in Yenagoa further showed that storage conditions affected microbiological and physicochemical quality over time, with higher microbial counts under room-temperature and outdoor storage than under refrigeration (Oyibo et al., 2026). The present study did not record detailed retail storage conditions or exposure duration, so the lower observed classification in sachet water cannot be attributed specifically to treatment effectiveness or assumed to represent consistent safety.

The recovery of E. coli, Klebsiella spp., Enterobacter spp. and other coliform organisms is relevant to drinking-water safety, and the organism-level findings are reported according to the laboratory identification criteria based on colonial morphology, cultural characteristics and Gram reaction. Species-level confirmation by biochemical or molecular methods was not part of the laboratory protocol. The study therefore provides evidence of detected microbiological growth under its operational definition rather than a regulatory determination of WHO compliance. Because only environmental water samples were examined, the findings indicate potential microbiological exposure and do not establish that waterborne disease occurred among consumers. Turbidity showed a weak positive correlation with the contamination outcome and was higher among samples classified as contaminated.

This relationship is biologically plausible because suspended particles may facilitate microbial attachment and transport. However, turbidity did not remain independently significant in the exploratory logistic model, suggesting that the observed source association was not explained solely by turbidity. The comparison shows that the present pilot contributes a distinct same-setting source-level association analysis in Akure, while also underscoring why its culture-based outcome should not be treated as equivalent to the quantitative and confirmatory microbiological endpoints used in some recent studies (Table 5).

## Key findings of the present pilot

(a) Detected microbiological contamination under the study operational definition occurred in 35/45 samples (77.8%), including 14/15 wells, 14/15 boreholes and 7/15 sachet samples.
(b) The three-source comparison was statistically significant ($\chi^2(2) = 12.60$, $p = 0.0018$; exact $p = 0.0028$), and the primary groundwater-versus-sachet contrast gave OR = 16.00 (95% CI: 2.76–92.72; Fisher's exact $p = 0.0009$).
( c )Turbidity was modestly higher among samples classified as contaminated and showed a weak positive correlation with the binary outcome, but it was not independently significant in the exploratory adjusted model.
(d) The study's strongest contribution is a direct well–borehole–sachet comparison within the same selected urban communities, while its main constraint is the non-quantitative, non-confirmatory microbiological endpoint.

## Limitations of the Study

This pilot study has several important limitations that affect interpretation and generalisability. First, the sample size was relatively small (n = 45), with only ten samples classified as non-contaminated. The purposive sampling design and equal allocation of source categories do not provide a probability sample of Akure Metropolis; therefore, the findings should be limited to the sampled communities and should not be interpreted as city-wide prevalence estimates. The wide confidence intervals around the odds ratios further limit precision.
Second, the cross-sectional design and single sampling period do not permit assessment of seasonal changes in microbiological or physicochemical water quality.
Third, although microbial-load assessment was conducted during the laboratory analysis, the primary statistical analysis used the binary culture-based detection outcome rather than numerical microbial-load measures. Consequently, the present results are not intended as a direct quantitative comparison with WHO microbiological criteria. Species-level confirmation by biochemical or molecular methods was not part of the laboratory protocol, so organism-level findings were reported according to the culture and Gram-reaction identification criteria used in the study. The study also did not directly assess sanitary-risk factors such as distance from wells to septic systems, well construction quality, surrounding land use, household storage conditions or waste-disposal practices.
Fourth, the study did not directly assess sanitary-risk factors such as distance from wells to septic systems, well construction quality, surrounding land use, household storage conditions, waste-disposal practices or detailed sachet-water retail storage. These unmeasured factors limit causal interpretation of the source association.
Fifth, samples were clustered within only three communities, and the regression did not account for community-level clustering because three clusters were insufficient for reliable multilevel modelling. Finally, because only environmental water samples were examined, the study cannot link the laboratory findings to actual waterborne disease occurrence among consumers. Sachet brand, NAFDAC registration, batch information and retail exposure time were also not systematically recorded in the available dataset.

## Conclusion

This pilot study demonstrated a strong observed association between drinking-water source and detected microbiological contamination under the study's operational culture-based definition in selected urban communities of Akure Metropolis. Detected contamination occurred in 35/45 samples (77.8%), including 14/15 well samples, 14/15 borehole samples and 7/15 sachet-water samples. The primary groundwater-versus-sachet comparison yielded a crude OR of 16.00 (95% CI: 2.76–92.72; Fisher's exact $p = 0.0009$), and the exploratory association remained after adjustment for turbidity (AOR = 11.42, 95% CI: 1.91–68.47; $p = 0.008$). Turbidity itself showed only a weak positive correlation with the binary outcome and was not independently significant in the adjusted model. Because the sample was purposive and pilot-sized, these estimates should not be generalised to Akure Metropolis or Nigeria as population prevalence measures. Within the studied communities, untreated groundwater warrants particular attention in drinking-water safety programmes. Improved physical protection of wells and boreholes, appropriate household water-treatment and safe-storage practices, routine microbiological monitoring, and continued regulatory oversight of packaged drinking water are proportionate recommendations. Larger studies should use probability-based sampling where feasible, repeated seasonal sampling, quantitative microbial-load measures with their numerical results reported alongside the culture-based classification, confirmatory biochemical or molecular identification, systematic sanitary-risk assessment, and detailed sachet-water brand and storage metadata. Such work is needed to determine the determinants and magnitude of microbiological contamination more precisely and to assess whether the patterns observed in this pilot persist across Akure and other Nigerian settings.

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**Appendix A.** Supporting Data Tables for Reproducibility

The following tables present the sample-level physicochemical data and operational contamination classifications used in the analyses. Sample codes: OBI = Oba-Ile, OKJ = Oke-Ijebu, AUL = Aule; Well / BH (borehole) / SAC (sachet); sequential number 1–5. "Yes" indicates detected microbiological contamination under the operational definition in Section 2.3; "No*" indicates no significant isolate or scanty/very low growth without MacConkey growth or identifiable indicator organisms. The appendix reproduces all 45 observations used to derive the primary source-level totals.

Appendix Table A1: Oba-Ile — physicochemical values and contamination status
Individual sample values for Oba-Ile are presented below.

| Sample | Temp (°C) | pH | EC (µS/cm) | TDS (mg/L) | Turb. (NTU) | Contam. |
|---|---|---|---|---|---|---|
| OBI Well 1 | 29.6 | 6.76 | 156 | 87 | 4.9 | Yes |
| OBI Well 2 | 29.3 | 7.2 | 367 | 178 | 3.6 | Yes |
| OBI Well 3 | 29.3 | 6.6 | 162 | 81 | 3.1 | Yes |
| OBI Well 4 | 29.7 | 7.1 | 251 | 125 | 4.8 | Yes |
| OBI Well 5 | 29.7 | 7.2 | 196 | 98 | 5.4 | Yes |
| OBI BH 1 | 29.5 | 7.6 | 237 | 118 | 3.8 | Yes |
| OBI BH 2 | 29.5 | 7.2 | 209 | 104 | 3.2 | Yes |
| OBI BH 3 | 29.5 | 7.5 | 170 | 84 | 7.2 | Yes |
| OBI BH 4 | 29.5 | 7.5 | 162 | 81 | 6.8 | Yes |
| OBI BH 5 | 29.5 | 6.7 | 207 | 103 | 4.0 | Yes |
| OBI SAC 1 | 29.5 | 7.5 | 198 | 93 | 3.2 | No* |
| OBI SAC 2 | 29.4 | 7.3 | 102 | 52 | 3.6 | Yes |
| OBI SAC 3 | 30.4 | 7.7 | 176 | 93 | 3.9 | No* |
| OBI SAC 4 | 29.4 | 7.0 | 154 | 97 | 4.1 | No* |
| OBI SAC 5 | 29.5 | 8.2 | 172 | 85 | 3.8 | Yes |

**No significant isolate / scanty growth only (classified as not contaminated). Oba-Ile: 12 contaminated, 3 not contaminated.*

Appendix Table A2: Oke-Ijebu — physicochemical values and contamination status
Individual sample physicochemical values and contamination status for all 15 Oke-Ijebu samples are presented below (from dissertation Table 4).

| Sample | Temp (°C) | pH | EC (µS/cm) | TDS (mg/L) | Turb. (NTU) | Contam. |
|---|---|---|---|---|---|---|
| OKJ Well 1 | 29.0 | 7.3 | 512 | 254 | 4.8 | Yes |
| OKJ Well 2 | 29.0 | 8.3 | 396 | 196 | 4.7 | Yes |
| OKJ Well 3 | 29.0 | 7.5 | 375 | 187 | 4.0 | Yes |
| OKJ Well 4 | 29.0 | 6.7 | 625 | 311 | 4.0 | Yes |
| OKJ Well 5 | 29.3 | 6.7 | 329 | 164 | 4.5 | Yes |
| OKJ BH 1 | 29.7 | 7.6 | 259 | 130 | 3.5 | Yes |
| OKJ BH 2 | 29.3 | 7.7 | 495 | 210 | 3.6 | Yes |
| OKJ BH 3 | 28.9 | 7.9 | 474 | 202 | 3.5 | Yes |
| OKJ BH 4 | 28.9 | 7.9 | 315 | 157 | 4.2 | Yes |
| OKJ BH 5 | 28.5 | 7.7 | 114 | 56 | 3.2 | Yes |
| OKJ SAC 1 | 29.3 | 8.2 | 152 | 75 | 3.4 | No* |
| OKJ SAC 2 | 29.3 | 8.2 | 295 | 147 | 3.4 | No* |
| OKJ SAC 3 | 29.5 | 6.8 | 174 | 85 | 3.8 | Yes |
| OKJ SAC 4 | 29.5 | 7.5 | 178 | 93 | 3.2 | No* |
| OKJ SAC 5 | 29.3 | 8.2 | 152 | 75 | 3.4 | Yes |

**No significant isolate / scanty growth (classified as not contaminated). Oke-Ijebu: 12 contaminated, 3 not contaminated. Source: Dissertation Table 4.8.*

Appendix Table A3. Aule — physicochemical values and contamination status
Individual sample values for Aule are presented below.

| Sample | Temp (°C) | pH | EC (µS/cm) | TDS (mg/L) | Turb. (NTU) | Contam. |
|---|---|---|---|---|---|---|
| AUL Well 1 | 28.7 | 7.8 | 627 | 315 | 6.9 | Yes |
| AUL Well 2 | 28.6 | 7.2 | 373 | 175 | 3.2 | Yes |
| AUL Well 3 | 28.6 | 7.2 | 430 | 214 | 4.7 | No* |
| AUL Well 4 | 28.6 | 6.9 | 306 | 154 | 5.6 | Yes |
| AUL Well 5 | 28.6 | 6.9 | 432 | 216 | 4.1 | Yes |
| AUL BH 1 | 28.9 | 7.7 | 566 | 282 | 3.5 | No* |
| AUL BH 2 | 28.9 | 7.7 | 351 | 175 | 3.6 | Yes |
| AUL BH 3 | 28.9 | 8.4 | 502 | 250 | 9.3 | Yes |
| AUL BH 4 | 28.9 | 7.1 | 253 | 127 | 4.6 | Yes |
| AUL BH 5 | 28.9 | 6.7 | 120 | 60 | 3.1 | Yes |
| AUL SAC 1 | 28.0 | 8.1 | 114 | 56 | 3.8 | Yes |
| AUL SAC 2 | 29.4 | 8.3 | 154 | 77 | 3.1 | No* |
| AUL SAC 3 | 29.4 | 8.1 | 293 | 145 | 4.7 | Yes |
| AUL SAC 4 | 29.0 | 8.5 | 8 | 4 | 3.7 | No* |
| AUL SAC 5 | 29.0 | 7.7 | 174 | 85 | 3.8 | Yes |

**No significant isolate / scanty growth (classified as not contaminated). Aule: 11 contaminated, 4 not contaminated.*